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Carbon impact & mitigation of housing developments on peatlands in the UK - A case study

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ABSTRACT

Peatlands are a key asset in the drive to reduce annual carbon emissions due to their potential as a carbon sink. This is especially important in Scotland where 25% of the land is covered by peat. Peatlands have historically been considered wastelands that needed to be re-used for other more productive purposes. For this reason, circa 78% of UK peatlands are currently in a degraded state. The favoured foundation option for any construction has been to excavate the peat and replace it with a more competent granular soil, but the excavation process risks drying sections of peatlands with the associated detrimental effect on the stored carbon. The purpose of this manuscript is to appraise the environmental impact associated with the construction of the foundation of a proposed development on a peatland. The research focuses on a case study in Bishopbriggs (Glasgow). The results of this study highlight that a positive effect on the overall carbon sink could be achieved if alternative approaches to a total peat removal were explored. The total restoration followed by the partial development of the site are demonstrated to be the best solutions, resulting in a net carbon gain in the long-term. The non-development scenario is shown to be the least environmentally sustainable option in the longer term. This case study highlights the significant contribution that the construction sector currently holds towards the GHG emissions abatement when building on peatlands in the UK.

Keywords: Climate change, peat-left-in-place options, peatlands, excavate-and-replace, peat degradation, sustainable foundation options.

1 INTRODUCTION

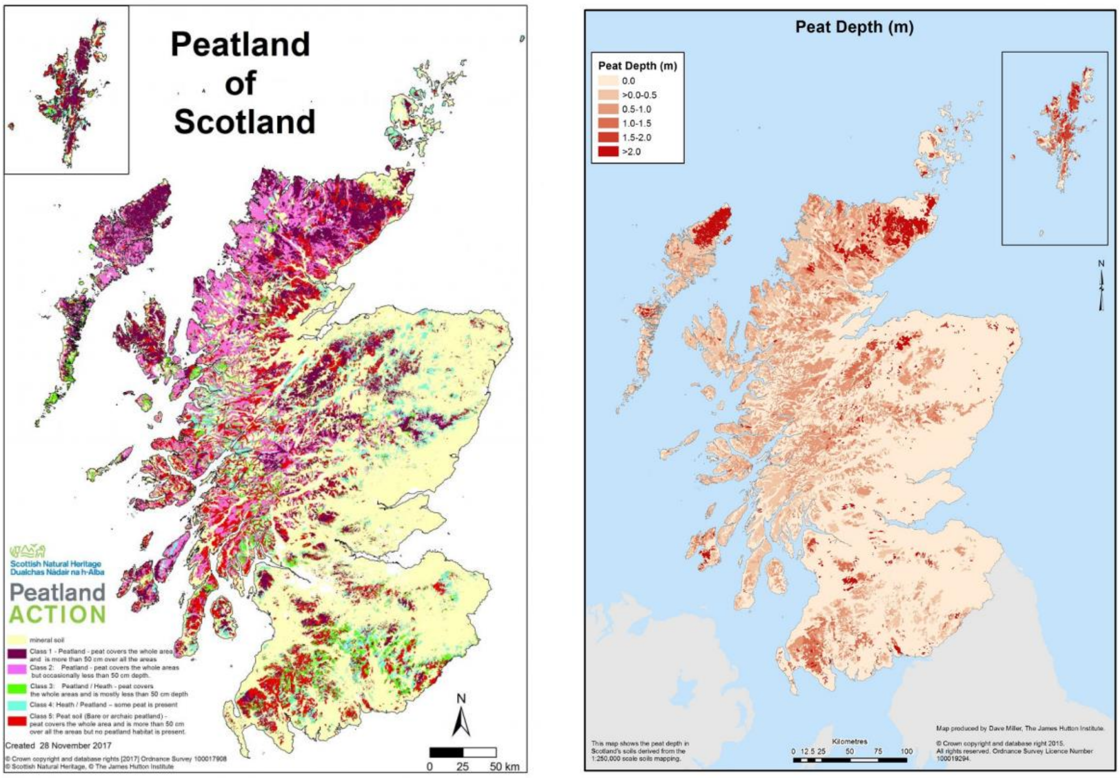
1.1 Climate change and peat(land)

Reducing greenhouse gasses (GHG) emissions is one of the main goals of the 1997 Kyoto Protocol and the Paris Agreement, which seeks to limit the global raise in temperature to 1.5 °C. Contributions from all the sectors are needed in order to reach this objective, and in recent years a renewed attention has been put on the protection of wetlands and other natural habitats. The importance of healthy peatland habitats in climate change regulation is widely recognised by the scientific community and has been highlighted in the literature (Lindsay et al., 2017; Horsburgh et al., 2022). Indeed, the 3 million hectares of UK peatland store over 3 $GtCO_2e$ and when in active conditions they can remove about 1.8 $MtCO_2e$ per annum (Evans et al., 2017; Thom and Doar, 2022).

On the other hand, human exploitation of the land has caused severe erosion and drainage issues which led to the degradation of 78% of the UK peatland (Horsburgh et al., 2022; Thom and Doar, 2022). The latter results in a carbon release of around 23 $MtCO_2e$ per year (Evans et al., 2017). This situation may exacerbate in the future as a high risk exists that degraded peatlands will be destroyed under the hotter and drier conditions predicted with the climate change. Consequently, the policies for a Net Zero UK published in the sixth carbon budget (CCC, 2020) proposed to ban rotational burning in 2020 and mandated that up to 100% of upland peatlands and 60% of lowland peatlands are to be restored by 2045 and 2050, respectively. These actions would aid in reducing UK-wide peatland emissions by 6 $MtCO_2e$ per annum by 2035 and around 10 $MtCO_2e$ per annum by 2050. Any case for further developments must therefore be robust and demonstrate net positive benefits to the society.

Carbon impact of housing developments on peatlands in the UK - A case study

This is particularly notorious in Scotland (Figure 1), where peatlands cover about 1.9 million ha (25% of the land area) with 1.5 million ha currently found in a degraded state. The 2018 figures estimate an annual 5.7 MtCO_2e released from degraded peatlands, corresponding to about 14% of the total Scottish GHG emissions (Horsburgh et al., 2022). Under this climate emergency, the Scottish Government has committed to annually restore 20k ha of degraded peatland from 2021 to 2030 (Scottish Government, 2021). The main aim is to avoid further emissions due to peatland degradation and potentially sequester carbon in the long-term. Nonetheless, the rate currently seen in peatland restoration is not sufficient to support the carbon reduction targets set in the 2019 Scottish Climate Change Act (Scottish Parliament, 2019). Therefore, alternative and more innovative construction approaches need to be considered in the short-term to minimise the impact on the carbon stocks of peatlands.



(a) (b)

Figure 1. *a) Peatland class of Scotland (Nature Scot, 2020) and b) peat depth (Waldron et al., 2015)*

1.2 Construction on peatlands in Scotland

The economic development and social resilience of communities in rural Scotland is being hampered by a shortage of affordable housing. Nationally, about 23,000 new homes per year are needed, whilst in the year up to October 2018, only 18,000 were built (Scottish Government, 2022). The more remote rural areas of Scotland are spacious enough to offer considerable room for affordable housing development and generally have lower land values, but other factors including challenging ground conditions (including the presence of peat) can make constructing in these areas economically unviable and environmentally unsustainable. Nonetheless, the need of new housing in Scotland is making difficult to avoid new constructions on peat, and new solutions need to be explored.

The James Hutton Institute (JHI) investigated the extent to which housing development in Scotland is constrained by biophysical factors (Towers et al., 2002). These factors relate to soil and vegetation properties, and other characteristics, such as the permanent high groundwater table, soils subject to flooding or with high shrink potential. However, the presence of peat was of greatest relevance to this study. According to the JHI criteria, some 56% of Scotland's land area is biophysically constrained. This was also highlighted by Bernal-Sanchez et al. (2021), who showed that the presence of peat is not uniform across the territory. The Highland Council area is one of the most affected areas, with 1195 out of the planned 1873 housing units currently limited by the presence of peat (Highland Council, 2015).

1.3 Current foundation options

Roads, housing or windfarm construction on peat requires some form of foundation. Typically, three general foundation types exist: a) total removal of peat and replacement with aggregate fill, b) soil improvement methods (peat left in place) and c) load transfer through peat layer to lower level, load-bearing soil/rock layers (Huat et al., 2014). Historically, the favoured foundation option in Scotland and the UK has been to excavate the peat, especially in those areas where the depth is not greater than 3-4 m, and then replace it with a suitable fill to provide a stable base. However, the excavation process risks drying sections of the peatland with the associated detrimental effect on the carbon stored in the peat (Munro, 2004). Drained peat allows stored carbon to readily decompose due to the created aerobic conditions. As a result, the direct GHG resulting from excavate-and-replace are significantly high especially for high volumes of peat replaced by fills.

Excavate-and-replace peat soils may be too expensive due to factors such as peat depth, cost of backfill material and availability of peat disposal areas (Bernal-Sanchez et al., 2021). Peat-left-in-place foundation options could be used instead. Amongst those, floating solutions are commonly adopted for the construction of access roads onshore wind farms in Scotland (NatureScot, 2015). Techniques such as trench fill and conventional driven piling have also been used in Scotland for housing foundations when it was required to ensure the stability of nearby buildings (Munro, 2004). Mass stabilisation is primarily used for road and railway embankments in peatlands and in the stabilisation of dredged materials for land reclamation and erosion control in Scandinavia (EuroSoilStab, 2010), Japan (Juha et al., 2018), and it has recently been introduced in the UK (ICE, 2020). Other forms of affordable and more sustainable peat-left-in-place options include the use of bamboo and timber pile raft system in Indonesia, known as “cerucuk”, due to the high availability of low-cost materials (Rahardjo, 2005).

1.4 “Optimum” construction approach for housing developments on peatlands

It is then known that alternative forms of construction on peat exist, but they are not commonly adopted for new housing developments, at least in Scotland and the rest of the UK, despite being more sustainable. Nonetheless, if new developments were to be planned, they would inevitably have an impact on the carbon stocks of peatlands in the long-term. Hence, the question is why the excavate-and-replace practice is still adopted as the default form of foundation construction. This was investigated by Edinburgh Napier University and Heriot-Watt University (Bernal-Sanchez et al., 2021), and an options matrix in relation to the most common foundation options was created (Table 1). The analysis is based on a selection of assessment criteria, chosen to reflect the (geo)technical, environmental and logistical context of domestic construction on peatlands. The ‘Red/Amber/Green’ (RAG) appraisal is the outcome of a desk study and interviews with key stakeholders where: i) red is a negative attribute of the foundation option in question, ii) green is a positive attribute, and iii) amber was assigned to those attributes that could not fall under the red or green criteria. The flags represent the countries that have more experience using certain types of foundation options. According to the study, albeit excavate-and-replace shows 3 red criteria (all of which are related to environmental factors) it reveals a better technical and logistical performance and, more importantly, a lower cost than the other options. The latter is believed to be the main driver for the adoption of the less environmentally friendly construction approach.

However, it is likely that environmental constraints will impose increasingly stringent peat protection measures. For instance, the 4th National Planning Framework in Scotland (Scottish Government, 2022) states that no new developments should be approved on peatlands unless they are “essential”. In particular, one of the “essentiality factors” for new developments to be approved on protected soil is their contribution to the restoration of the soil itself. There is however no precise and objective way of measuring the “essentiality” of new developments on peatlands. This inevitably clashes with the aforementioned evident housing need in certain settlements in Scotland. For this reason, a more quantitative framework needs to be proposed in order to measure how sustainable/detrimental foundation construction approaches can be. This is one of the main objectives of this manuscript.

In this regard, the Scottish Environment Protection Agency (SEPA) interests lay in the minimisation of the environmental impact of construction (SEPA, 2017). At present, this results in the common objection to the approval of new development proposals whenever the information on the measures taken to minimise the impact on peat are believed to be insufficient. The interest in alternative foundations has been increasing, especially if economically viable and more sustainable. According to SEPA, the excavation of peat should be avoided as much as possible. When the extraction is “inevitable”, a peat management plan should be developed with the main aim to prevent carbon loss, including proper peat storage methods that could decrease the loss rate.

Table 1. *Criteria matrix for foundation options on peatlands (Bernal-Sanchez et al., 2021)*

Criteria Matrix for RAG Appraisal of Foundation Options												
Criteria Categories	Geotechnical				Environmental			Logistical			Other	
Criteria / Options	Bearing capacity	Settlement	Temporary works	Peat depth (m)	Impact on peat	Impact on hydrology	Embodied carbon	Approval	Durability	Cost	Experience (1)	Adaptability
Excavate-and-Replace (E&R)				< 3								
Floating solution				> 1.5								
Preload-and-surcharge				No limit								
Mass stabilisation				< 20								
Trench fill				1 - 3								
Piling (Concrete/ Steel)				> 3								
Piling (Timber)				3 - 10								

Nonetheless, a "carbon calculator" or a method for carbon estimation have not been implemented for new housing developments, contrary to what occurs with the carbon appraisal on new windfarm developments in Scotland (Scottish Government, 2018). This indicates that the environmental impact of planned housebuilding activities may be underestimated and any form of measuring the overall impact on the national carbon budget would fall short. A framework should then be adopted to at least have a preliminary estimation of how much carbon content of peatlands would be under threat.

1.5 Scope of the study

The purpose of this document is to study the potential carbon emissions linked to the disturbance of peatlands when constructing new developments. For that, a case study is herein investigated. The scope of this paper focuses on a site located in Bishopbriggs (Glasgow). The site is currently owned by Caledonian Properties. The whole area is identified as an open space hence the site is not directly destined to housing. Moreover, due to the presence of an active peat bog at the northern side it is essential to protect and maintain the habitat. Nonetheless, the degraded state of the southern section opens the opportunity for its development as a residential area. This was proposed by a regional constructor, Taylor Wimpey (TW), together with the purpose of protecting the existing active peat.

The presence of a significant amount of degraded peat, with depths of up to 4.9m, in the southern section of the 20 ha site was highlighted during the first site investigation. The proposed foundation technique, adopting the mentioned excavate-and-replace, has been deemed too environmentally damaging due to the volume of soil involved (about 210k m^3). Hence, SEPA has objected its construction and asked for alternative (more sustainable) forms of construction. It is however being challenging for the company to measure how harmful/beneficial one technique is with respect to others whilst considering the potential costs of each solution. Thus, this manuscript introduces an "adapted" carbon calculator to measure the impact that a new development may cause on a peatland in the UK.

2. METHODOLOGY

This paper seeks to measure the potential carbon impact of the disturbed peat if different development approaches were proposed at Bishopbriggs following a Life Cycle Analysis (LCA). For that, four scenarios have been set out at the southern (degraded) section of the site: i) complete development, ii) partial development, iii) no development, iv) restoration. The appraisal of the carbon emissions from the disturbed peat will thus bring some light into the questions surrounding the environmental "measurability" of a construction approach over others.

The proposed LCA follows the elements outlined by Duggan et al. (2015) who analysed the embodied carbon (EC) and embodied energy (EE) associated with the construction of a road segment on degraded peat in Ireland. Only the EC will be considered in this study, dividing the GHG emissions into three categories: i) direct emissions from the disturbed peat, ii) materials used, iii) machinery & transport.

The EC calculations are determined through a custom-built Excel worksheet that has been developed in conjunction with a literature review on restoration projects, LCA methods and technical and environmental insights obtained from SEPA. In particular, a first iteration of the carbon balance assessment has been performed following the guidelines of BS EN 14044 (British Standards Institution, 2020), which requires to define a precise goal and scope, to perform a Life Cycle Inventory analysis (LCI) and assessment (LCIA). The final step (i.e. life cycle interpretation) was not included in this study due to time constraints. Note that in absence of site-specific data related to Bishopbriggs, the values provided by Duggan et al. (2015) are used.

2.1 Development proposal scenarios

Due to the presence of the active peatland at the northern area of the Bishopbriggs site, the available space for any residential development would be limited to about 10 ha at the southern region, with the presence of degraded peat. Discussions were held between SEPA and TW to further reduce the development area, restricting the development to the South-West part of the site to allow a peatland restoration project to be undertaken. Thus, for the scope of this document, four scenarios are set out:

1) **Complete development**. A residential development is proposed on the entire southern side of the land (10 ha), and a peat management plan is followed for the excavated peat. A total of 210000 m^3 of peat are excavated and 100000 m^3 are to be displaced to a suitable receptor site for the creation of a new peat bog. The receptor is assumed to be at a 40 km distance. Further 20000 m^3 of peat are assumed to be reused within the development site for restoration works, while the remaining peat (90000 m^3) would be sent to landfill, at 20 km. About 160000 m^3 of fill have been estimated for the new foundation base.

2) **Partial development.** A residential development is proposed only on the South-West area of the site (5 ha), and a peat management is followed for the excavated peat. In this analysis, this option is assumed to involve the complete excavation of the 5 hectares involved (for a total peat volume of about 100000 m^3). The whole volume will be restored as new a peat bog (3 ha) on the South-East area, and 100000 m^3 of filling would be required to provide the foundation stratum.

3) **No development.** The area is left at its current state, and it will remain undisturbed for the studied timespan. No residential area is constructed, and no peat restoration is provided for the degraded peat on the southern section. A proper land management would thus not be possible due to the cost of the investment. The southern peat is identified as a drained extensive grassland. Its degradation is expected to continue at a constant rate. No protection, modification, or management of the peat bog on the northern section is expected.

4) **Peat restoration**. Peat will be completely restored at the southern region in order to minimise the carbon released due to the current level of degradation. This is a hypothetical scenario, not having been proposed yet by TW or SEPA due to the current lack of funding.

2.2 SEPA and peat management plan

According to SEPA, peat excavation should be avoided as much as possible. When the extraction is "inevitable", a peat management plan should be developed with the main aim to prevent carbon loss, including proper peat storage methods that would decrease the loss rate. A proper hierarchy of peat management options preference is set out as follows in SEPA Regulatory Position Statement on Developments on Peat (SEPA, 2017):

1) Prevention of peat excavation, as it might accelerate the carbon emission in case of degraded peat.

2) Reuse of the peat on-site (ideally for peatland restoration or site-restoration works, preventing additional carbon emissions due to peat transportation).
3) Reuse of the peat off-site for peatland restoration.
4) Reuse of the peat off-site for other purposes (Recycling, recovery, and treatment).
5) Storage (with prevention of high carbon emissions).
6) Disposal.

Following the SEPA guidance, the peat management options will be taken into consideration when calculating the carbon impact under each of the four scenarios herein studied.

2.3 Outbound transport and machinery

For the transport of peat to the receptor site and to the landfill, some assumptions have been made for the Bishopbriggs site. Distances were taken as 40 km to the nearest restoration site and 20 km to the landfill. The used lorries were assumed to consume 0.86 kgCO_2e/km (Duggan et al., 2015) and to transport 8 m^3 of peat per journey. The latter was calculated from the data given by TW, stating that about 26000 lorry journeys would be needed for the transfer of 210000 m^3 of peat.

The carbon emissions for the machinery used for excavating and/or mixing the peat are calculated using the values given in Duggan et al. (2015). The embodied carbon linked to the manufacturing of the equipment and its transport to the site are excluded – as they are expected to be constant for all the options. For the peat excavation, the use of a 21 tonnes excavator is considered, with a carbon emission rate of about 0.42 kgCO_2e/m^3 peat. The stabilising machinery emits about 2.52 kgCO_2e/m^3 peat.

2.4 Materials

It is fundamental to note that for the LCA only the materials which are directly linked to the peat treatment or substitution have been considered. Other materials, required to construct the foundation (e.g., geotextiles, drains, etc.), are out of scope. The excavated peat is assumed to be substituted with aggregate, which volume has been estimated by TW as 160000 m^3 in Scenario 1. On a conservative side, the volume required to substitute the 100000m^3 of excavated peat (Scenario 2) has been estimated to be 80000 m^3. The calculations have resulted in an aggregate EC of 12.48 kgCO_2e/m^3.

3. RESULTS

3.1 Peat properties

A total of about 270000 m^3 of peat is estimated to be in good conditions on the northern part of the site. The active peat bog (average depth of 2.7 m) is Class 1 peatland and cannot be disturbed by any means, and the peat underlaying the birch forest is assumed to be actively forming. A series of tests were undertaken following ASTM D2974 (2020) to determine the dry density and the organic content. For the active bog, the average dry density (ρ_d) is 63 kg/m^3 and the organic carbon content (OC) is 88%.

The southern part is underlaid by about 210000 m^3 of unclassified deep peat with average depth of about 2.1 m (and depths of up to 4.9 m), which is assumed to be heavily degraded, possibly due to drainage and excessive livestock grazing. The average dry density (ρ_d) of the degraded site is 97 kg/m^3, and the organic carbon content (OC) is 85%. This value for the southern section of the site is consistent with the one proposed by Duggan et al. (2015) and Alonso et al. (2021) for catotelmic peat in Scotland.

3.2 Carbon content stored

Using the formula suggested by Duggan et al. (2015), the peat carbon content per m^3 (C_{peat}) is calculated as:

$$C_{peat} = \rho_d \times \frac{OC}{100} \times \frac{44}{12} \times \frac{1}{F} \div 1000 \quad (1)$$

Where, ρ_d = Peat dry density ($\frac{kg}{m^3}$), OC = Organic Carbon content (%) and F = Conversion factor (For OC=58%, F=1.724).

The carbon content per volume unit is estimated as 0.175 tCO_2e/m^3 for the degraded peat and 0.124 tCO_2e/m^3 for the active peat at the site.

The total equivalent carbon content (tCO_2e) stored in the peat is thus calculated as:

$$C_{tot} = C_{peat} \times V_{peat} \quad (2)$$

Where, V_{peat} = peat volume (m^3).

3.3 Emission factors and carbon storage

Given the lack of specific data from the site due to insufficient sustained monitoring, measurement of carbon fluxes from peat are taken from Alonso et al. (2021) and represent the most updated values of GHG emissions for a peatland habitat in Scotland. Emission factors (t CO2e ha-1 y-1) include CO2, CH4 and N2O. A positive EF indicates net GHG emission, and a negative EF indicates net GHG removal. The undrained near-natural bog is a small GHG sink (-0.02 $tCO_2e/ha\ yr^{-1}$). Moreover, the active peat in the forest is assumed to be undrained and therefore a carbon sink (-0.09 $tCO_2e/ha\ yr^{-1}$). Additionally, a carbon sink potential of -7 $tCO_2e/ha\ yr^{-1}$ is assumed for the birch forest. A carbon emission factor of 13.03 $tCO_2e/ha\ yr^{-1}$ is adopted for the southern part of the site, identified as a drained extensive grassland.

Table 2 shows a summary of results obtained considering the carbon stored today at the site and the emission factors (EF) for both the active and degraded peat. The GHG exchanges (tCO_2e) due to the different scenarios are here calculated for two target periods: i) 50 years; to emphasise the short-term effects, and ii) 120 years; to account for both the design life of the development foundation and the time required for the peat to be effectively restored. The results from Equation 2 provide the reference value regarding the total amount of carbon currently stored, which will be used as the baseline for the remaining calculations.

The active bog contains a total of 33,394 tCO_2e and the degraded peat contains 36,672 tCO_2e, which brings to a total of over 70 k CO_2e when considering the entire Bishopbriggs site (Table 2). Furthermore, this study assumes a worst-case scenario where degraded peat loses carbon at the same yearly rate and no modification occurs in the active peat, which remains a carbon sink. Given the considered emission factors, the results show that the stored carbon reduces significantly in the degraded peat whilst the amount stored in the active bog gradually (but slowly) increases. It is fundamental to note that at its current state, the whole site is a net carbon emitter, meaning that the carbon stored is being released at a rate of 106.56 $tCO_2e\ yr^{-1}$.

Table 2. *Total carbon stored at Bishopbriggs site now, after 50 years, and 120 years*

Peat state	Volume [m3]	Carbon stored year 0 [tCO_2e]	EF [$tCO_2e\ yr^{-1}$]	C stored year 50 [tCO_2e]	C stored year 120 [tCO_2e]
Active	270000	33394	23.74	34581	36243
Degraded	210000	36672	-130.3	30157	21036
Total	480000	70065	-106.56	64737	57278

3.4 Carbon balance at the southern section

In this section, the impact of the development on the southern section of the Bishopbriggs site is explored. For this purpose, the construction process has been broken down into three categories: i) peat management (which includes peat movement, restoration, re-use, and off-site landfilling), ii) outbound transport of the peat and machinery, and iii) materials. The carbon balance is the result of subtracting the carbon intake from the carbon loss, hence a positive value means a net loss of carbon content. In other words, the higher the bar chart is above the zero value in Fig. 1, the greater the carbon loss exhibited by the degraded peat at the southern section of the site.

Carbon impact of housing developments on peatlands in the UK - A case study

Figure 1 provides a summary of the main results corresponding to the proposed four scenarios. It is evident that the peat management is the main factor influencing the carbon balance of the degraded peat for all the scenarios, whilst materials and transport/machinery have a lower impact on the balance. This suggests that the greatest protection of the stored carbon comes from following the hierarchy proposed in Section 3.1 (i.e., reduce > re-use > dispose, in accordance with SEPA). Scenarios 1 and 3 show a greater influence on the carbon appraisal associated with the peat management than the other two scenarios. The latter is a consequence of the inevitable movement and further degradation experienced by the peat in a total excavation and removal of peat (Scenario 1), whilst the no-intervention option (Scenario 3) would inevitably result in an additional degradation of peat. Scenario 2 assumed a more practical approach whereby peat would be moved and restored within the site. Scenario 4 refers to the hypothetical case of peat being completely restored now, representing the only case in which the net balance turns negative. Hence, the site would be working as a carbon sink after 50 and 120 years.

Interestingly, the comparison between Scenarios 2 - 3 demonstrates how the option of partially constructing and restoring peat on-site at the southern region (i.e. Scenario 2) results in a lower carbon balance than remaining in its current state, almost becoming a carbon sink after 120 years. The latter is due to the lower volume of peat being disturbed, added to the rationale that any displaced peat is restored on-site (up to 100k m^3), avoiding any transport and subsequent off-site disposal, as mainly occurs in Scenario 1. This in line with the literature (SEPA, 2017) which establishes that any disturbance upon peat can result in significant carbon emissions due to its excavation, transport and time span until the restored peat newly absorbs CO2 from the atmosphere, accentuated the further the peat is disposed. On the other hand, the no development approach (i.e. Scenario 3) would result in an inevitable degradation of the peat (assumed at a constant rate), which would lead to a significant carbon loss in the medium/long term. Scenario 3 is, however, a better option than the “default” approach of completely removing and replacing peat by a competent fill (i.e. Scenario 1). Scenario 1 is unfortunately the most common option in the UK. In the case of Bishopbriggs, it would cause a carbon loss of up to 12k tCO_2e after 50 years or over 22k tCO_2e after 120 years, even with the inclusion of off-site restoration.

From a purely environmental point of view, Scenario 4 (whole-site restoration) is the best option among those considered, followed by Scenario 2 (partial development and on-site peat restoration). The results of the carbon appraisal for Scenario 1 (development of the whole southern section of the site) corroborate the initial objection of SEPA and should be withdrawn by the constructor. Even in the case that only 90k m^3 were sent to the landfill, and over 100k m^3 were sent to a nearby receptor to create a new peat bog, the peat management carbon assessment reflects an excessively high carbon loss. If no other Scenario was adopted, then inevitably the whole carbon balance would fall into Scenario 3 due to the inaction to restore the currently degrading peat. This would result into a carbon loss of over 6.5k tCO_2e after 50 years or around 15.5k tCO_2e after 120 years.

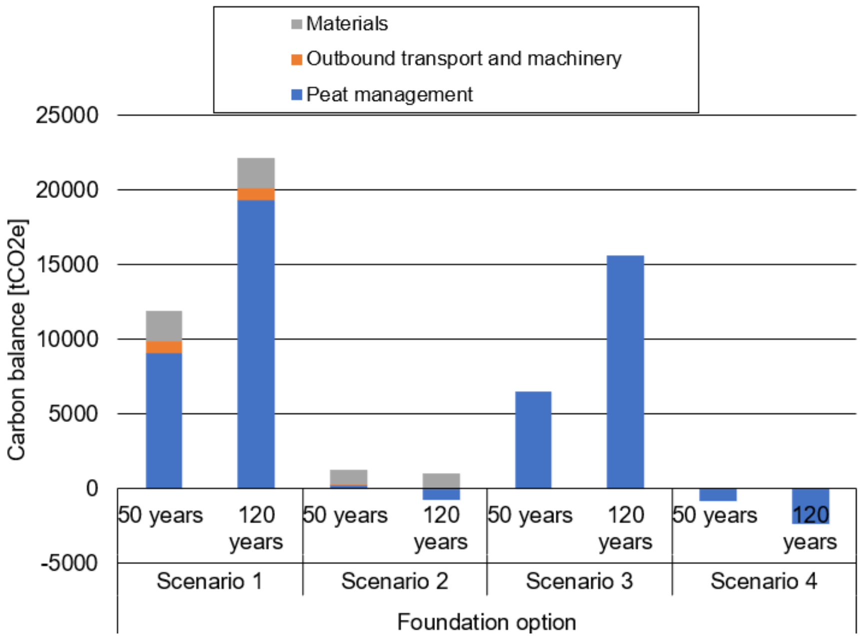


Figure 2. *Breakdown of EC balance according to each construction scenario at southern section*

Carbon impact of housing developments on peatlands in the UK - A case study

4. DISCUSSION

As established in Section 1.4, at present no common tool or framework exists to assess the environmental impact of a construction option over others when building on peatlands. In general, the construction of new developments on peatlands is highly discouraged, at least in Scotland. However, the high presence of peat across the whole territory makes almost inevitable that new developments happen on sites containing peat. In these cases, some framework should be adopted to measure the environmental impact (if any) that any form of construction may cause. The well-known carbon calculator has already been adopted to determine the carbon balance of new windfarms when built on peatlands. However, a similar metric is yet to be introduced to assess the carbon appraisal of new housing developments on peatlands in Scotland and the UK.

From the environmental point of view, an intervention is needed to stop the GHG to be released from peatlands. The hypothesis of developing a residential area has been studied in this manuscript to find alternative avenues to overcome the profit issue. Therefore, if the construction was proved to be more sustainable than leaving the site as it currently is, the developer would take charge of reducing the GHG emissions. Results in Figure 1 bring some light into the unknown of measuring how harmful/beneficial a new development on a peatland could be to the environment. Ideally, a peat restoration project should be undertaken for the whole site, but its financial viability needs to be assessed, which might not happen.

This study has then demonstrated the high impact that a full excavate-and-replace foundation would cause to the environment, reason why it was initially objected by SEPA, although without the support of sufficient data. Alternatively, the partial development proposed by TW would be more beneficial, since it was proposed that a lower amount of peat would be disturbed whilst most would be restored on-site, with a lower risk of drying and releasing carbon. If no construction or restoration took place, the current gradual degradation of the southern region would continue, resulting a significant carbon loss .

The authors of this study recognise that any form of construction should be avoided on peatlands to avoid the impact on the carbon storage (as addressed by SEPA). However, it is also necessary to find a form of measuring the potential environmental impact that a construction method would have, especially in the Scottish context where building on peat is often the only option. A tool has thus been created for this study to assess the carbon appraisal of new developments on peatlands. As observed in the case of Bishopbriggs site, specific forms of foundation construction need to be discarded whereas others could be considered by the constructor to minimise the environmental disruption.

5. CONCLUSIONS

Under the current climate change emergency, the high impact of peat degradation on the global carbon emission has recently been made evident. Limiting, stopping, and finally reversing the release of the carbon that is being stored in the soil has become one of the most crucial factors, which could offer a major contribution to the goals of the Paris Agreements of limiting the temperature increment to 1.5 °C.

Peat degradation a particularly notorious problem in Scotland since over 25% of the territory is covered by peat. In contrast with the windfarm developments on peatlands, a tool to accurately measure the carbon appraisal of housing developments on peatlands does not exist. Instead, the avoidance of new construction on organic soils is recommended, accentuating the housing crisis in certain settlements. However, construction on peat is sometimes inevitable, and default excavate-and-replace options are adopted, with significant impact on the carbon storage of peat sites. This manuscript aimed at understanding the carbon impact that a series of development options would have upon a peatland at a site in Bishopbriggs (Glasgow). These are some of main results:

- The active bog is estimated to contain a total of 33.4k tCO_2e whilst the degraded peat contains 36.7k tCO_2e, which brings up to a total of over 70 k CO_2e stored today. Also, the whole site is a net carbon emitter, meaning that the carbon stored is being released at a rate of 106.56 tCO_2e per annum, leading to a progressive carbon loss at the southern region.
- By considering the carbon balance at the degraded (southern) area, four scenarios have been proposed in this manuscript. The restoration of the peatland (Scenario 4) is seen to have the most beneficial outcome, becoming a carbon sink in the time-period herein considered (50-120 years).
- The results highlight that the construction could indeed offer a positive effect on the overall carbon sink potential if alternatives to complete peat removal (Scenario 1) are explored. In particular, the

best solution has been identified to be the partial development of the site (Scenario 2), which could result in a net carbon gain in the long-term. On the other hand, the no-development scenario (Scenario 3) would have an impact on the carbon storage in the medium and long term.

The Bishopbriggs site has the potential to demonstrate how the contribution of the construction sector, and more specifically the land use, holds a great importance in the GHG emissions abatement. Moreover, it is important to highlight that alternative, and more sustainable, construction approaches are available when building on peatlands, and they need to be further explored. An easy-to-use carbon calculator has been developed in this manuscript to estimate the carbon appraisal of peatlands which may be disturbed by new developments. More studies will be proposed to extend its use to other foundation techniques (i.e. mass stabilisation, piling, or trench fill) and other sites in the UK. The main limitations of this study are related to the lack of site-specific data and the more general lack of monitoring data from previous projects and emission data from degraded peat, including restoration effectiveness timespans and actual GHG fluxes.

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