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Carbon Calculator for wind farms on Scottish peatlands: an evidence assessment

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1 Executive summary

The Scottish Government's Carbon Calculator for wind farms on Scottish peatlands was developed in 2008, to calculate the impact of wind farm development on peatland carbon stocks in Scotland and thereby support decision making. Electricity generation emission factors are updated annually, but no major revisions have been made to the Carbon Calculator since 2014.

1.1 Aims

The increased focus on the transition to net zero might affect the suitability of the Carbon Calculator for future use. This research conducted a detailed review of the latest spreadsheet version of the Carbon Calculator (v2.14), which mirrors the web version (v1.8.1). It provides an evidence base for future considerations and recommendations.

This review has initiated further discussions and highlighted the need for ongoing engagement, which will be instrumental in the development of the Carbon Calculator.

1.2 Key findings

Based on the findings of a technical assessment, evidence review and quality control mechanisms, we recommend that when considered against recent policy updates and advancements in science, the Carbon Calculator, in its current form, should be updated. Each area of the Carbon Calculator was assessed for scientific accuracy and data availability:

- The 'payback time and CO_2 emissions' are not relevant/consistent with the findings of the technical assessment and literature review. It is important to consider whether emissions due to turbine life and back up are required, given new planning policy and the applicability of whole lifecycle carbon assessments.

- For all peat-related areas of the Carbon Calculator, as well as the forestry area, accuracy is lacking in one or more methodologies, use of emission factors and assumptions.
- While some data are accessible to users, it is not clear if they are able to accurately obtain some of that data – in particular, for variables that drive the results (the water table depth and extent of drainage), which could affect the accuracy of outputs.

In addition to the technical assessment, the research has triggered the need to examine the wider planning and consenting context through the following questions:

1.2.1. Does the calculator need to consider the lifecycle emissions of the wind farm, or could the focus be purely on the impact of development on peat?

Well established methods and tools are available to undertake Whole Life Carbon Assessments (e.g. PAS2080), including forthcoming offshore wind carbon footprinting guidance. This aspect of the Carbon Calculator might not be necessary as it replicates these approaches. Instead, it may be more beneficial to concentrate efforts on analysing the specific impacts of development on peatlands/habitat carbon emissions.

1.2.2. Is the output of the Carbon Calculator useful as a decision-making tool?

Since the inception of the Carbon Calculator, it has become clearer that improving and restoring biodiversity is important to tackling climate change. This progress is reflected the National Planning Framework 4's mitigation hierarchy.

As the UK transitions to net zero, the current 'carbon payback' approach becomes less relevant, as it compares development emissions to the counterfactual of electricity generated by fossil fuels. The focus should shift to evaluating the impact of the developments on the natural environment, specifically, whether it improves the environment and sequesters CO_2 effectively.

To better assess the development's impact on peatland carbon emissions, the timeline for achieving 'carbon payback' or 'carbon neutrality' should consider land-based emissions. For example, 'payback time' could be defined as the period needed to restore peatland to a 'near pristine' condition from a reported baseline, compared to the site's baseline emissions without development and counterfactual scenarios for non-peaty sites, and Scotland's widespread peatland restoration efforts.

1.2.3. Should the Carbon Calculator incorporate other land use types?

This would offer a more comprehensive view of the carbon impact on other land use types, as compared to the carbon impact on peatland. This aspect should be evaluated considering Scotland's evolving biodiversity net gain requirements, current Peatland Management Plans (PMP), Habitat Management Plans (HMP), and their anticipated updates.

1.2.4. Are the quality controls sufficient?

There are no in-built quality control mechanisms within the Carbon Calculator. Due to its complexity and skillsets required to review the data outputs, the Carbon Calculator is not used as a decision-making tool in the capacity it is intended. Additional quality controls would be beneficial.

1.3 The future of the Carbon Calculator

In addition to the technical review, the report also considers the future of the Carbon Calculator in terms of a review of incorporating high-resolution spatial data (HRSD) and/or peatland condition categories (from the Peatland Carbon Code), and applicability of the Carbon Calculator to other developments.

Integrating HRSD into the Carbon Calculator would enable an understanding of land cover types, providing proxies for peat condition and water table depth. This could reduce the need for manual site surveying for data collection and enable wider evaluation of the site.

We recommend that the integration of HRSD is explored for future versions of the Carbon Calculator, to ascertain the level of accuracy these enhancements could bring (i.e. through reduced manual inputs and/or quality controls). This can be done in conjunction with the findings from Scottish Government's exploration of a national LiDAR mapping scheme.

The Peatland Code's emission calculator provides emission factors to calculate the average net emissions from peatland in various conditions, based on the UK inventory. Whilst not Scotland-specific, integration of the peatland condition categories could provide a recognised approach to quantifying the benefits of peatland restoration activities.

There is potential for the Carbon Calculator to be adapted and applied to grid infrastructure and other development types on peatland and carbon rich soils, even though it is currently employed solely for wind farm developments. There are no concerns on the Carbon Calculator's ability to be used on projects of all sizes. However, to be applied to different infrastructure types, consideration would need to be given to their unique spatial aspects, e.g. the effects of shading and effect of excess heat for solar farms. Further research is needed to understand the implications of other infrastructure developments on peatland and carbon rich soils prior to extending the applicability of the Carbon Calculator.

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Glossary / Abbreviations

Baseline	Current baseline represents existing GHG emissions from the project boundary site prior to construction and operation of the project under consideration (IEMA, 2022).
Carbon-rich soils	Organo-mineral and peat soils are known as carbon-rich soils. A peat soil is defined in Scotland as when soil has an organic layer at the surface which is at least 50cm deep. Organo-mineral soil or peaty soil is soil which has an organic layer at the surface less than 50cm thick and overlies mineral layers (e.g. sand, silt and clay particles). There is also a relatively rare group of soils in Scotland known as humose soils. These have organic rich layers with between 15 and 35% organic matter. These are mineral soils but also considered to be carbon rich.
Dissolved Organic Carbon	fraction of organic carbon that can pass through a filter with a pore size between 0.22 and 0.7 micrometres.
High-Resolution Spatial Data	High-resolution spatial data refers to detailed information about the Earth's surface captured with exceptional precision by satellite imagery.
Life Cycle Assessment	A Life Cycle Assessment (LCA) is a methodology for assessing environmental impacts associated with all the stages of the life cycle of a commercial product, process, or service.
PAS 2080	PAS 2080 is a globally applicable standard for managing carbon in infrastructure. The standard looks at the whole value chain of a project and aims to reduce carbon and cost through design, construction, and use.
Particulate Organic Carbon	fraction of organic carbon that can't pass through a filter with a pore size between 0.22 and 0.7 micrometres.
Payback period	Payback period is used within the Carbon Calculator to estimate the time it will take for a wind farm to 'offset' the greenhouse gases emitted. I.e., the displacement of the carbon 'costs' of construction with the carbon 'savings' due to the displacement of grid-based electricity generation from non-renewable sources.
Peat	Peat is organic material formed when dead plant material collects in cool, waterlogged conditions where there is very little oxygen, it breaks down slowly forming a layer of mainly organic matter.
Peat soil	(organic soil) in Scotland is defined as soil with a surface peat layer with more than 60% organic matter and of at least 50cm thickness.
Peaty soils	(organo-mineral soil) have a shallower peat layer at the surface less than 50cm thickness over mineral layers.
Peatland	Under NPF4, peatland is defined by the presence of peat soil or peaty soil types. This means that "peat-forming" vegetation is growing and actively forming peat, or it has been grown and formed peat at some point in the past. Peatlands can include blanket bog, upland raised bog, lowland raised bog and fens.

Peatland Code	The Peatland Code is a voluntary certification standard in the UK and is designed for peatland restoration projects aiming to market the climate benefits of restoration. The Peatland Code ensures that restoration projects are credible and deliverable, providing assurances to carbon market buyers. The Peatland Code defines ‘peatland’ as ‘areas of land with a naturally accumulated layer of peat, formed from carbon-rich dead and decaying plant material under waterlogged conditions’.
Peat Management Plan	A peat management plan (PMP) is an operational plan in development projects on peat, describing baseline peat conditions, detail on excavation and reuse volumes, classification of the excavated material, how the excavated peat will be handled, stored, reinstated or other use or disposal.
Peatland Restoration	Carrying out an intervention which in combination with natural processes improves the hydrological function and coverage and good condition of priority peatland habitat vegetation, aiming to result in a peatland that is actively forming peat and sequestering carbon. Further detail will be stated in the Peatland Standard (under preparation).
Priority Peatland Habitat	Peatland National Vegetation Classification communities noted as a Priority Peatland Habitat are: M1, M2, M3, M15, M17, M18, M19, M20 and M25, together with their intermediates. These have been recognised under the Scottish Biodiversity Framework as being important to protect for their conservation and biodiversity value.
Scottish Environment Protection Agency	The Scottish Environment Protection Agency is Scotland’s principal environmental regulator, its main role is to protect and improve Scotland’s environment.
Whole life carbon	Assessment of emissions associated with an asset over its entire life; encompassing its development, operation, and end-of-life.

CH_4	Methane
CO_2	Carbon Dioxide
DOC	Dissolved organic carbon
ECU	Energy Consents Unit
EIA	Environmental Impact Assessment
ESA	European Space Agency
GHG	Greenhouse Gas
GIS	Geographic Information Systems
HRSD	High-Resolution Spatial Data
IPCC	Intergovernmental Panel on Climate Change
JHI	James Hutton Institute
kWh	Kilowatt-Hour
LCA	Life Cycle Assessment
LiDAR	Light Detection and Ranging airborne mapping technique
MW	Megawatt
MWh	Megawatt-Hour
NASA	National Aeronautics and Space Administration
NPF4	National Planning Framework 4
N_2O	Nitrous Oxide
PEAG	Scottish Government's Peatland Expert Advisory Group
PMP	Peat Management Plan
POC	Particulate Organic Carbon
SAR	Synthetic Aperture Radar
SEPA	Scottish Environment Protection Agency
IUCN	International Union for Conservation of Nature
WLCA	Whole lifecycle carbon assessment

2 Introduction

2.1 Background

The Scottish Government's Carbon Calculator for wind farms on Scottish peatlands (hereafter referred to as 'the Carbon Calculator') was developed in 2008 and updated in 2011 and 2014. It was developed due to concerns raised about the reliability of methods used to calculate the time taken for these facilities to reduce greenhouse gas emissions, combined with an increasing public policy demand for renewable energy following Scotland's commitments at the time to reduce greenhouse gas emissions by reducing the use of fossil fuels for energy generation, principally; Scottish Planning Policy 6: Renewable Energy to deliver renewable energy in a way that "affords appropriate protection to the natural and historic environment without unreasonably restricting the potential for renewable energy development" (Scottish Government, 2007).

The Carbon Calculator was developed to 'support the process of determining wind farm developments in Scotland. The tool's purpose is to assess, in a comprehensive and consistent way, the carbon impact of wind farm developments. This is done by comparing the carbon costs of wind farm developments with the carbon savings attributable to the wind farm.' (Nayak et al, 2008). The output of the Carbon Calculator compares the carbon costs of a wind farm development with the carbon savings attributable to the production of renewable energy (when compared to a counterfactual alternative). Electricity generation emission factors are updated annually, but no major revisions have been made to the Carbon Calculator since 2014.

The Scottish Environment Protection Agency (SEPA) developed the Carbon Calculator into a web Carbon Calculator (C-CalcWebV1.0), which has been available since 2016. The calculator is currently owned by the Scottish Government and is hosted and maintained by SEPA. The Carbon Calculator is currently used by developers to submit project carbon assessments. These submissions are then evaluated by the Energy Consents Unit (ECU) as part of the application for consent.

2.2 An evolving legislative, policy, science, and technology landscape

In the 16 years since the Carbon Calculator's inception, there has been an increased focus on the transition to net zero, with updates to Scottish legislation and policy reflecting this shift. Key legislation and policy drivers include:

- **The Climate Change (Emissions Reduction Targets) (Scotland) Act 2019 (updated):** sets a key driver for Scotland to deliver and meet its carbon reduction targets.
- **Scotland's National Planning Framework 4 (NPF4) (adopted in February 2023):** sets the framework for development across Scotland, including renewable energy. NPF4 includes national planning policies which set out *'to protect carbon-rich soils, restore peatlands and minimise disturbance to soils from development'*. Policy 5 sets out a mitigation hierarchy[1], and new development proposals on peatlands, carbon-rich soils, and priority peatland habitat are

[1] Avoid - by removing the impact at the outset, Minimise – by reducing the impact, Restore – by repairing damaged habitats, Offset – by compensating for residual impact that remains, with preference to on-site over off-site measures.

only supported in certain limited circumstances, including renewable energy generation. The policy also outlines the need for a site-specific assessment (such assessments may include peat depth surveys, Peat Landslide Hazard Risk Assessment, and detailed habitat and condition surveys) to identify the likely net effects of the development on climate emissions and loss of carbon. The mitigation hierarchy can be achieved through the Construction Environmental Management Plan, Habitat Management Plan (HMP), and Peat Management Plan (PMP), developed at the application stage.

There have also been significant advancements in science and technology during this period. The collective understanding of peatland science has evolved, and research, technology, and collaborative groups have fostered a greater understanding of the science, with the likes of the Peatland Code and NatureScot National Peatland Plan emerging as a result. This new legislative, policy and science landscape highlight the need for a comprehensive review of the Carbon Calculator's original design and purpose.

2.3 Aim of the report

This report provides the findings of a technical assessment of the latest spreadsheet version of the Carbon Calculator (v2.14), which mirrors the web-version (v1.8.1) to determine if in its current form it remains fit for purpose, considering recent policy updates, the ongoing transition to net zero, and advancements in science. Furthermore, the report provides an evidence base for future considerations and explores how the Carbon Calculator could be improved via Peatland Code category integration, use of High-Resolution Spatial Data (HRSD), and improved quality controls.

3 Carbon Calculator Technical Assessment

3.1 Overview

The Carbon Calculator features numerous components used to assess the carbon impact of wind farm developments on Scottish peatland. The Carbon Calculator is split into the areas shown in Table 1. Appendix 10.3 provides a detailed breakdown of each section, including their specific calculations and assumptions.

Table 1: Carbon Calculator Section

Areas of the Carbon Calculator	Report Section
Data inputs	**3.2**
The core input data, forestry input data, and construction input data tabs are used by the user to insert key variables into the Carbon Calculator, to inform the development's estimated payback time and CO_2 emissions.	
Payback time and CO_2 emissions	**3.3**
Collates the results from each area of the Carbon Calculator and presents the carbon payback period and carbon intensity per kWh electricity generated.	
Wind farm CO_2 emission savings	**3.4**
Savings are calculated against the electricity generated by coal, a fossil-fuel mix, and the UK average grid mix, multiplied by the wind farm's lifetime electricity generation at the time of the development's application.	
Emissions due to turbine life	**3.5**
Emissions associated with turbine life (manufacturing, construction, and decommissioning) are presented based on user input or estimated based on installed capacity. Emissions associated with foundations (concrete) are calculated separately.	
Loss of carbon due to back up power generation	**3.6**
Emissions associated with back up requirements are calculated against the electricity generated by coal, a fossil-fuel mix, and the UK average grid mix, multiplied by the wind farm's lifetime electricity generation.	
Loss of carbon fixing potential of peatlands	**3.7**
Quantification of the annual carbon sequestration from bog plant fixation (without the wind farm) and thereby the loss as a result of development.	
Loss of soil CO_2	**3.8**
Emissions associated with loss of soil organic carbon from the peat removed and peat drained.	
CO_2 loss by DOC and POC loss	**3.9**
CO_2 losses from dissolved organic carbon (DOC) and particulate organic carbon (POC) within waters in drained land that has been restored.	
Loss of carbon due to forestry loss	**3.10**
Loss of future carbon sequestration associated with forest felling as part of the wind farm development.	
Carbon saving due to improvement of peatland habitat	**3.11**
Estimates the reduction in GHG emissions due to restoration following the end of the wind farm's lifespan.	

The assessment provides a review of each area of the Carbon Calculator as outlined in Table 1. Each section consists of the following:

- **Assessment findings** – narrative summarising the findings from the technical assessment and evidence review. For the technical areas of the Carbon Calculator a Red, Amber, Green (RAG) rating has been provided to illustrate the technical accuracy and data availability of each area. It uses the colour rating system presented in Table 2.
- **Key considerations and questions -** considers the key takeaways from the assessment, and outlines questions for policy decision makers when considering revisions to the current Carbon Calculator.

Table 2. RAG Ratings

RAG		Criteria: Scientific accuracy	Criteria: Usability
White	○	Not applicable (rationale explained within narrative).	
Green	●	The methodologies, use of emissions factors and assumptions are relevant and consistent with best practice.	Data is site/project specific, is available to the Carbon Calculator user, and supports an accurate outcome.
Amber	●	Accuracy is lacking in one or more methodologies, use of emissions factors and assumptions.	There is some uncertainty around the data availability.
Red	●	The methodologies, use of emissions factors and assumptions are not relevant/consistent with findings of the literature review.	Data is not site specific/ is inaccessible/unavailable to the user.

3.2 Assessment findings: Data inputs

3.2.1. Scientific accuracy

The scientific accuracy of the data inputs is provided as part of the narrative within the assessment findings for the corresponding technical areas of the Carbon Calculator (Sections 3.3-3.11). Therefore, no RAG rating has been provided.

3.2.2. Usability

The following commentary applies to the Carbon Calculator's core input data. Specific commentary relating to data inputs of the technical areas of the Carbon Calculator are covered within the corresponding sections of this report (Sections 3.3-3.11).

- The user is required to input a high number of variables (i.e. for the core input data, 70 input variables are required).
- Each input variable requires an expected value, as well as a minimum and maximum range, therefore over ~200 input variables are required in total for core inputs.
- For infrastructure design related inputs (wind farm characteristics, borrow pits, foundations, access tracks, cable trenches and peat excavated) the values are well defined based on the wind farm design, therefore the minimum and maximum ranges could represent unnecessary data requirements for design related inputs given their level of certainty. If still viewed as necessary in some instances, a minimum and maximum range could be automated, and/or an optional requirement for users.

3.2.3. Key consideration: Minimum and maximum data inputs

Wind farm characteristics - consider removal/option to 'opt out' of minimum and maximum variables where site specific data is known and can be evidenced by the user.

Peat variables - Review the minimum and maximum parameters for peat variables and explore replacing with individual infrastructure specific inputs (i.e. Turbine 1, 2 etc). Industry feedback indicated that prior to completing the Carbon Calculator, users proactively aim to reduce the impact of development on peat through the design process. If there is large variation in peat parameters around the site, should more detailed site-specific data be captured (to reflect the construction and forestry 'areas', and/or align with the PMP reporting where individual infrastructure outputs are provided) as an alternative?

3.3 Assessment findings: Payback time and CO_2 emissions

3.3.1. Scientific accuracy

- Although the calculations that produce the payback time and CO_2 emissions are accurate (i.e. there are no errors in them), the carbon payback time that is generated (measured against the current fossil-mix of electricity generation) is a significant simplification which does not present an accurate representation of future payback. This is because the payback calculations assume a consistent counterfactual for the lifetime of the wind farm. However, as we transition to net zero, the National Grid is rapidly decarbonising and forecast to be near net zero by 2035 (DESNZ, 2023).

3.3.2. Usability

- Payback combines infrastructure emissions (embodied carbon from wind turbines and their construction) with site-specific factors associated with peatland disturbance, and/or management. Emissions from the wind turbine manufacturing make up the largest proportion of the emissions, and so in this context, the overall carbon impact on peat (i.e. all peat related carbon calculations) appears to the user as a small proportion.
- Currently there are no official guidelines about what constitutes an acceptable or unacceptable payback time, which would benefit both users and decision makers in determining 'what good looks like' for land based emissions.

3.3.3. Key consideration: Is the output of the Carbon Calculator useful as a decision-making tool?

As the National Grid transitions to net zero, the presented 'savings' (comparison to fossil generated electricity) become less relevant. It may be more appropriate to consider the 'payback time' as the time taken to restore the peatland condition to 'near pristine' from a reported baseline. To inform this, the sources of emissions could be split out and reported separately:

- Emissions resulting from land use change (the impact on land carbon emissions as a result of the development including all peatland and other carbon rich soil related carbon sources), should be compared against the project site's baseline emissions.
- Emissions associated with the construction, operation, and decommissioning (Whole Lifecycle Carbon Assessment (WLCA)) of the wind farm. To aid decision making, this should be benchmarked

against industry best practice, and/or compared against the whole life carbon impact of the counterfactual (e.g. gas turbine plant). Although this may be included within a WLCA, in which case this function is not required.

- The carbon intensity of electricity generated could primarily be compared against i) the current back-up energy source of natural gas and ii) against the UK average (considering future decarbonisation) if not done so via a WLCA.

3.3.4. Key consideration: Is the focus of the Carbon Calculator correct?

Currently, the main use within decision making is the payback period. However, this is based on the counterfactual of electricity generated by fossil fuels. Focusing on land-based emissions and the impact of development on peatland, an alternative would be to consider the baseline site conditions and 'payback' time to a restored site (see 3.3.3 for suggested approach). There is widespread action to restore degraded peatland across Scotland (Scottish Government, 2024), it could be expected that if a wind farm is not developed, the sites would be restored through a variety of financial mechanisms such as the Peatland Code, and Scottish Government funding (ibid). Another relevant counterfactual could include the land-based emissions from a non-peaty site. Whether a counterfactual payback period should be updated to reflect this context is an important consideration.

3.3.5. Key consideration: Does the Carbon Calculator need to consider the lifecycle emissions of the wind farm, or could the focus be purely on the impact of development on peat and other carbon rich soils?

In order to demonstrate a minimisation of emissions, established methods and tools are available to undertake WLCA (e.g. PAS2080), which will include materials, construction, operational and decommissioning emissions of the entire wind farm. NPF4 Policy 2 (climate mitigation and adaptation) states that all proposals will be 'be sited and designed to minimise lifecycle greenhouse gas emissions as far as possible.' Given the new policy context in combination with the Carbon Calculator's core aim (to determine the impact of development on peatland carbon emissions), key considerations include:

- Whether the lifecycle emissions of a wind farm need to be included in the Carbon Calculator?
- Could the calculations in the Carbon Calculator solely be focused on the impact of the development on peatland emissions?
- Is the presentation of the current payback output necessary or appropriate for decision making?

3.4 Assessment findings: Wind farm CO_2 emission savings

3.4.1. Scientific accuracy

- The UK grid average is forecast to be broadly decarbonised by 2035 (BEIS, 2020). Using the current grid average (DESNZ, 2023) across the lifetime of the wind farm project represents a 'static' coefficient which is not representative of long-term UK grid decarbonisation over time. Additionally, over time as the grid average decarbonises this comparison will not show an operational benefit of using renewable energy.
- The UK generates ca. 1% of electricity from coal (Statista, 2024). The emissions factors in the Carbon Calculator are updated annually. If users apply the current (optional) coal factor, this factor is also a 'static' coefficient. Coal is due to be phased out completely by the end of September 2024 (BEIS, 2021), and therefore the 'coal-fired electricity generation' comparison should be removed as it is not a representative comparison.
- Renewable energy from wind and solar is not guaranteed and therefore a backup is required. Currently, where back up for renewables is required, gas peaking plants provide additional capacity. As we transition to a zero-carbon grid, natural gas will continue to be used to support both renewable back-up and additional demand (BEIS, 2020). There is also work ongoing nationally (Great Grid Upgrade, (National Grid, 2024)) to improve infrastructure and connectivity which will reduce the reliance on back-up energy requirements.
- Most of Scotland's electricity demand is already met by renewables (Scottish Government, 2024). There is an opportunity to increase renewables across the UK and for exports, however, this will require appropriate infrastructure.
- The counterfactual emission factors only include electricity generation (i.e. the emissions associated with burning fossil fuels to generate electricity). They exclude the development of the infrastructure (i.e. the power station). Therefore, savings are based on operational energy efficiency, there is no consideration to the embodied carbon or operational maintenance of the alternative power.
- Noting the transition to net zero, consideration needs to be given to the appropriateness of represented savings.

3.4.2. Usability

- This section of the Carbon Calculator is used to calculate the Wind farm CO_2 emissions. The input variables which inform it are acceptable in terms of usability.

See Section 3.3.4 Key consideration: Is the focus of the Carbon Calculator correct?

3.5 Assessment findings: Emissions due to turbine life

3.5.1. Scientific accuracy

- The methodology for estimating emissions is based on turbine capacity derived from the regression analysis of data points found within a selection of papers dated between 2002 and

2006. The wind industry has evolved in the last 20 years and these assumptions are outdated, for the following reasons:

  - The average onshore wind turbine has increased over recent years to 2.5-3MW (National Grid, n.d.). the references within the current Carbon Calculator are based on studies around 1MW (Lenzen and Munksgaard, 2002; Ardente et al., 2006; Vestas, 2005) and have a direct correlation between turbine MW and embodied carbon (i.e. the greater the power, the higher the embodied carbon), however due to technology advancements (i.e. lightweighting), increased power may not require increased materials. The methodology should be updated to consider more recent manufacturer lifecycle assessments.
  - The physical size of UK wind turbines (i.e. height and turbine span) have increased.

- The Carbon Calculator uses an emissions factor for reinforced concrete taken from The Concrete Centre (2013). This reference has been superseded with the most recent market data being available for 2023 (Concrete Centre, 2023) and should be updated.
- Estimations only account for lifetime emissions attributed to turbine structures and concrete hard standings. The methodology disregards emissions from the manufacture, construction, and disassembly of other wind farm assets (e.g., site fences, access tracks, battery storage, etc) (Appendix 10.1). Carbon emissions resulting from the transport of labour and materials to the construction-site is also excluded. This underestimates emissions and does not align to common WLCA practice (e.g., PAS 2080).
- Emissions exclude decommissioning; due to the uncertainty in this area this would be difficult to estimate, however it should be recognised that decommissioning activities would result in additional disruption to peat. With the net zero transition and increasing energy demand it is likely that sites will be repowered rather than decommissioned. However, as wind farm developments are only provided with consent to operate for fixed period (and should be followed by decommissioning), it may not be appropriate to include this functionality.

3.5.1. Usability

- Many lifecycle assessments for wind turbines include foundations (e.g. Vesta, n.d.). Therefore the 'carbon dioxide emissions from turbine life' variable may result in double counting of construction emissions when using the 'direct input of total emissions' option if not split out by the turbine provider and/or Carbon Calculator user, when paired with foundations and hardstanding emissions, and/or the construction input data tab.
- As this is a significant part of the assessment, lifecycle emissions should be modelled on site specific data.
- Depending on the size of the development, developers may be required to submit an Environmental Impact Assessment (EIA), including a WLCA. Scottish Government is preparing Planning and Climate Change guidance, which includes consideration of information sources, tools, methods and approaches (including WLCAs) that can be used to demonstrate whether and how lifecycle greenhouse gas emissions of development proposals have been minimised. For reference, there is currently an industry standard approach for wind farm LCA being developed for offshore wind developments through the Offshore Wind Sustainability JIP (anticipated to be released by the end of 2024) (The Carbon Trust, 2022).

See Section 3.3.4 Key consideration: Is the focus of the Carbon Calculator correct?

See Section 3.3.5 Key consideration: Does the Carbon Calculator need to consider the lifecycle emissions of the wind farm, or could the focus be purely on the impact of development on peat?

3.6 Assessment findings: Emissions due to back up power generation

3.6.1. Scientific accuracy

- Back up requirements are typically modelled using the guidance note assumption of 5% of the wind farm capacity following guidance within the Carbon Calculator (Dales et al, 2004). The wind industry has evolved in the last 20 years. From a review of literature and current policy, there are no specific requirements for back-up in planning applications for renewable energy. As the National Grid decarbonises (DESNZ, 2023) back-up will increasing be supplied by other renewable energy. Therefore, this area of the Carbon Calculator could be redundant.
- Emissions associated with back up are calculated based on a grid connection. See Section 3.4 regarding selection of counterfactual emission factors. There are other options such as interconnections, energy storage solutions and nuclear that provide alternatives (National Grid, 2024).

3.6.2. Usability

- The input variable is acceptable in terms of usability.

3.6.3. Key consideration: Should the Carbon Calculator include 'Back-up requirements'?
From a review of literature and current policy, there are no specific requirements for back-up in planning applications for renewable energy, As the National Grid decarbonises (DESNZ, 2023) back-up will increasing be supplied by other renewable energy. Where back-up requirements are specified, it's anticipated that these would be included within an WLCA. Therefore, this area of the Carbon Calculator could be redundant.

3.7 Assessment findings: Loss of CO_2 fixing potential

3.7.1. Scientific accuracy

- This section of the Carbon Calculator quantifies the annual carbon sequestration from bog plant fixation (without the wind farm). The loss of carbon fixing potential is calculated from user inputs for the area which peat is removed (m^2) as well as the area affected due to drainage (m^2). Loss of CO_2 fixing potential has a low significance within the outputs of the Carbon Calculator (typically 1-2% of the total lifetime emissions), most land-based CO_2 losses due to wind farm development are associated with soil organic matter (see Appendix 10.3).

- Loss of carbon fixation is calculated based on the lifetime of the wind farm and time required until full peatland functioning is restored. No consideration is given to the condition the peatland will be restored to.

- The Carbon Calculator currently assumes that peatland is in a pristine condition and therefore is a net carbon sink. However, 80% of UK peatland is already degraded (NatureScot, 2015). Degraded peatland is likely to be a net source of emissions rather than a sink (NatureScot, 2015).
- The Carbon Calculator assumes a constant rate of carbon fixation over time, failing to take account for the impact of changing climatic conditions e.g. increased frequency of drought. See key consideration 3.7.4 on the impacts of climate change.
- The condition of the peatland is influenced by vegetation composition (Marshall et al, 2021), and degraded peat is associated with changes to vegetation structure with scrubbier species to the disadvantage of characteristic peatland species (NatureScot, n.d.). Literature was located which described the known link between ecosystem resilience and peatland vegetation (Speranskaya et al, 2024), and highlighted that the interactions between temperature, precipitation, nitrogen deposition, and atmospheric CO_2 and their effects can be a result of vegetation composition (Heijmans et al, 2008).
- The literature review indicates that the Carbon Calculator's current output for 'loss of carbon fixation potential' may not be accurate, because: i) the current condition of peatland may not be pristine, and may therefore have a lower carbon fixation rate, and ii) there is considerable uncertainty in the ability to restore peatland to its fully functioning 'pristine' state so the future fixation rate may be overestimated.
- However, no research was located which presented the relationship between peatland condition and bog fixing potential, or updated fixation emission factor rates. This is anticipated to be because other methodologies (e.g. Evans et al, 2023) do not explicitly assess the loss of bog fixing potential, but instead assess the 'Net Ecosystem Production of the peatland'. There was also no literature located to explain how the interaction between vegetation and hydrology impacts carbon fixing potential, and so the degree to which peatland condition impacts the carbon fixation value in the Carbon Calculator is uncertain and represents an evidence gap.
- This review is unable to conclusively determine the accuracy of this area of the Carbon Calculator and whether carbon fixation is accurately represented. Although carbon fixation represents a very small proportion of the total emissions, the current assumption is likely to represent a worst case (in terms of emissions) and may be suitable in the absence of other literature to inform it. This area of the Carbon Calculator could be superseded through the integration of the Peatland Code which uses the UK inventory and includes carbon sequestration (e.g. carbon fixation from bog plants) within its net emission factors.

3.7.2. Usability

- Carbon fixed by bog plants is a user input (a guidance note within the Carbon Calculator states 'the Scottish National Heritage use a value of 0.25tC/ha/yr.' however the guidance which informs this is no longer available, and this is highlighted as an evidence gap.

3.7.3. Key consideration: Should the baseline condition of peatland be incorporated in the Carbon Calculator?

Whilst the loss of CO_2 fixing potential will remain the same, degraded peatland is likely to be a net source of emissions rather than a sink (ibid) and there is no consideration of these emissions within the Carbon Calculator. Other reasons for incorporating the baseline condition and replication of the Peatland Code's calculation methodology are provided within this report (see Section 3.11.1). The use of HRSD could support the identification of peatland condition.

3.7.4. Key consideration: Impacts of climate change

Carbon fixing potential of blanket bogs (which make up 90% of Scotland's peatland) is anticipated to decline/be under threat by 2050-80 when considering the impact of climate change (Ferretto et al, 2019). The impact of climate change on peat has not previously been considered, however is of growing concern. Degraded peatlands are less resilient to the impacts of climate change, so the emissions will change proportionally more in degraded versus pristine peatland. Climate change is also likely to make successful restoration more challenging Norby et al (2019), although it has also been indicated that successful restoration of degraded/actively eroded sites could see the greatest CO_2 improvements (Evans et al, 2023), there is variation in results of the impacts of climate change on carbon fluxes following restoration (see Section 3.11 for more information).

3.8 Assessment findings: Loss of soil CO_2

3.8.1. Scientific accuracy: Peat removed

- **Calculating volume of peat removed**:
  - The Carbon Calculator uses an appropriate methodology for calculating the volume of peat removed for borrow pits, turbine foundations, hard-standing and access tracks, as well as any additional peat.
  - However, the use of averages may be producing a less accurate result than if actual numbers for each infrastructure feature (i.e. turbine foundation #1,2,3 etc) were inputted, as carried out in PMPs. This was reflected in industry feedback where it was highlighted that excavation volumes shown in the PMP are more realistic than what is shown in the Carbon Calculator.
- **Calculating CO_2 loss from removed peat:**
  - This is the largest source of peatland related carbon emissions because of development.
  - The carbon content of dry peat and dry soil bulk density are important parameters which drive the outputs of the Carbon Calculator. Sensitivity analysis (Appendix 10.2) demonstrates the correlation between carbon content of dry peat and dry soil bulk density and carbon losses from soil organic matter. Halving the data input values of either independent variable has the impact of a 60% reduction on emissions associated with carbon losses from soil organic matter.
  - Literature review findings indicate that carbon content of dry peat has a typical range of 50% to 55% and dry soil bulk density a range of 0.06 to 0.25 gcm^3 (e.g., Chapman et al., 2009; Ratcliffe et al., 2018; Heinemeyer et al., 2018; Howson, 2021, Lindsay, 2010; Parry and Charman, 2013; Levy and Gray, 2015; Carless et al., 2021; Howson et al., 2022).
  - The calculation methodology is appropriate.

- The Carbon Calculator assumes a worse-case scenario that all peat removed is destroyed and the carbon content is lost. Although in practice peat is often relocated, which should be more favourable, subject to it being sensitively relocated (SEPA, 2012; IUCN, 2023), there is an evidence gap in literature which illustrates successful peat relocation (i.e. via emissions rates from relocated excavated peat). In the absence of evidence, the assumption that the carbon content will be lost over time is an appropriate worst-case conclusion.

3.8.2. Usability: (Peat removed)

- **Calculating volume of peat removed**:
  - The 'average depth of peat at site' input variable in the 'characteristics of peatland before wind farm development' is not applied to any of the calculations in the Carbon Calculator. However, the 'average depth of peat removed' from each development feature (i.e. 'average depth of peat removed from borrow pit, hard standing, turbine foundations') is applied to calculate the quantity of peat removed. This provides greater accuracy than the singular 'average depth of peat at site' variable which could be removed from the Carbon Calculator.
  - Mirroring the assessment findings from 3.8.1, the data inputs for peat depth provide an average peat depth for each development feature type (e.g. 'average depth of peat removed from turbine foundations') they are not specific to each individual feature on which the average is may up of. For example, there will be multiple turbine foundations. The use of an average in this context may be a poor representation of the spatial variability in peat cover, as well as the positioning of infrastructure within that peat cover. This is particularly relevant where there are different peat conditions, depths and land use types across a site. Peat depth is not uniform and varies over short distances due to the underlying topography (Parry et al., 2014). Under blanket peat thickness is typically 0.4–6 m; it can be up to ten metres and often more in raised bogs, and in fens is 0.4–5m. Peat soil is defined as requiring a depth of 0.5m and a surface peat layer containing more that 60% organic matter (NatureScot, 2023). A more detailed data input, like the 'construction and forestry input data' sheets and/or reflecting how peat is reported in the PMP (i.e. by turbine, borrow pit etc.) could allow for a more accurate assessment of the quantity of peat removed.
  - NPF4 requires consideration of peaty soils, peat soil and peatland. Whilst the Carbon Calculator can be used in its current form on any peatland and responds appropriately to shallow peat depths (inputted as averages for each infrastructure type) a more specific data input for peat depth from each area where peat is removed would allow for better differentiation between different depths.
- **Calculating CO_2 loss from removed peat:**
  - Carbon content of dry peat and dry soil bulk density are user inputs. Whilst the exact metrics will be site specific, industry feedback indicated that these data inputs were difficult to obtain due to the lab analysis requirements (to obtain accurate data peat samples requiring drying out for long periods of time) and are therefore often based on assumptions, with one user utilising the von post scale. The ranges identified from the

literature review could be incorporated into the Carbon Calculator as recognised minimum and maximum parameters to inform an inbuilt quality control measure.

3.8.3. Key consideration: replace the use of averages with infrastructure specific inputs
This approach would provide more accurate outputs and replicate how peat is reported in the PMP.

3.8.1. Key consideration: Reuse of removed peat
Feedback from industry indicated that where possible projects seek to relocate peat (excavate peat for development and then reuse it where there is a need e.g. due to cut and fill balance) rather than remove from site. There were concerns the Carbon Calculator assumes a worse-case scenario. Consideration of whether the Carbon Calculator should incorporate an option to include peat reuse needs to be weighed up against whether this would be appropriate, as the reuse of peat is site specific, i.e. there will be limited sites with options appropriate for peat reuse, and unless peat for reuse is handled carefully it is likely to oxidise over time and lose carbon to the atmosphere. Options for positive reuse are highlighted as an evidence gap and would require additional research prior to updating the Carbon Calculator.

3.8.2. Key consideration: Incorporate minimum and maximum parameters into the Carbon Calculator for the carbon content of dry peat and dry soil bulk density variables
These two variables have a significant impact on the Carbon Calculator output. The literature review has identified an acceptable range for both variables which could act as parameters and inform quality control.

3.8.3. Key consideration: the use of HRSD
A recent study from JHI explored the mapping of soil profile depth, bulk density and carbon stock in Scotland using remote sensing and spatial covariates (Aitkenhead and Coull, 2020), Although further research is required to determine the appropriateness of this approach, in relation to bias in datasets, model complexity and comparison, model performance, and separate models for interrelated properties, and further engagement with JHI and NatureScot on the role of HRSD in this context is recommended as a next step.

3.8.4. Scientific accuracy: Peat drained

- **Calculating volume of peat drained:**
    - Volume of peat drained is calculated based on the depth of the drain and the extent of drainage. However, accurately establishing drainage efficacy is complicated as it affected by other parameters which are not well documented, and the changes brought about by drainage are expressed over a long period of time (IUCN, 2014).
        - In pristine peatland the water table is typically close to the surface. As a result of excavation, drainage causes a drop in the water table (Irish Peatland Conservation Council, n.d.). This stimulates soil respiration and the release of carbon (Ma et al., 2022).

        - Drainage also leads to subsidence (Ma et al., 2022) (IUCN, 2014). Subsidence should be measured alongside the water table depth to fully inform the likely extent of drainage.
        - Drainage can be influenced by distance between ditches, hydraulic conductivity, and slopes (Price et al, 2023).
        - There is a linear relationship between age of a drain and the cumulative carbon lost (Evans et al, 2021).
        - Within degraded peat, the local formation of drainage 'pipes' is common, therefore possibly enhancing the extent of drainage.
    - Despite research in the area there is an evidence gap in understanding what a suitable average is, and the methodologies to define the extent of drainage are difficult to apply.
- **Calculating CO_2 loss from drained peat:**
    - In flooded soils, CO_2 emissions are equalled or exceeded by fixation leading to near-zero emissions or net carbon sequestration, whilst in drained soils CO_2 emissions exceed fixation leading to net emissions. The carbon emissions associated with peat drainage are calculated based on the difference between emissions from drained land and emissions from undrained land.
    - **If site is not restored after decommissioning***:* The Carbon Calculator assumes a worse-case scenario that all carbon is lost (i.e. full drainage) following the same approach as removed peat. Due to the uncertainty in the parameter of the extent of drainage, this approach provides an appropriate worst-case scenario.
    - **If site is restored after decommissioning:** The Carbon Calculator calculates emissions from drained land against the lifetime of the wind farm, restoration period (as defined by the user) and considers the number of flooded days per year based on IPCC (1997) assumptions, which should be updated to reflect more recent literature (see below 'calculating emission rates from soils'). Due to the uncertainty around end-of-life and decommissioning it may be more appropriate to assume a worse-case scenario (i.e. assume site is not restored after decommissioning), and separately account for the benefits from restoration within the 'CO_2 gain – site improvement' tab so that it is reported separately to the impact during the lifetime of the wind farm.
    - See Section 3.8.1 for commentary on 'carbon content of dry peat' and 'dry soil bulk density' data inputs.
- **Calculating emission rates from soils:**
    - The purpose of this calculation is to determine the loss of soil carbon in the peatland as a result of a wind farm development. This is calculated from the total carbon loss from physically removed peat, and total carbon loss from peat drainage.
    - There are two approaches included within the Carbon Calculator - the IPCC methodology is a default approach and excludes any site detail; the model used by Nayak et al, 2008 is provided as a site-specific option. Users have the option to use either the IPCC (1997) methodology or the site-specific methodology. However, the Carbon Calculator states the site-specific method must be used for planning

applications. If the IPCC (1997) methodology is redundant, it should be removed from the Carbon Calculator.

- IPCC 1997:
  - This has been superseded by the 2014 Wetland Supplement.
  - Whilst the Carbon Calculator does not include N_2O (as it uses IPCC (1997) emission factors), the implications of this are small, and further updates could be made to include this. Whilst not expected to be a significant emission (ca. 2%) and dependent on the nutrient content of soils, it could be incorporated based on nitrogen content of soil samples. Where relevant (in the instance of intensive farming) N_2O emissions could be comparable to CH_4 .
  - The IPCC emission factors referenced are Tier 1, and therefore not representative of Scotland's peatlands. The factors are mainly based on warm season data, and peatlands in colder climates are likely to emit less (Hongxing and Roulet, 2023).
  - Although these Tier 1 emissions factors could be updated by those represented by Evans et al, 2023 (Tier 2) and used within the 2021 update to the Emissions Inventory for UK Peatlands, they may not be fully representative of Scotland (which is wetter, and agriculture is predominantly less intensive). Furthermore, the Carbon Calculator states the site-specific method must be used for planning applications. It is therefore recommended that the IPCC (1997) methodology is removed due to the greater accuracy that the site-specific methodology can provide.
- Nayak et al, 2008:
  - Calculates emissions factors via a bespoke methodology. Two options for type of peatland provided: acid bog, and fen (core data inputs). This covers the four main peatland habitats in Scotland; blanket bog (acid bog), raised bog (acid bog), fen (fen) and bog woodland (acid bog).
  - The methodology equations for CO_2 and CH_4 emissions are derived by regression analysis, considering the average annual air temperature and average water table depth. Whilst the methodology does not directly refer to peatland condition, it incorporates air temperature and water table depth which is a good proxy in establishing emission rates (Tiemeyer et al., 2020) (Ma et al, 2022), as the water table has a significant influence on peatland CO_2 and CH_4 emissions (Huissteden et al, 2016, Evans et al, 2021). Empirical relationships between water table depth and CH_4 and CO_2 emissions defined by Evans et al (ibid) enable it to be used to calculate carbon emissions, as illustrated by Evans et al (2023).
  - The evidence base for the methodology uses multiple peer reviewed studies (Bubier et al. 1993, Martikainen et al. 1995, Silvola et al. 1996, MacDonald et al. 1998, Nykänen et al, 1998, Alm et al. 1999), the analysis includes a robust sensitivity analysis which supports accuracy. However, the studies referenced reflect boreal peatland, and this element of the Carbon Calculator could be updated to reflect more recent literature ((Evans et al, 2021), (Evans et al,

2023), (Ojanen and Minkkinen, 2019), (Wilson et al, 2016), (Tieymer et al, 2016)) which reflects a temperate climate and/or accounts for land use type.

3.8.5. Usability: Peat drained

- **Calculating volume of peat drained:**
  - The volume of peat drained is highly sensitive to the user input for the 'average depth of peat removed' from each development feature (i.e. 'average depth of peat removed from borrow pit, hard standing, turbine foundations'); increasing the depth and/or extent of drainage directly correlates with the volume of peat effected by drainage. This volume feeds into the calculations for CO_2 loss from drained peat.
  - The average water table depth and extent of drainage is a user input. These parameters vary depending on the specific site, and within the site itself. Authors of the Carbon Calculator, Nayak et al (2008) underline the importance of accuracy in the choice of these inputs. However, the cost of correctly following the methodologies presented in the Carbon Calculator were highlighted by industry stakeholders as 'prohibitively high' for projects that may not obtain planning consent.
    - **Average water table depth variable:** The Carbon Calculator describes this variable as the upper boundary of the groundwater. Considerable variety in the method used to obtain the 'average water table depth' by users was observed – from obtaining an average depth via hydrologists, to using the water table depth from a previous similar site. Evidence of the hydrology calculations to inform user inputs were not assessed as part of this research, and could merit further research in conjunction with a review of other EIA deliverables and their applicability to the Carbon Calculator's data inputs. The narrow timescales associated with the preparation of planning documents (i.e. EIA) present a challenge in obtaining reliable information, and the current approach does not account for the temporal changes of the water table. The Carbon Calculator output likely only represents a 'snapshot' which consequently, in combination with the variety in approaches to obtaining the variable, may be inaccurate.
    - **Average extent of drainage around drainage features at site' variable:** Industry feedback on this variable's method was resolute in it being impractical to collect this data (due to both time requirements and associated cost) during planning timescales. Despite reviewing available evidence, a practical methodology (i.e. within planning timescales) to inform this variable could not be identified.
- **Calculating CO_2 loss from drained peat:**
  - See Section 3.8.2 for commentary regarding carbon content of dry peat and dry soil bulk density.
- **Emission rates from soils:**
  - See Section 3.8.2 for commentary regarding emission rates from soils.

3.8.6. Key consideration: update the methodology for emissions rates from soils

The methodology should incorporate recent literature and a temperate peatland that reflects the Scottish context, it should also acknowledge the role of the mean annual water table depth, which has

been identified as the overwhelmingly dominant control on CO_2 fluxes (Evans et al, 2021). The literature review identified papers which should be reviewed when undertaking this update:
- Tiemeyer et al (2020)'s 'A new methodology for organic soils in national greenhouse gas inventories: Data synthesis, derivation and application' incorporates HRSD and uses water table data to determine Germany's GHG estimate for organic soils at a National level, which it states could be applied at a project level.
- Evans et al (2023) 'Aligning the Peatland Code with the UK peatland inventory' provides an overview of low-cost methodologies to obtain site data to inform peat-carbon variables, including water table depth and reference to 'Eyes on the bog' methodologies (Lindsey et al, 2019).

3.8.7. Key consideration: should the Carbon Calculator account for emissions from drainage ditches?

Although the extent of drainage is captured in the Carbon Calculator, drainage ditches represent an additional source of CH_4 emissions from drained organic soils (Peacock et al, 2021) which are not currently included in the calculations. Emissions from ditches are captured in the IPCC's 2014 Wetlands supplement and could be applied to developments if the Carbon Calculator were to specify to peat condition, to replicate the approach used in the Peatland Code (Evans et al, 2023). The inclusion of drainage ditches could also be informed by the use of HRSD (see 3.8.12).

3.8.8. Key consideration: Investigate the use of HRSD in measuring water table depth

HRSD can be utilised to ascertain water table depth and provide historic trends. This could enhance the accuracy of Carbon Calculator when combined with ground truthing. For more information, please see Section 5. This could also inform Quality Control Mechanisms.

3.8.9. Key consideration: to what extent can assumptions/parameters, and HRSD be used to inform 'Average extent of drainage around drainage features at site'?

The current methodology to obtain the extent of drainage is viewed as being impractical within planning timescales. Whether this variable (using an indicative assumption) should be automated, and/or include parameters, requires careful consideration, particularly as it is a highly sensitive input. The IUCN classifies drained peatland as that which lies within 30m of an active drain, (IUCN, 2022). The literature review was unable to determine a range to inform parameters on this variable, although it did identify a paper where GIS was utilised to establish surrounding drainage areas (Sallinen et al, 2019). The role of HRSD in informing this input variable should be considered in conjunction with other efforts being undertaken to establish better accuracy in quantifying drainage impacts. This includes work undertaken (and ongoing) at the James Hutton Institute (e.g. Aitkenhead et al, 2016, the Peat Mothership Project (2024)) to inform the best approach. Discussion of the draft report highlighted an additional study utilising HRSD to provide a national scale map of Scotland's individual drainage channels and erosion features (Macfarlane et al, 2024) which would further inform the role of HRSD in this context and Section 3.8.10.

3.8.10. Key consideration: what quality control mechanisms are needed to enable a consistent (and accurate) approach to obtaining WTD and extent of drainage?

Industry feedback consistently highlighted concerns around the time and cost in obtaining the input variables required for extent of drainage and water table. These variables have a significant bearing on the carbon outputs, and so the approach to obtaining them should be uniform and feasible within planning timescales. This could be remedied through further engagement, the subsequent development/updating of guidelines (i.e. Guidance on Developments on Peatland, 2017), and/or the provision of training (to users and decision makers) and reinforced through the appropriate use of quality controls. This data could then go on to inform a national dataset of measurements.

3.9 Assessment findings: CO_2 loss by Dissolved Organic Carbon (DOC) and Particulate Organic Carbon (POC) loss

3.9.1. Scientific accuracy

- This area of the Carbon Calculator determines the gross loss of soil carbon from both DOC and POC loss following peat drainage. Only restored formerly drained land is included in this calculation because if land is not restored, the carbon lost has already been counted as carbon dioxide via 'CO_2 loss from drained peat' (Section 3.8.7). CO_2 loss by DOC and POC has a low significance within the outputs of the Carbon Calculator, most CO_2 losses due to wind farm development is associated with soil organic matter (see Appendix 10.2).
- The Carbon Calculator advises that "No POC losses for bare soil included yet. If extensive areas of bare soil is present at site need modified calculation (Birnie et al, 1991)".
- Assuming site restoration, DOC and POC are calculated for the period (years) of site restoration (i.e. the time between the year of site improvement and the year of the sites habitat and hydrology being restored).
    - Emissions are calculated based on a percentage of the total gaseous losses of carbon from improved/restored land, these are based on averages from Worrall (2009) which provide the following:
        - DOC – 26% (7-40%)
        - POC – 8% (4-10%)
- These assumptions (including the minimum and maximum) are tied into the Carbon Calculator (i.e. not editable by the user). DOC has a broad range, which could be causing some inaccuracy in the results. The Carbon Calculator's assumption that DOC and POC loss is only applied to restored formerly drained sites may be underestimating DOC and POC emissions for sites which have eroding peatland.
- The Peatland Code methodology Smyth et al. (2015) uses DOC and POC emission factors (reflecting condition type) which follow Tier 1 default values for drained and rewetted temperate peatlands developed for the IPCC Wetland Supplement (IPCC, 2014). Evans et al (2023) note for DOC that few limited UK studies have been published, and other studies fall outside the UK-relevant climatic region; and similar for POC; few additional POC flux estimates exist to enable refinement. Although some recent UK evidence indicates DOC increases may be larger or smaller depending on the peatland type, there is insufficient DOC flux data across the range of UK peat types and condition classes to support a full country specific approach (ibid).
- Pickard et al (2022) found that increased DOC concentrations were detected in areas of drained peatland relative to non-drained peatland from the UK's largest tract of blanket bog in the Flow Country of northern Scotland. These findings could be incorporated into the Carbon Calculator, however, as they represent one study based on a unique area of pristine peatland, a more conservative approach is recommended until further research is available.

- Discussion of the draft report raised an additional study from the Whitlee wind farm development exploring the effect of development phasing in relation to DOC and POC loss over a ten-year timespan, we suggest that further review incorporates the findings from this study.

3.9.2. Usability

- DOC and POC calculations require no inputs from the user.

3.9.1. Key consideration: align DOC and POC with the 2014 IPCC Wetland Supplement

For the purposes of the Carbon Calculator, emissions factors for DOC and POC could be applied to projects based on the peat condition, utilising the IPCC 2014 methodology, replicating the Peatland Code (Evans et al, 2023) which uses the UK inventory emissions factors. This would replace the current methodology but is more robust as the studies used to inform these default factors were based partly on a small number of UK studies (including two from Worrall), rather than a single study as currently used. This approach would have the added benefit of capturing DOC and POC emissions that are already occurring on eroding peatland and provide greater accuracy. The literature review highlighted an evidence gap where additional research is required to provide more specific DOC and POC estimations, building on the findings from Pickard et al (2022).

3.10 Assessment findings: CO_2 losses associated with loss of forest

3.10.1. Scientific accuracy (simple)

- The simple methodology for forestry CO_2 loss uses figures obtained from a single source (Cannell, 1999). Loss of future carbon sequestration is calculated by multiplying an emission factor by the area of forestry and lifetime of the wind farm. In the simple methodology this is a user input, “estimated carbon sequestered (t C ha^{-1} yr^{-1})”. The guidance note provides an assumption of 3.6 tC ha^{-1} yr^{-1} for yield class 16 m^3 ha^{-1} y^{-1} (Cannell, 1999). Whilst this is comparable with an average (over 200 years) from the Woodland Carbon Code (Yield 16, 1.7m spacing, thinned) Woodland Carbon Code, 2024) it doesn’t consider aspects such as species, age, density etc of the site-specific parameters. Therefore, a level of uncertainty/ error can be inferred for users with differing site characteristics (tree species).
- There is no consideration of emissions associated with the felling activities. Whilst this is likely to be insignificant, it could be incorporated into the Carbon Calculator for completeness.
- There is no consideration of emissions associated with the loss of carbon stock (i.e. if the felled forest wood is destroyed), which depending on the use of the wood could be relevant (e.g. if the timber is burnt).
- There is no consideration of the impact on the peatland of removing the trees (where forestry is located on peatland). Whilst expected to have a positive impact over time on peatland restoration, it is acknowledged that further research is required in this area (Howson et al, 2021; IUCN, 2020).

- Based on our sensitivity analysis results (Table 3) from the simple and detailed methodology vary significantly based on similar parameters:

Table 3: Forest methodologies sensitivity analysis

Simple methodology		
Data inputs	Area of forestry plantation to be felled (ha)	100
	Average rate of carbon sequestration in timber (tC ha-1 yr-1)	3.6
tCO_2e		**33,003**

Detailed methodology (presenting a reference scenario comparable to the simple methodology and subsequently scenario adjustments to consider the sensitivity of each input variable)						
Data inputs	**Reference scenario**	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**
		(Peat type)	**(Species)**	**(Age)**		
Soil type	Deep peat	Peaty gley				
Area to be felled (ha)	100					
Width of forest around felled area (m)	1					
Tree species	Scots pine		Sitka spruce			
Age (yrs.)	10			5	20	40
tCO_2e	**99,465**	**90,149**	**110,282**	**98,170**	**100,625**	**96,990**

This is due to the simple methodology not accounting for/underestimating the following:

- Tree species and age.
- cleared forest emissions (currently labelled 'carbon sequestration in soil under trees' in the detailed methodology).
- Underestimating the amount of carbon lost due to felling in comparison to the detailed methodology (likely because of the additional variables that inform the detailed methodology – light interception and primary production).

3.10.2. Usability (simple)

- The input variables are acceptable in terms of usability. However, there is the potential for error with the current input variables guidance. The Carbon Calculator notes that sequestration rate is dependent on the yield class of the forestry. The guidance note provides an assumption of 3.6 tC ha^{-1} yr^{-1} for yield class 16 m^3 ha^{-1} y^{-1}. No guidance is provided as to how the species of tree influences yield class, although poplar, Sitka, and beech CO_2 sequestration rates are provided in the separate user Guidance document, they are not visible in the Carbon Calculator. Enhanced user guidance and/or reference to sources of information (e.g. The Woodland Carbon Code) could be provided.

3.10.3. Scientific accuracy (detailed)

- The detailed method uses similar principles to the simple method, however, differs in its calculation of 'the average carbon sequestered per year', it requires additional user input (‘forestry input data tab’) to account for carbon loss based on soil type, species, and age of forestry, and provides a more complete account of the emissions from forestry in comparison to the simple methodology (see Table 3) .
- The method which informs these calculations (Xenakis et al, 2008) is comprehensive in calculating emissions from forestry. It uses the uses 3-PG (Landsberg, J.J., Waring, R.H., 1997). A generalised model of forest productivity using simplified concepts of radiation-use efficiency, carbon balance and partitioning, and builds on this to incorporate a soil organic matter decomposition mode, incorporating differences due to age of forestry at felling. The model has been calibrated and tested for commercial plantations of Scots pine in Scotland.
- **'Carbon sequestration in soil under trees':** is noted within the Carbon Calculator as 'more data needed'. ' It states that the aim of this calculation is to ‘account for the respiration from newly felled and disturbed soil, so as to include respiration from fresh plant inputs, from background soil organic matter decomposition, and from the disturbance of soil resulting in the release of additional carbon from soil aggregates. Different types of management disturbance should be considered’. This is labelled as ‘Cleared Forest Floor Emissions’ within the Carbon Calculator. It later states that this information is not yet available, so as an interim measure, carbon sequestration in soil under trees (including background respiration from soil organic matter decomposition and respiration from fresh plant input) is used.
- The two emissions factors currently used for the ‘Carbon sequestration in soil under trees' are based on two studies located in Scotland which is appropriate. However, both studies assumes that forestry is on peaty soils, which may not be the case for all forestry inputs. Given that this element of the Carbon Calculator was originally planned to account for the ‘Cleared Forest Floor Emissions’ only (see previous paragraph), the emissions factors used in lieu of this are possibly overestimating the carbon sequestration associated with soil under trees. Since this literature was published, there has been further research to understand the relationship between carbon emissions and newly felled/disturbed soils (West, 2011) (Matthews et al. 2012), these studies have informed the development of the Woodland Carbon Code (2024).

- The detailed methodology also provides a calculation to determine the capacity factor for the turbines at the site. This is dependent on tree height, forest width and distance of the forest from the turbine. Although this methodology appears scientifically correct in terms of the measurements being used, none of the references provide justification of the overarching rationale/purpose of this calculation. Some of the references used for wind speed calculations are over 20 years old and it’s unclear whether these factor in the impacts of climate change on wind speeds. The technological advances in turbine functionality (and the extent to which they are impacted by forestry) needs to be considered. It is also reasonable to assume that the potential capacity of the wind turbines and influence of forestry on a wind turbine's power curve will be considered by developers when establishing the Levelised Cost of Electricity (i.e. site feasibility) for a development. Overall, the appropriateness of this calculation in the context of the Carbon Calculator's purpose is questionable and should be removed (see 3.3.4 Key consideration: Is the focus of the Carbon Calculator, correct?).

3.10.4. Usability (detailed)

- Feedback from industry engagement highlighted that the detailed methodology is not used as the number of input variables required is perceived as onerous/requiring specialist support.
- The forestry input data tab provides two options for soil types provided: peaty gley and deep peat. This appropriately covers both peat (organic) soils and peaty (organo-mineral) soils.
- The forestry input data tab provides two options for species: Scots pine and Sitka spruce. Scots pine is the main species in bog forests (NatureScot, n.d) the inclusion of other species may be beneficial in providing a more accurate output.
- The separate user Guidance document states the following: 'Loss from soils of non-forested land is given by the estimated rate of carbon loss for two peat depths taken from Zerva et al (2005) for peaty gley (peat depth 5 to 50cm = 3.98 t C ha-1yr-1), and Hargreaves et al (2003) for deep peat (peat depth>50cm = 5.00 t C ha-1 yr-1)'. The reference to 'non-forested land' in the Guidance may be an error given the references used.
- Emissions from felling and transportation are a user input; these could be estimated based on assumptions and utilisation of UK Government emission factors. The existing guidance notes provide outdated references (Morison et al, 2011). The most up-to-date UK Government emission factors should be used and could be automated within the Carbon Calculator.

3.10.5. Key consideration: Replace the simple and detailed methodologies with one approach, informed by Woodland Carbon Code calculations

Although the detailed forestry methodology is comprehensive, it is perceived as onerous/requiring specialist support by users, and so in many applications the simple methodology is used. The simple methodology is likely to be underestimating carbon impacts. In turn, the detailed methodology may be providing inaccuracies in relation to 'Carbon sequestration in soil under trees'. The comprehensive nature of the detailed approach also has implications for the ability to 'futureproof' the Carbon Calculator. The equations which inform it and the formula within the Calculator, are complicated and difficult to interpret without advanced excel skills. This presents a risk when undertaking future updates to the Carbon Calculator.

Having one option in the Carbon Calculator which strikes a balance between inputs required and the generation of an accurate output is an important consideration. The Woodland Carbon Code's (WCC) (Woodland Carbon Code, 2024) calculator includes a wider range of tree species with rates based on spacing (m), yield class, management type and age. The WCC is supported by Scottish Forestry and has undergone independent validation and verification. It provides a credible dataset that is reviewed and updated regularly. To enable a more robust output, the sequestration rates 'Biomass Carbon Lookup Table' could be replicated in the Carbon Calculator and aligned with the WCC to enable consistency in reporting methods.

3.10.6. Key consideration: Remove the option to affect the wind turbine's capacity factor via the forestry inputs tab

The calculations that inform this appear to go beyond the remit of this Section's purpose in calculating the CO_2 losses associated with forestry. More rationale on why this is not appropriate and should be removed is provided in Section 3.10.3 bullet point 6.

3.10.7. Key consideration: Use of HRSD in determining forestry inputs

The role of HRSD and whether it could be utilised to determine key input variables for forestry and/or estimated carbon stocks (see Tolan et al, 2024, Cheng et al, 2024, which use cutting edge technology to estimate carbon stocks) should be explored in collaboration with forestry organisations (i.e. Scottish Forestry, NatureScot, Forestry and Land Scotland, Forest Research). There are several open resources that could inform this (i.e. Scottish Forestry Map viewer (Scottish Forestry, n.d.), Habitat Land Cover Map of Scotland (2024), Scottish Remote Sensing Portal (Scottish Government, n.d.)). Process-based modelling, data assimilation and remote sensing has been applied by the University of Edinburgh to quantify carbon stock changes, and remote sensing is used by Forest Research to accurately map woodland.

3.11 Assessment Findings: CO_2 gains from site improvement

3.11.1. Scientific accuracy

- This area of the Carbon Calculator estimates the reduction in GHG emissions due to restoration of the site. The calculation for this area of the tab replicates the calculation used to ascertain loss of soil CO_2 (peat drained) (Nayak et al, 2008), and so the findings from 3.8.7 and 3.8.8 are also relevant to this section.
- The current calculations assume that restoration will be successful, and that peatland will be restored to pristine condition. The UK Inventory and Peatland Code transitions land from degraded condition categories to 'modified bog' upon restoration, it does not apply the 'near-natural' emission factor to restored peatland, recognising the difficulty in fully restoring peatland to the full sequestration potential.
- It is difficult to accurately model emission reductions associated with restoration at pre-planning phases – in particular, the 'depth of peat above the water table after restoration.' There are several restoration activities (hydrology and habitat 'yes/not applicable' inputs) within the Carbon Calculator are assumed to occur post wind farm operation (>20 years in the future), although these are not linked to any calculations.
- Undisputed, is that the restoration of degraded sites should be a priority, and the benefits of such activities are well documented. However, there is variation in understanding the impact of restoration on carbon savings. How restoration affects carbon fluxes and storage on degraded sites shows variety in the potential results. Peatland recovery is not instantaneous (Gatis et al.,2023, Alderson et al, 2019), with interventions taking at least 5 years or more for ecosystems changes to stabilise (Gregg et al., 2021). Artz et al. (2012) note that carbon savings are dependent on the starting condition prior to restoration with some research indicating that severely degraded sites take longer to achieve emissions reduction than less

affected peatlands. Restoring the carbon 'sink' functionality of a degraded peatland is possible, however this may take decades, and be dependent on the initial level of site degradation (Gregg et al., Ibid). Lindsay (2010) notes that peat accumulation in blanket bogs can be half that of raised bog due to warmer climatic conditions and suggests a timeframe of around four decades before restoration to a fully functional bog can achieve net carbon gain, although emissions reduction will occur much earlier. Although there can be short term CH_4 fluxes because of restoration the long-term carbon savings can negate this short-term effect (Emsens et al., 2021– note this study relates to fen bogs, but also highlights the important role of vegetation establishment). Evans et al. (2022) note that independent modelling studies by Heinemeyer et al. (2019) for the Defra Peatland-ES-UK (Defra BD5104) project, and Simon et al. (2021) for the BEIS review of UK GGR potential both suggested that degraded peatlands have the potential to accumulate carbon rapidly, and therefore that the CO_2 sequestration potential of peat restoration may have been significantly underestimated. The current methodology does not take these considerations into account.

- Future climate conditions (e.g. rising temperatures, extreme weather events) could affect the 'success' of peat restoration (i.e., carbon accumulation). Climate change is noted to exacerbate ecological stresses on less resilient, managed peatlands over the next 60 years, leading to more rapid losses of stored peat carbon (Worral et al, 2010) (Ferretto et al, 2019) (Natural England, 2020). Any estimates made have a high level of uncertainty, given the relatively short timeframe of restoration in the context of a wind farm's lifespan.
- The calculations for site restoration are sensitive to water table depth changes, pre- and post-restoration (Appendix 10.3). Water table has a significant influence on peatland CO_2 and CH_4 emissions (see section 3.8.7). However, there is limited empirical data to provide a high level of certainty in relation to future carbon stocks and carbon flux; carbon benefits can be difficult to quantify and affected by environmental conditions on a site-by-site basis (Wille et al, 2023), Gregg et al. (2021) state in relation to blanket bogs, raised bogs and fens that 'large spatial variability has been shown and studies have often been carried out at the same sites or regions', blanket bogs are less responsive to drainage and rewetting alone, but can be beneficial when coupled with peatland stabilisation and re-establishment of vegetation cover, the role of vegetation as well as hydrology in site restoration should therefore be taken into account. Further research is required in the context of restoration, including blanket bog rewetting (Evans et al., 2014; Williamson et al., 2017), and restoration of plantations to semi-natural peatland.
- See also the commentary on **'emission rates from soils'** within Section 193.8.

3.11.2. Usability

- Calculations within this tab are based on the changes to water table depth pre- and post-restoration of peat (inputted by the user) and the calculated emission rates from soils. It has been noted that small changes to the figures for water table depth can significantly increase the value of carbon gains due to peat restoration. Although the methodology for 'Water table depth after improvement' variables indicate an optimal water table level is 'probably just below the surface (-10 to -6 cm)', within planning timescales the future water table depth (and other associated variables) can only be approximated. When accounting for the high level of uncertainty regarding restoration, the question of whether this element of the Carbon Calculator should be conventionalised to replicate the Peatland Code's calculations and guidance requires consideration.

- See also commentary on **'emission rates from soils'** within Section 193.8.

See 3.3.3 key consideration: is the output of the Carbon Calculator useful as a decision-making tool?

The timeframe for achieving a 'carbon payback' or 'carbon neutrality' should be considered on a land for land basis (e.g. restoration gains vs construction losses) instead of relying on savings from generation. More information on how this should be presented is provided in 3.3.3.

3.11.1. Key consideration: the Carbon Calculator should be updated to replicate the Peatland Code

Site restoration should explore the option to replicate elements of the Peatland Code's approach, including its requirements around restoration success. In particular, the Peatland Code utilises up-to-date emissions factors (aligned with the UK inventory), and includes a 15% sensitivity buffer to accommodate the risk of future carbon losses (e.g., restoration failure) (see Section 4 on the Peatland Code). Establishing a baseline condition that reflects the Peatland Code's classification, would simplify the input required for site restoration (by then selecting the appropriate condition post-restoration). Considering the degree of uncertainty, this is appropriate and could prevent the risk of inaccuracy and/or 'fixing' of the current variables. This would negate the use of 'carbon fixing', 'loss of DOC and POC', and 'peat drainage after restoration' calculations. By bringing different funding mechanisms together, this alignment could also support data collection at a national restoration level. Through our engagement with the Peatland Expert Advisory Panel, it was determined that the full implementation of the Peatland Code on development sites is not suitable. Further dialogue with the Peatland Code representatives is recommended to identify the optimal approach for this consideration.

3.11.1. Key consideration: Quality control should review the Carbon Calculator in conjunction with the Peat Management Plan (PMP) and Habitat Management Plan (HMP)

In determining whether a development should be built on peatland, a key decision factor should be the extent to which the developer is able to illustrate site restoration post installation, reflecting the requirements of NPF4 (mitigation hierarchy) and Good Practice restoration Guidance (e.g. NatureScot, Peatland Code). Resilient restoration through credible restoration techniques which prioritise vegetation establishment and a return to high water tables are critical components of this. The remit of the Carbon Calculator is to determine whether the carbon impact of the development on peatland is acceptable, any carbon savings from site restoration should be reviewed holistically in conjunction with a robust PMP and HMP that evidences credible restoration techniques. To inform this, a review of the requirements for key EIA deliverables (i.e. PMP, HMP, Carbon Calculator) could be undertaken, to enable a streamlined decision-making process.

3.12 Summary

Based on the findings from the technical assessment and evidence review, Table 4 presents a summary of the Carbon Calculator's scientific accuracy and data usability ratings.

Table 4. Carbon Calculator areas summary

	Areas of the Carbon Calculator	RAG rating Scientific accuracy	RAG rating Data usability
3.2	Data inputs	-	Amber
3.3	Payback time and CO_2 emissions	Red	Amber
3.4	Wind farm CO_2 emission savings	Red	Green
3.5	Emissions due to turbine life	Red	Amber
3.6	Loss of carbon due to back up power generation	Red	Green
3.7	Loss of carbon fixing potential of peatlands	Amber	Amber
3.8	Loss of soil CO_2	-	-
	- Peat removed	Amber	Amber
	- Peat drained	Red	Red
3.9	CO_2 loss by DOC and POC loss	Amber	-
3.10	Loss of carbon due to forestry loss	-	-
	- Simple	Red	Amber
	- Detailed	Amber	Red
3.11	Carbon saving due to improvement of peatland habitat	Red	Red

In summary, the 'payback time and CO_2 emissions' is not relevant/consistent with the findings of the technical assessment and literature review. The focus of the Carbon Calculator (3.4) requires revisiting, with consideration of whether 3.5. and 3.6. are required considering new planning policy and applicability of WLCAs.

Accuracy is lacking in one or more of the following: methodologies, use of emission factors and assumptions, for all peat-related areas of the Carbon Calculator, as well as the forestry area. The usability of the Carbon Calculator presents a more varied picture, with some data accessible to the user. However, there was uncertainty in the ability to accurately access some of the data required for the Carbon Calculator – in particular, for variables that drive the results, which could have a material bearing on the accuracy of outputs.

Further commentary is provided in 7. Conclusion and recommendations.

3.13 SWOT analysis

Table 5 presents the strengths, weaknesses, opportunities, and threats of the current Carbon Calculator identified from this Report's findings:

Table 5: SWOT analysis

Strengths
• Allows previous iterations of inputs to be saved and updated. • Used by applicants for over 16 years. • User guidance document and detailed guidance within the Carbon Calculator are provided. • The data variables for Wind farm CO_2 emission savings are site specific, are available to the Carbon Calculator user, and support an accurate output. • The data variable for Emissions due to back up power, is available to the Carbon Calculator user. • The calculation methodology for calculating CO_2 loss from removed peat is appropriate. • DOC and POC calculations require no inputs from the user. • The method which informs the detailed forestry tab is comprehensive.
Weaknesses
Accuracy • Accuracy is lacking in one or more across methodologies, use of emissions factors and assumptions for Loss of CO_2 fixing potential, due to not considering the condition of the peatland. However, it has a very small bearing on carbon output. • Accuracy is lacking in one or more across methodologies, use of emissions factors and assumptions for Loss of soil CO_2 (peat removed), due the use of averages. • Accuracy is lacking in one or more across methodologies, use of emissions factors and assumptions for CO_2 loss by DOC and POC loss, due to more recent literature updates. • Accuracy is lacking in one or more across methodologies, use of emissions factors and assumptions CO_2 losses associated with loss of forest (both simple and detailed).
Usability • The user is required to input a high number of variables (i.e. for the core input data, 70 input variables are required). Each input variable requires an expected value, as well as a minimum and maximum range, therefore over ~200 input variables are required in total for core inputs, this has been highlighted as cumbersome by some users. • The peatland related carbon emissions are presented to the user as a small proportion of overall carbon emissions because the emissions from the wind turbine are far greater. • There is some uncertainty around the data availability for Emissions due to turbine life, this may be causing double counting in foundations emissions, and this area of the Carbon Calculator may be redundant with the development of WLCA. • There is some uncertainty around data availability for Loss of soil CO_2 (peat removed) due to it being difficult to obtain some of the variables and/or assumptions used.
Opportunities
• Replace the use of averages with infrastructure specific inputs, this approach would provide more accurate outputs, improved usability, and replicate how peat is reported on in the PMP. • Opportunity to remove/option to 'opt out' of minimum and maximum variables where site specific data is known and can be evidenced by the user, reducing number of inputs required overall. • Opportunity to present the impact of development on peatland via the baseline site conditions and 'payback' time to a restored site in relation land use emissions. • Opportunity to illustrate a 'counterfactual' that demonstrates the benefits of restoration without development taking place (if restoration takes place as a result of Scotland's proactive approach and financial mechanisms that support restoration)

- The emissions associated with wind turbine LCA, back up requirements, and current 'payback' approach could be removed from the Carbon Calculator as existing tools and approaches exist for WLCA.
- Opportunity to incorporate minimum and maximum parameters into the Carbon Calculator to support quality control.
- Evidence gap - in relation to bog fixing potential and peatland condition relationship.
- The use of HRSD could support the identification of peatland condition, as well as ascertaining water table depth and providing historic trends. This could enhance the accuracy of the Carbon Calculator when combined with ground truthing and inform Quality Control Mechanisms.
- Further research/engagement with JHI could inform estimating the 'Average extent of drainage around drainage features at site' and 'soil bulk density' input via HRSD and/or GIS.
- Further engagement, the subsequent development/updating of guidelines, and/or the provision of training (to users and decision makers) would support quality control. Data outputs from applications could then go on to inform a national dataset of measurements.
- Opportunity to align DOC and POC with the 2014 IPCC Wetland Supplement to capture DOC and POC emissions that are already occurring on eroding peatland and provide greater accuracy.
- Opportunity to Replace the simple and detailed methodologies with one approach, informed by Woodland Carbon Code calculations (which is supported by Scottish Forestry and has undergone independent validation and verification).
- Opportunity to align the inputs used in PMPs, HMPs and other related EIA deliverables with the Carbon Calculator's inputs to streamline decision making.
- Opportunity to integrate the Peatland Code calculation methodology to support greater accuracy.
- Opportunity to evolve the Carbon Calculator to assess more land use types.
- Opportunity to evolve the Carbon Calculator to assess different infrastructure/development types.

Threats

- The focus of the Carbon Calculator and 'Payback time and CO_2 emissions' in calculating the lifecycle emissions of wind farms based on a counterfactual of electricity generated by fossil fuels no longer accurately represents the impact of developments on peatland.
- The methodologies, use of emissions factors and assumptions are not relevant/consistent with findings of the literature review for Wind farm CO_2 emission savings, the assumptions are not representative of current context.
- The methodologies, use of emissions factors and assumptions are not relevant/consistent with findings of the literature review for Emissions due to turbine life. The assumptions are out of date.
- The methodologies, use of emissions factors and assumptions are not relevant/consistent with findings of the literature review for Emissions due to back up power generation, there are no specific requirements for back-up, and this area of the Carbon Calculator may be redundant.
- The methodologies, use of emissions factors and assumptions are not relevant/consistent with findings of the literature review for Loss of soil CO_2 (peat drained) due to new literature findings.
- The methodologies, use of emissions factors and assumptions are not relevant/consistent with findings of the literature review for CO_2 gains from site improvement, due to uncertainty in the method, and new literature findings.
- Data for Loss of soil CO_2 (peat drained) is inaccessible to the user, for extent of drainage and water table, and this has a material impact on the outcome of the Carbon Calculator.

- Data for CO_2 losses associated with loss of forest (detailed) is inaccessible to the user, and this has a material impact on the outcome of the Carbon Calculator.
- The comprehensive nature of the detailed forestry approach has implications for the ability to 'futureproof' the Carbon Calculator. The equations which inform it and the formula within the Carbon Calculator, are complicated and difficult to interpret without advanced excel skills. This presents a risk when undertaking future updates to the Carbon Calculator.
- Minimal quality controls in place could enable gamification/errors in user outputs - there is significant variety in the methods used to obtain the input variables required for extent of drainage and water table. These variables have a significant bearing on the carbon outputs. There are no quality control mechanisms in place to ensure that the inputs entered are accurate.
- Capacity building is required within quality control as the Carbon Calculator outputs (and the inputs and calculations which inform these) are very complicated.
- Based on the findings in this report, certain elements of the Carbon Calculator are open to external scrutiny, particularly if decision-making on planning approval uses Carbon Calculator outputs.
- There is a risk of fragmentation/overlap/methodological inconsistencies within the Carbon Calculator if the collaborative efforts of multistakeholder organisations that specialise in i) forestry (WCC) and ii) peat restoration (Peatland Code) are not considered.

4 Evaluation of Peatland Code

The IUCN Peatland Code is a voluntary certification standard for UK peatland (fens and bogs) projects seeking financial benefits from restoration activities through 'carbon units.' The code provides a framework for the validation and verification of greenhouse gas reductions.

The principle of the Peatland Code is classification of land use or peatland condition pre-restoration and post-restoration. In the following subsections we explore the value add of integrating this categorisation into the Carbon Calculator, focusing on bog peatland.

The Carbon Calculator does not currently fully align with the Peatland Code; there are opportunities to replicate elements of the Peatland Code within the Carbon Calculator, as well as aligning emission factors.

4.1 Overview of the Peatland Code

The Peatland Code encompasses a simplified methodology to quantify the effect of peatland restoration on land emissions, for the purpose of verification for 'carbon units.' The Peatland Code considers accuracy and reliability when quantifying the climatic benefits of peatland restoration. As such key requirements on projects include:

- **Validation and Verification:** There is a requirement for restoration projects to undertake third-party validations and verifications to ensure climate benefits are quantifiable, additional, and permanent.
- **Management and monitoring plan:** all projects are required to have a restoration management plan for the duration of the project. The monitoring plan should track the peatland condition over time.

- **Management of Permanence:** to manage the risk of project permanence, a 15% risk buffer is applied to emission reduction calculations. This acknowledges the risk of future carbon losses; either from emissions associated with restoration activities (e.g. fuel use) or to future peatland restoration failure.

4.2 Bog emissions calculator

The bog emissions calculator requires four inputs (area, project duration, pre-restoration condition and post-restoration condition) (Table 6) from which emission reductions (tCO_2e) are calculated from a 'emissions lookup table' across 100-year period (Table 7). The emission factors have been developed to align with the UK Greenhouse Gas Inventory, based on recent research from the UK Centre for Ecology & Hydrology, and the JHI (Evans et al, 2023). The difference between the pre- and post-restoration emission factors provides the carbon reductions achieved through restoration.

Table 6: Peatland Code Condition Categories (bogs)

Pre-Restoration (Baseline) Condition Category	Post-Restoration Condition Category
a. Actively Eroding: Hagg/ Gully b. Actively Eroding: Flat Bare c. Drained: Artificial d. Drained: Hagg/ Gully e. Near natural	a. Revegetated b. Rewetted Modified Bog c. Near natural

Table 7: Peatland Code Bog Emission Factors

Peatland Condition		tCO_2e/ha/year	
Baseline / Pre-restoration	Post-restoration	Pre-restoration	Post-restoration
Actively Eroding: Hagg/ Gully	Revegetated	17.72	3.42
Actively Eroding: Flat Bare	Revegetated	17.72	3.42
Drained: Artificial	Rewetted Modified Bog	3.32	0.32
Drained: Hagg/ Gully	Rewetted Modified Bog	2.51	0.32
Modified	Rewetted Modified Bog	2.51	0.32
Near natural	Near natural	0.32	0.32

4.3 Fen emissions calculator

The fens emissions calculator requires three inputs for both the pre- and post-restoration scenarios (land use classification, average annual water table depth and average peat depth) (Table 8), from which emissions from peat are calculated. Unlike the bogs emission calculator the emission factors are locked, however are understood to be a combination of Tier 1 and 2 emission factors (IPCC), and emission estimated derived from the site's effective water table depth (Evans et al. 2021).

Table 8: Fen Land Uses

Fen Land Uses	
• Near-natural fen • Rewetted fen • Modified fen	• Grassland (intensive) • Grassland (extensive) • Cropland

4.4 Benefits and drawbacks

Based on our findings of the Carbon Calculator's technical assessment (see Section 3) and review of the Peatland Code, Table 9 provides a high-level summary of the benefits and drawbacks of integrating the Peatland Code's methodology and emission factors within the Carbon Calculator.

Table 9: Peatland Code Summary

Benefits	Drawbacks
• Emission factors within the peatland code have recently been updated and are aligned with the UK inventory, therefore are considered as current best practice. • The peatland code's calculations include a risk buffer to account for the risk of restoration failure and additional emissions from restoration activities. • Restoration projects are required to have a 'restoration management plan' ensuring peatland condition is tracked across the project's duration.	• Emissions factor are not Scotland-specific. • The Peatland Code's third-party verification and validation would not be applicable to users of the Carbon Calculator. • Through our engagement with the Peatland Expert Advisory Panel, it was determined that the full implementation of the Peatland Code on development sites would not be appropriate.

4.5 Recommendations for the Carbon Calculator

The Peatland Code provides an established methodology to quantify GHG benefits across the UK. Aligning with this methodology could improve the accuracy of baseline carbon flux and consistency in reporting the benefits of restoration activities. However, through our engagement with the Peatland Expert Advisory Panel, it was determined that the full implementation of the Peatland Code on development sites is not suitable. Further dialogue with the Peatland Code representatives is recommended to identify the optimal approach for the following opportunities for the Carbon Calculator:

- The condition categories could be replicated to establish a more representative baseline and subsequent restoration status. The Carbon Calculator currently assumes peatland is pristine and presents a worse-case scenario in terms of carbon lost, however lost carbon may not be fairly attributed to the wind farm development.
- Whilst the emission factors may not be wholly representative of Scotland (based on a UK average) they are widely recognised as best practice. Integration of the peatland condition categories could provide a recognised approach to quantifying the benefits of peatland restoration activities (site improvements tab).
- Use of a risk buffer (measure of uncertainty) within the site improvements tab.
- If building on degraded peatland, the Carbon Calculator could include a requirement on developers to improve condition of the site through the project's lifespan. The principles of the Peatland Code could be used to inform guidance on this.

5 High Resolution Spatial Data (HRSD)

A literature review (Appendix 10.4) of eight data sources was conducted to identify HRSD measures that could indicate the presence and condition of peat. The following subsections provide analysis of the benefits and drawbacks of HRSD, and how it might improve the Carbon Calculator's accuracy.

5.1 Summary of HRSD methodologies

To date, multiple types of imagery have been used to varying degrees of success (Table 10).

Table 10: HRSD summary of findings

#1: Optical/near infrared spectral imaging	**Method**	ESA' Sentinel 2, NASA LandSat
	Author	Pontone et al., 2024.
	Benefits	• Useful for gaining understanding of landcover types on the ground. • Free to use.
	Drawbacks	• Not successful in providing a good measure of condition. • Limited to 10m, distinguishing between different types of peat at this resolution is challenging.
#2: Infrared Land Surface Temperature	**Method**	MODIS TERRA Grid data
	Author	Worrall et al. 2019
	Benefits	• Difference in land surface temperature can detect the energy balance of ecosystem, a proxy for peat health. • Archive data can be used to understand long term health.
	Drawbacks	• Very limited resolution of 1km sq.
#3: Synthetic Aperture Radar (SAR)	**Method**	Sentinel 1 VV/VH Backscatter
	Author	Toca et al. 2023, Pontone et al. 2024, Lees et al. 2020
	Benefits	• Provides a proxy measurement of water table depth. • Archive data can be used to look at water table depth over time. • Free to use.
	Drawbacks	• Limited to a resolution of 22m. • Measurement can be affected by other variables such as inundation and vegetation compositions.
#4: InSAR	**Method**	Sentinel 1 Interferometry, Intermittent Small Baseline Subset method
	Author	Bradley et al. 2022, Alshammari et al. 2018
	Benefits	• Detects the surface motion of peat, a direct indicator of peat health/resilience. • Archive data can be used to look at peat health over time. • Free to use.
	Drawbacks	• Limited to 90m + resolution. • Complex processing pipeline (which would require additional costs).
#5: LiDAR	**Method**	Bespoke airborne LiDAR
	Author	Carless et al. 2019
	Benefits	• Useful in picking up the micro-topographic features such as drainage ditches and peat cuttings. • Can be mapped to a very high resolution (<1m).
	Drawbacks	• Prohibitively expensive to capture all, but a one-time snapshot given. Requires airborne imaging (e.g. drone or plane).

5.2 Summary of literature review findings

For **optical based imagery** (#1 and #2) cloud cover often limits the number of temporal snapshots captured, although it has not been successful in providing a good measure of condition, it can provide an understanding of landcover, including vegetation.

Active based sensing (#3, #4 and #5) can be coupled with landcover information provided from optical based imagery to provide a holistic understanding of peat condition and water table depth proxies. LiDAR data, as demonstrated by #5, is very useful for mapping topographical features such as draining channels and flow paths in high resolution but is expensive to obtain in real-time, given these features are relatively stable, LiDAR surveys commissioned over a wide area (i.e. a National Scheme) would be a useful dataset for identifying hydrological features that could inform the Carbon Calculator inputs. Our findings indicate that SAR data, coupled with the methodologies referenced in #3 and #4 appears to be the most promising in both its ability to capture hydrological condition of peat (including water depth) and the ability to obtain temporal imagery. More information on ESA's Sentinel 1 platform is provided in Appendix 10.4. The limiting resolution of this approach may reduce the accuracy for small and/or spatially varying sites, but is advantageous over the deployment of ground-based sensors in that:

- It provides continual mapping across the whole site, compared to a sparse deployment of specific ground-based sensors.
- Archival data and repeated visits provide a longer temporal dataset from which to establish condition compared to ground-based sensors placed for a discrete time interval.

Future trends show a rise in popularity for SAR data products, with companies like Umbra offering high-resolution (1m) options, mitigating some of the current limitations. However, as SAR is unable provide landcover information, combining it with optical imaging could yield the most informative and accurate maps.

Although not assessed as part of this review, it is understood that Scottish Government is exploring a national LiDAR scheme with repeat collections every few years, which could track the stability, loss, and/or growth of peatlands. LiDAR alongside optical SAR and InSAR data could provide key data to inform the Carbon Calculator.

5.3 Recommendations for the Carbon Calculator

Scottish Government is exploring a national LiDAR scheme with repeat collections every few years, the results of this could be integrated into the Carbon Calculator, and reviewed to understand whether any further use of HRSD would provide additional transparency and support accuracy, over and above the following:

- Integrating HRSD into the Carbon Calculator, through a model which combines #1, #3 & #4 HRSD types, would enable an understanding of i) land cover types, providing proxies for ii) peat condition, and iii) water table depth, as well as the provision to understand the history of prospective sites to better inform peat condition. It could therefore also be used to inform subsequent monitoring activities. The condition of peat is causally related to the emission and sequestration of carbon sequestration and since this not currently considered by the Carbon

Calculator, adding this capability would provide a step change in improving the accuracy of the Carbon Calculator. The water table depth is currently considered in the Carbon Calculator but requires manual surveying. Adopting the remote sensing approach would be advantageous in providing consistent and temporal measurements that would improve the accuracy between sites and support quality control.

- Integrating remote sensing into the Carbon Calculator will depend on having data products that are deemed accurate enough and are readily available at little or no cost. The products from TerraMotion (#4) would appear to be the most promising for peat condition but further stakeholder engagement would be needed to determine whether their offering suffices both in accuracy and cost, over and above the nationwide LiDAR scheme being explored by Scottish Government.
- An additional piece of work could be carried out to explore a proof-of-concept data product that brings together the surface motion, water table depth and vegetation cover measures identified in the review. Combining all three types of data is likely to provide the most informative and accurate measure of presence and condition of peat. The output should be validated against a typical ground-based survey carried out by an organisation using the Carbon Calculator.

6 Quality Control Mechanisms

Decision makers that utilise the outputs of the Carbon Calculator include the Energy Consents Unit (ECU) and local planning authorities. ECU review applications for consent for the construction, extension and operation of electricity generating stations with capacity more than 50MW. Applications below this threshold are reviewed by the relevant local planning authority. Following engagement with ECU, it has been ascertained that the existing quality assurance processes undertaken to evaluate and support decision-making would benefit from significant enhancement. Due to the Carbon Calculator’s complexity and the skillsets required to review the data outputs, it is ascertained that the Carbon Calculator is not currently used as a decision-making tool in the capacity it was intended but is used to check the credibility of the ‘payback period.’

6.1 Recommendations for the Carbon Calculator

The following actions are recommended to improve the utility of the Carbon Calculator as a decision-making instrument:

- The Carbon Calculator should have automated mechanisms for input variables that exceed acceptable error margins or contradict other variables.
- A guidance document should be produced to support developers, ECU, and local planning authorities on the key drivers of peat-related carbon emissions and potential variances (i.e. carbon fluxes), this could be done through the updating of existing guidelines (i.e. Guidance on Developments on Peatland, 2017).
- The decision to build on peatland should consider the developer’s ability to demonstrate post-installation site restoration, in line with NPF4 and Good Practice restoration Guidance (e.g. NatureScot, Peatland Code). Resilient restoration through credible restoration techniques which prioritise vegetation establishment and a return to high water tables are

critical components of this. The Carbon Calculator's purpose is to assess the carbon impact of the development on peatland. Carbon savings from site restoration should be reviewed holistically alongside a robust PMP and HMP. A review of the requirements for key EIA deliverables in terms of the inputs they require could benefit quality control and streamline the decision-making process.

A further consideration is that through the implementation of the above recommendations, Quality-controlled application data could contribute to a national database.

7 Carbon Calculator applicability

Based on our findings, this section explores the Carbon Calculator's applicability as a decision-making Carbon Calculator across proposals for alternative infrastructure (e.g., transmission and distribution, battery storage options) and renewable energy development (e.g., solar) on peatland and carbon rich soils within Scotland. Whilst the Carbon Calculator, in its current form, would not be fully applicable to alternative development proposals, modifications can be made to increase transferability. Table 12Table provides some considerations against each area of the Carbon Calculator.

Table 11. RAG Ratings

RAG	Criteria
Green	Fully transferable to alternative developments
Amber	Limited modifications required to enable the Carbon Calculator to be used for other developments
Red	Area would require significant work to enable the Carbon Calculator to be used for other developments

Table 12: Increasing Carbon Calculator applicability (Note Section 3 recommendations apply to the below).

Areas	RAG	Potential modification/considerations
Data inputs	Amber	Data inputs would need reviewing to cover the characteristics of other renewable technologies and developments.
Payback time and CO_2 emissions	Amber	Payback time may not be an appropriate measure for all asset types.
Carbon emission savings from wind farms	Amber	Minor modifications would be required to calculate back-up requirements for other renewable energy assets. For some developments (e.g. battery storage) this area may not be relevant.
Emissions due to turbine life	Red	Currently wind farm specific, however data inputs and assumptions could be modified to allow for a broader selection of assets / technologies (e.g. drop-down selection for technology option).
Loss of carbon due to back up power generation	Amber	Minor modifications would be required to calculate back-up requirements for other renewable energy assets. For some developments (e.g. battery storage) this area may not be relevant.
Loss of carbon fixing potential of peatlands	Amber	For wind turbines this area of the Carbon Calculator considers the loss of future carbon fixation through the removal of peat. As the turbines are tall and provide little shading there is minimal impact to the wider

		area. However, consideration would need to be given to the spatial factors of alternative technologies. For example, if solar panels shade large areas of peatland this is likely to affect the sequestration rate of bog plants. There may also be impacts to peatland carbon cycling through the heat projected into the ground. There is a need for further research to understand the full implications (NatureScot, 2022).
Loss of carbon stored within peatlands	Green	Methodologies are relevant to any development on peatland.
Loss of carbon due to leaching of DOC & POC	Green	Methodologies are relevant to any development on peatland.
Loss of carbon due to forestry loss	Green	Methodologies are relevant to any development on peatland.
Carbon saving due to improvement of peatland habitat	Green	Methodologies are relevant to any development on peatland.

7.1 Recommendations for the Carbon Calculator

In summary, although amendments would be required to the data inputs, wind turbine related emissions, and the presentation of 'payback' and carbon emission savings, the majority of methodologies for the peatland related calculations are relevant to any development on peatland. Whilst currently employed solely for wind farm developments, there is potential for the Carbon Calculator to be adapted to apply to grid infrastructure and other development types on peatland and carbon rich soils. There are no concerns on the Carbon Calculator's ability to be used on projects of all sizes. However, to be applied to different infrastructure types, it is essential to consider their unique spatial characteristics, such as the shading effects and excess heat generated by solar farms. Further research and engagement are necessary to thoroughly understand how these factors impact peatland and carbon-rich soils before extending the Carbon Calculator to other development types.

8 Conclusion and recommendations

8.1 Conclusion

This report concludes that, based on the findings of a technical assessment, evidence review and quality control mechanisms, we recommend updating the Carbon Calculator in its current form to align with recent policy updates and advancements in science.

Our conclusions and recommendations set out how the Carbon Calculator could be updated through:

- **Section 8.2:** Addressing 'big picture' questions regarding the Carbon Calculator's current remit to inform future decision making.
- **Section 8.3:** Making a series of updates to the current Carbon Calculator to bring it in line with scientific understanding and improve its accuracy.

Further areas of research due to evidence gaps identified during the literature review are summarised in Section 8.4.

8.2 Overarching considerations to inform future decision making

Key consideration: Does the calculator need to consider the lifecycle emissions of the wind farm, or could the focus be purely on the impact of development on peat? (Section 3.3.5)

Well-established methods and tools are available to undertake Whole Life Carbon Assessments (e.g. PAS2080). NPF4 Policy 2 (climate mitigation and adaptation) states that all proposals will be "be sited and designed to minimise lifecycle greenhouse gas emissions as far as possible." Given this context, it is pertinent to question the necessity of the Carbon Calculator in replicating these existing approaches. Instead, it may be more beneficial to concentrate efforts on analysing the specific impacts of development on peatland/habitat carbon emissions. Key considerations include:

- Whether the lifecycle emissions of a wind farm need to be included in the Carbon Calculator?
- Could the calculations in the Carbon Calculator solely be focused on the impact of the development on peatland/habitat carbon emissions?
- Is the presentation of the current payback output necessary or appropriate for decision making?

Key consideration: Is the output of the Carbon Calculator useful as a decision-making tool? (Section 3.3.3)

Since the inception of the Carbon Calculator, scientific advancements have deepened our understanding of the interplay between nature and climate change. This progress is reflected in NPF4's mitigation hierarchy and Policy 3b, which require substantial biodiversity improvements alongside restoration and offsetting requirements. In this context, it is important to acknowledge that carbon emissions sources should be segregated and reported separately to facilitate informed decision-making.

As the UK transitions to net zero, the current carbon payback' approach (comparing development emissions to the counterfactual of electricity generated by fossil fuels) becomes less relevant. The focus should shift to evaluating the developments on the natural environment, specifically, whether it improves the environment and sequesters CO_2 effectively. This method is more insightful than balancing combined wind farm and peatland emissions against 'carbon payback,' which does not provide significant insights.

To better assess the carbon impact on peatland, the timeline for achieving 'carbon payback' or 'carbon neutrality' should consider land-based emissions. For example, 'payback time' could be defined as the period needed to restore peatland to a 'near pristine' condition from a reported baseline, compared to the site's baseline emissions without development and counterfactual scenarios for non-peaty sites, considering Scotland's widespread peatland restoration efforts (refer to Section 3.3.3 for more details).

Key consideration: Should the Carbon Calculator incorporate other land use types?

Considering the previous point, it's important to consider whether the Carbon Calculator should be updated to account for various land use and habitat types. This would offer a more comprehensive view of the carbon impact on other land use types, as compared to the carbon impact on peatland. This aspect should be evaluated considering Scotland's evolving Biodiversity Net Gain requirements, current PMPs, HMPs, and their anticipated updates.

Key consideration: The current quality control mechanisms are insufficient

The scope of this report was to identify the key updates or improvements which would bring the tool in line with current scientific understanding and improve the accuracy to better inform decision making. However, this report concludes that due to its complexity and skill sets required to review the data outputs, the Carbon Calculator is not currently used as a decision-making tool. Section 6 on Quality Controls provides more detail on the rationale behind this, and provides recommendations to improve the current approach, which should be considered ahead of updating the Carbon Calculator.

8.3 Key updates to bring the Carbon Calculator in line with scientific understanding and improve accuracy

8.3.1. Updates to the current Carbon Calculator

This report concludes that the current Carbon Calculator is no longer up to date following advancements in science, but it could be brought in line with scientific understanding and improved accuracy through the updates to the following:

3.2 Data inputs:
To improve data usability, explore options to integrate the Carbon Calculator and/or allowance for easy transfer from/to input variables that align with/can be obtained directly from other sources, i.e. Peatland Management Plan, Hydrological Assessment, HMP, and (in future) WLCA.

3.3 Payback time and CO_2 emissions:
Section 8.2 concludes that this area requires a significant update to accurately reflect a carbon 'payback time' in relation to land use emissions, and so updating the technical elements of its current calculation approach (Section 3.3.1) would not be appropriate.

3.4 Wind farm CO_2 emission savings, 3.5 Emissions due to turbine life and 3.6 Loss of carbon due to back up power generation:
Section 8.2 concludes that these areas of the Carbon Calculator are not required. Updating the respective technical elements of each where inaccuracies have been identified would not be appropriate.

3.7 Loss of carbon fixing potential of peatlands:
To improve both scientific accuracy and data usability the baseline condition of peatland should be incorporated into the Carbon Calculator, the inclusion of the Peatland Code's calculation methodology may make this area of the Carbon Calculator redundant (Section 3.7.3).

3.8 Loss of soil CO_2:
To significantly improve the scientific accuracy and data usability of this area:

- Incorporate minimum and maximum parameters into the Carbon Calculator for the carbon content of dry peat and dry soil bulk density variables (Section 3.8.5).
- Update the methodology for emissions rates from soils to reflect more recent literature and Scottish context (see Section 3.8.9 for more information).
- Account for emissions from drainage ditches (Section 3.8.10).
- Replace the use of averages with infrastructure specific inputs to replicate how peat is reported on in the PMP.

3.9 CO_2 loss by DOC and POC loss:
To improve scientific accuracy, align DOC and POC with the 2014 IPCC Wetland Supplement, replicating the Peatland Code's calculation methodology (Section 3.9.3).

3.10 Loss of carbon due to forestry loss:
To improve both scientific accuracy and data usability:
- Replace the simple and detailed methodologies with one approach, informed by Woodland Carbon Code calculations (Section 3.10.5) and HRSD.
- Remove the option to affect the wind turbine's capacity factor via the forestry inputs tab (Section 3.10.6).

3.11 Carbon saving due to improvement of peatland habitat:
To significantly improve scientific accuracy and data usability, Update the Carbon Calculator to replicate the Peatland Code's principles (Section 3.11.3).

5. High Resolution Spatial Data (HRSD):
HRSD has the potential to improve and enhance the data usability of the Carbon Calculator and could support quality control mechanisms. Recommendations include:
- Consider options to integrate HRSD into the Carbon Calculator to enable an understanding of i) land cover types, providing proxies for ii) peat condition, and iii) water table depth, as well as the provision to understand the history of prospective sites to better inform peat condition, drainage variables, and subsequent monitoring activities. This could act as a quality control measure against inputted variables.
- Further engagement with JHI and other key stakeholders involved in HRSD within Scotland (i.e. Nature Scot, CivTech) is recommended to enable a joined-up and effective approach to the solution developed.

8.4 Further research

This review has identified the following evidence gaps that necessitate further research and/or engagement:

- Further research is required to understand the impacts of climate change on the carbon fixing potential of peatlands.
- Further research is required to understand whether the option to reuse peat elsewhere would be appropriate.
- Further research required into the link between peatland condition and bog plant fixing potential, or on updated fixation emission factor rates (if appropriate).

- Further research is required to identify a suitable ‘average extent of drainage.’
- Further research is required to provide more specific DOC and POC estimations.
- Further research is required to understand whether HRSD could inform the carbon content of dry peat and dry soil bulk density variables.
- Further research on the impact on peatland from the removal of trees (where located on peatland and other carbon rich soils).
- Further research is necessary to understand how the spatial variability of different development types could impact peatland and carbon-rich soils.

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10 Appendices

The following appendices open a download link to each of the spreadsheets.

10.1 Technical assessment

10.2 Sensitivity Analysis

10.3 High Resolution Spatial Data (HRSD) Assessment

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