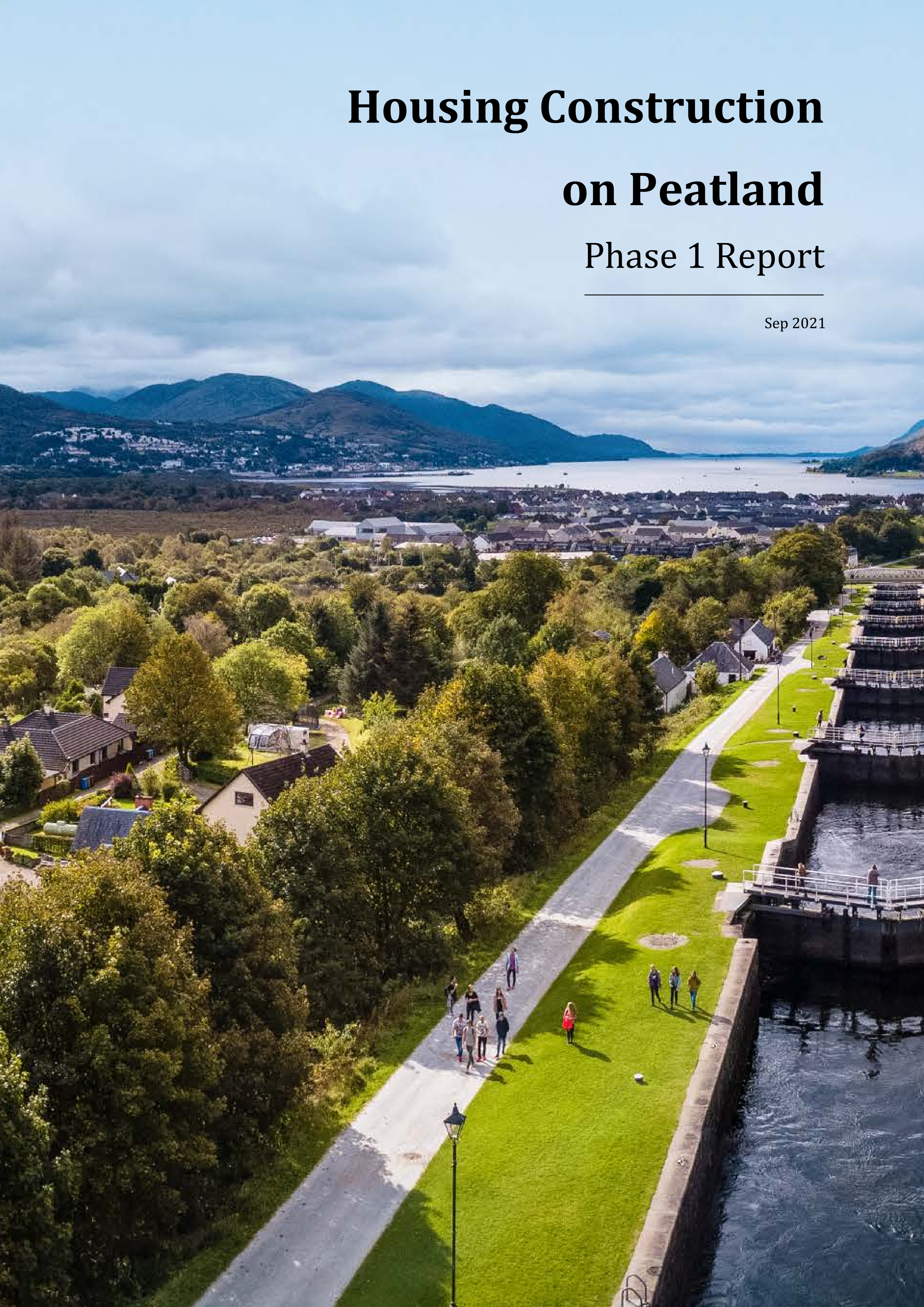
Housing Construction on Peatland

Phase 1 Report

Sep 2021



Project Title	Housing Construction on Peatland: Opening up Opportunities and Minimising Disruption through Innovation – Phase 1 Feasibility of Proposed Solutions
Work-Package Titles	Work Package 1 - Demand for Housing in Rural Scotland Work-Package 2 - Ecosystem, Environmental Impacts and Regulatory Framework Work-Package 3 - Foundations on peat. Options appraisal and adaptability
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Executive Summary & Background to the Project

Background

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 (BBC, 2019). The remoter rural areas of Scotland are spacious enough to offer considerable scope for affordable housing development and generally have lower land values but other factors including challenging ground conditions, notably peat, can make development in these areas economically unviable and environmentally unsustainable.

Scottish peatlands are predominantly blanket bogs, the largest of which are found in the Highlands and Western Isles. Around 20% of Scotland's land surface area is covered by blanket bogs alone, which in turn is about 15% of the global total for this habitat (Bruneau and Johnson, 2014).

In response to the shortage of affordable housing and the incidence of peat soils, this project sought to:

- Identify the scale of the shortage,
- Recognise the significance of construction on the peat from a multidisciplinary standpoint,
- Compare, existing and innovative options for foundation design on peat, so as to lessen the magnitude of the construction challenge.

The three bullet points correspond to the first three work packages of this project. A fourth work package will allow for dissemination of findings.

Summary of findings

Work Package 1

Whilst headline figures relating to a shortfall in house building, such as those introduced at the beginning of this document, are compelling, they are often aggregated figures that hide complex local situations over time. It must be born in mind that the housing need and new build situation in Western Highlands & Islands, where peat is a significant complicating factor in the design and construction of housing, is not a microcosm of the national picture. We have noted that a range of factors, including biophysical constraints, second home or retirement purchase and crofting rights influence the supply and demand for new build. There is nevertheless an interest in alternative foundation options to better manage construction costs if not to bring hitherto unworkable locations into the calculation. In this way, larger "volume" private housebuilders may be enticed into the WH&I area.

Work Package 2

The first work-package has highlighted the role of peatland as a carbon reservoir, but one that without proper management or control may become a carbon source. Construction on the peat has the potential to create such a source and so as background to the wider ranging foundation option appraisal that makes up WP3, this work package has set out the key features of the interdependencies that exist between construction, foundation and the underlying peat and their collective impact on the environment. We have noted that 35-60% of peatlands in Scotland are in degraded conditions. If degradation continues at the same rate, peatland will switch from being a carbon sink to being a source of GHGs.

The favoured foundation option for any form of construction development in Scotland has been to excavate the peat and then replace it with a competent fill to provide a suitable formation, however, the carbon emissions associated with this technique are very high. Other forms of foundation, e.g. peat-left-in place techniques, such as *mass stabilisation, preload-and-surcharge, or piling*, have the potential to minimise the excavation and drainage of peat.

Work Package 3

This work package developed a RAG analysis of 7 options for foundations in the peat. The analysis has been based on a selection of assessment criteria, chosen to reflect the (geo)technical, environmental and logistical context of domestic construction on peatlands. The following observations were made:

Excavate and replace – scores poorly in RAG for environmental criteria but good for logistical criteria and adaptability.

Mass stabilisation – scores well for depth but has significant cost and temporary works impact.

Piles – conventional vs timber – durability of timber may be a problem and further investigation is required to understand the performance of locally sourced timber.

Work Package 4 – Gateway to Phase 2

There are at present too many uncertainties to consider the creation of a universal geotechnical design guide. Phase 2 needs to be led **by a multidisciplinary consultant / commercial / design-led team** (as opposed to an overarching academic project). The parties to and stakeholders in Phase 2 should:

- identify viable sites,
- recruit a project team, which can identify ground conditions and
- design accordingly, and reveal any foundation related problems, and
- call on academic support as required.

Overall Aim

To produce a comprehensive assessment report into current practice and feasibility of innovative options for domestic foundations on peat including scope for field trials in a Phase 2 calling upon geotechnical, environmental, economic and logistical criteria.

There were 4 work packages required to complete Phase 1 as summarised below.

Work Package 1 – Demand for Housing in Rural Scotland

Main objectives:

- Project lead/academic team, in collaboration with other partners, to summarise local/regional housing demand forecasts and supply constraints.
- Establish the extent to which these supply constraints are exacerbated by the existence of peat.

Work Package 2 – Peatland: Ecosystem, environmental impacts and regulatory framework

Main objectives:

- Project lead/academic team, in collaboration with other partners, address issue of peat as ecosystem and its ability to tolerate disruption due to construction.
- Investigate the extent to which designers and engineers are aware of the carbon costs of different foundation options in particular the carbon benefits that locally sourced timber piles can offer.

Work Package 3 – Identify Viable Technical options (including international context)

Main objectives:

- Project lead/academic team, in collaboration with other partners, will consider foundation options for domestic developments on peatland in Scotland in terms of current local practice and with reference to overseas experiences.
- Project lead/academic team will consider foundation options in isolation, that is in terms of the mechanics of their performance. Next, the adaptability of options to different and/or varying ground conditions and loading scenarios will be presented.

Work Package 4 – Planning for field trials and dissemination

Main objectives:

- Project lead/academic team, in consultation with other partners, will scope timber pile field and laboratory trials, namely location, duration, contractor/procurement, foundation pile configuration, piling platform, access roads and materials logistics.
- Dissemination: Organisation of workshop to communicate outcomes of Report into Timber Pile Foundations on Peat (Phase 1) combined with scope for field tests (Phase 2) for approval by Steering Committee.

Work Package 1: Demand for Housing in Rural Scotland

The principal aim of WP1 is to reveal the scale of the impact that different domestic foundation options would have on bringing the supply of viable sites into line with housing need. In other words, to what extent can the supply of financially viable sites be increased by innovative foundation methods to alleviate an unmet housing need?

Data resolution – interpreting local housing demand and supply

The main data items sought were population trends, associated housing need and housing development. However, these data, when available, were at national and regional scale and not always over a consistent time frame. Moreover, housing need is defined in terms of units or households, with the occupancy issues not directly addressed. For example, some sources refer to the preponderance of single-occupant households as characteristic of new housing need. It became apparent that the correlation of population trends with, say local development plans (LDP) were not readily matched. That is not to say that the LDPs were deficient, rather population drivers, household, new build and land-use were inter-related through a complex network of demographic detail.

The project team have had conversations with key individuals in the planning process: Tim Stott (TS), Principal Planning Officer at Highland Council. The insights provided by TS have allowed us to formulate a less quantitative but more realistic interpretation of the competing demands of housing demand and supply in locations where peat is a complicating factor.

The following sections seek to provide something of the background to this problem, i.e.,

- location (what parts of Scotland does peat presently complicate the supply of housing),
- population trends,
- housing need,
- housing completions,
- how the relevant LDPs have sought to manage the problem and
- peat as the complicating factor

Study location

Inspection of a peat map of Scotland (Fig. 1) reveals that peat does not affect development in all locations. We may note that the largest blanket bogs are located in the Highlands and Western Islands. Moreover, a considerable surface area of peat in this part of Scotland exceeds 1 m depth (see Fig 2). It is also significant on the European stage, the region having the highest percentage cover of peatlands of anywhere in Europe (Fig. 3).

Figures 1 and 2 show that Scotland's most extensive and deep peat deposits are found in the region of the Highland Council (HC). It is the largest local government area in the UK and the seventh most populous council area in Scotland (out of 32). The region is largely remote rural according to the Scottish Government's Rural Scotland Key Facts (Scottish Government, 2018a). It comprises three local development plan areas (Fig 4): West Highland & Islands, Caithness and Sutherland and Inner Moray Firth, each of which, through their respective Local Development Plans (LDP), reveal a different level of susceptibility to the presence of peat. It is therefore a good region on which to base this investigation.

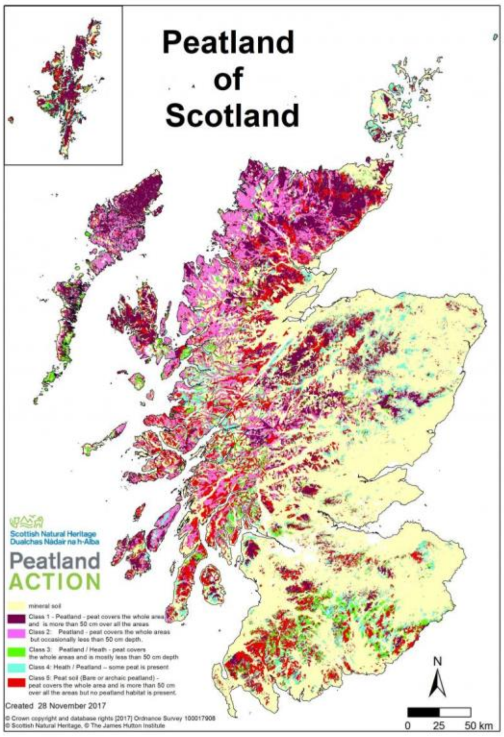


Figure 1. Peatland of Scotland (SNH, 2019)

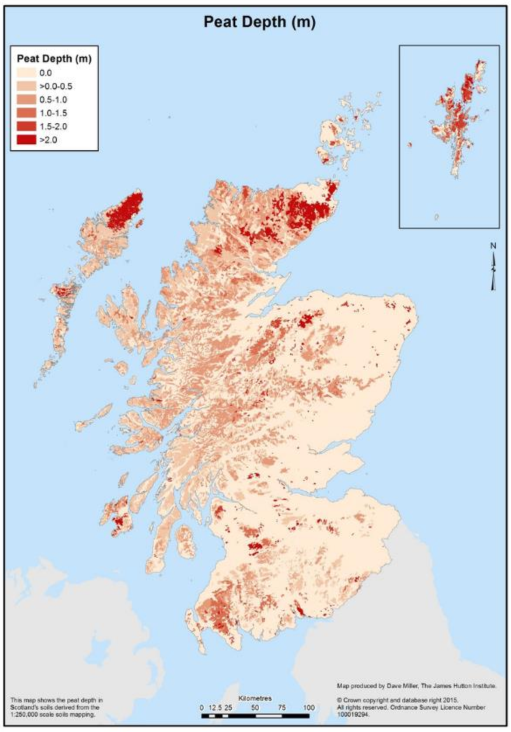


Figure 2. Peat depth (Waldron et al., 2015)

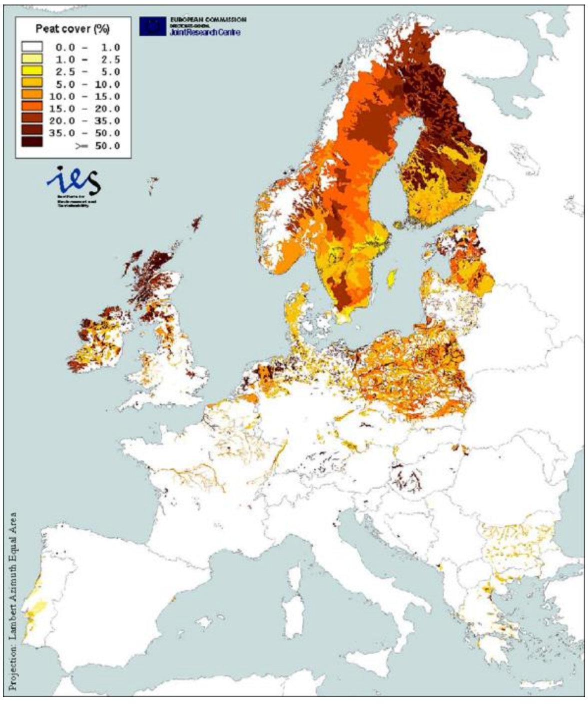


Figure 3. Peatland distributions across Europe from Montanarella et al. (2006). Percentage peat cover indicates the percentage of ground covered by either peat or peat-topped soils.

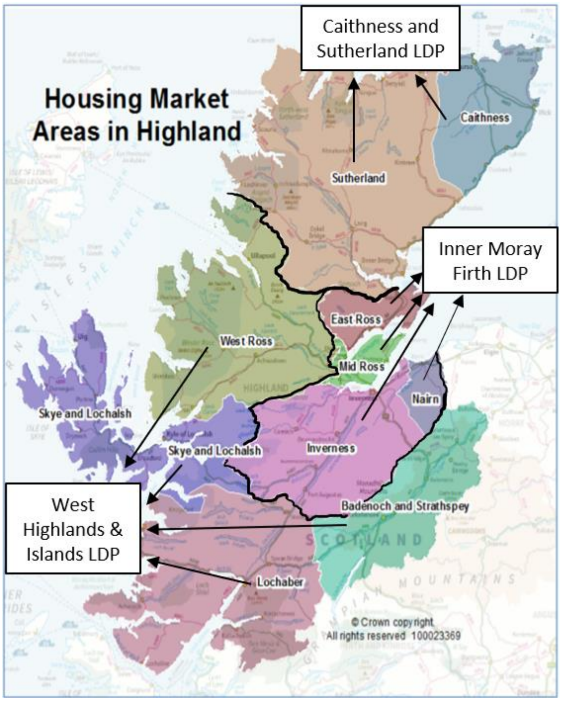
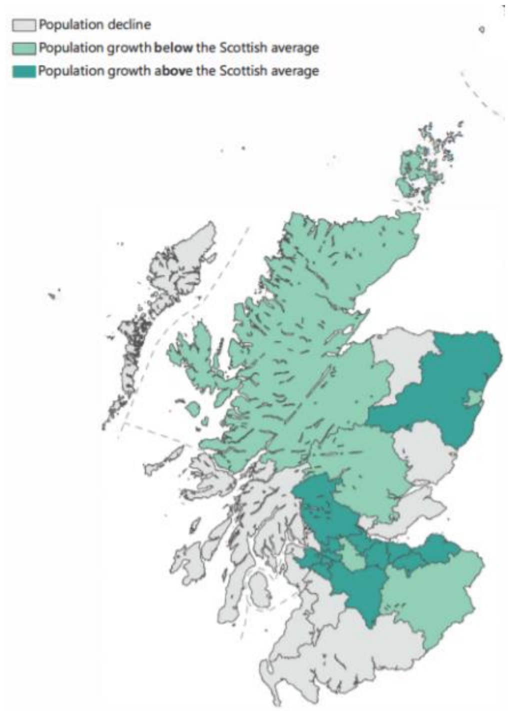


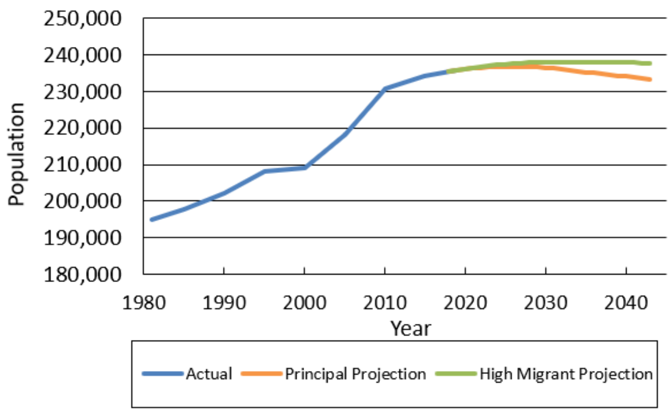
Figure 4. Highland Council region showing area maps for the three local development plans. Based on Highland Council (2017)

Population trends

Figure 5 shows recent and projected population trends for the HC region, having grown from 192,000 in 1981 to 236,000 in 2018 (NRS, 2020a). Under the most likely migration estimates, the population of the Highland Council region will increase by 0.5% by 2028, which is below the Scottish average (Figure 5a) but could increase to nearly 238,000 under a high migration scenario (Figure 5b). Whilst population trends drive little change in HC population forecasts, an increase in numbers of older people and the fact that they are more likely to live alone or in smaller households, means the number of households is projected to increase faster than the population as a whole.



(a)



(b)

Figure 5. a) Population growth per local council in Scotland and b) actual and projected population for the Highland Council area. Based on NRS (2020a)

Housing need & LDPs

Land use, planning and development is set out at a regional scale by the Highland-wide Local Development Plan (Highland Council, 2012), which itself is underpinned by the three area Local Development Plans: Inner Moray Firth (IMF) (Highland Council, 2015a), Caithness and Sutherland (C&S) (Highland Council, 2018), and West Highland & Islands (WH&I) (Highland Council, 2019). These are the documents used by the planning authority to guide development over a 20-year period towards supporting the growth of all communities across HC region.

The Local Housing Strategy is delivered by the local councils in partnership with a wide range of public, private and third sector parties. One of them is the Housing Strategy Group that provides a strategic lead for developing, monitoring and reviewing the local housing need planning.

For the analysis of housing demand in the area covered by the three LDPs, the Housing Strategy Group identified 10 Housing Market Areas (HMAs) across HC region, as shown in Fig. 4 (Highland

Council, 2017a); 2 for C&S and 4 for each of WH&I and IMF LDPs. Based on existing stock in all 10 HMAs and population trends, analysis of the three LDPs indicated that an additional 16,077 dwellings/housing units (804 p.a.) would be required to accommodate the existing needs and forecast population changes between 2015 and 2034. The totals are derived from the "continued growth" scenario, which assumes that the economy and population will continue to grow at rates seen over the last 20 years, and as described in the Housing Need and Demand Assessment (HNDA) (Highland Council, 2015b). The annual need figure obtained from the LDPs is lower than the value proposed by the HNDA in 2015, which predicted 1,013 households (p.a.). This discrepancy is because housing demand has been historically assessed based on different scenarios over the last decade due to variable predictions in relation to the projected population change, household projections or changes in household type.

Recent housing completions

Figure 6 shows the number of additional houses completed in HC region between 2000 and 2020 (Scottish Government, 2020) together with the need predictions from HNDA (2015) and the three HC LDPs. Looking at data which underpins Fig. 6 for the period 2011-2016, a total of 5,117 dwellings were completed across HC region. Although below HNDA forecasts, construction during this period (2011-16) in HC region is more or less consistent with LDP forecasts, subsequently increasing to be above HNDA forecasts for the period 2017-2019.

Subsequent years revealed an improved situation due, in part, to the "Help to Buy Affordable New Build" and "Help to Buy Smaller Developers" schemes launched in January 2016, which increased completions up to 1,365 in 2018 and 1,207 in 2019 (Powell et al., 2020). In 2020, although still around the annual housing need established by the LDP forecasts, the number of completions dropped to 795.

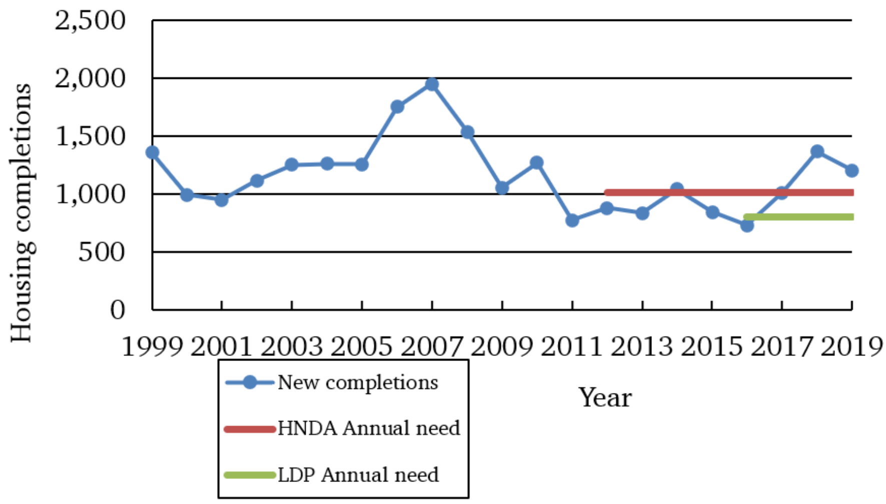


Figure 6. Housing completions versus HNDA and LDP need figure HC. Based on Scottish Government (2020)

Peat as the complicating factor

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, of greatest relevance to this study is the presence of peat. According to the JHI criteria, some 56% of Scotland's land area is biophysically constrained. Figure 7 indicates that 78% of HC region (or 20,410 k ha) is similarly constrained, with peat being one of the main limiting factors.

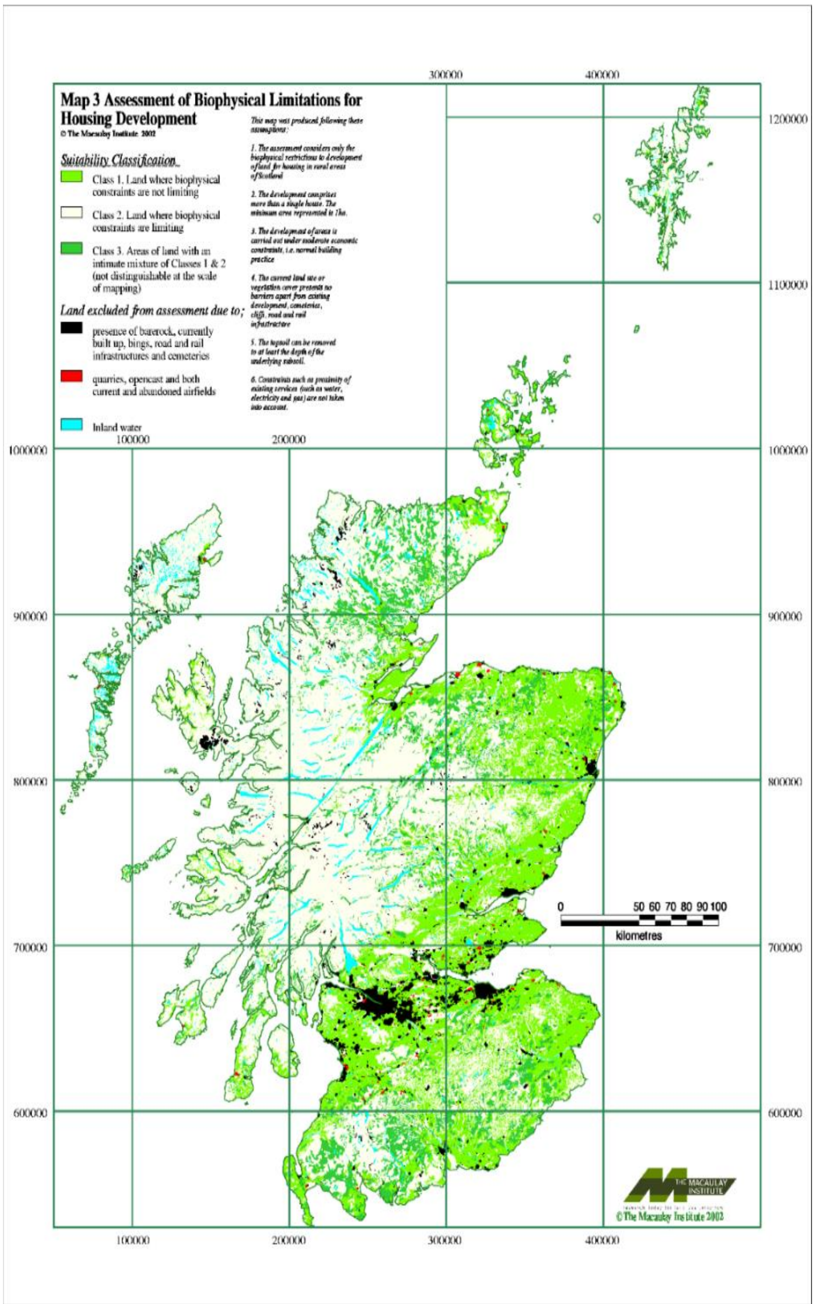


Figure 7. Biophysical constraints for housing development (Towers et al., 2002)

The Highland-wide Local Development Plan (Highland Council, 2012) and the Scottish Planning Policy (Scottish Government, 2014a) highlight the importance of the peatland resource as a carbon sink and for nature conservation. In collaboration with key consultees including SEPA and NatureScot, who provide support at the local development plan stage, new applications (commercial or housing) proposed on peat sites need to demonstrate how they avoid unnecessary disturbance, degradation or erosion of peat. By complying with the Scottish Planning Policy and the Local Development Plans, for cases where development on peat is demonstrated to be unavoidable, a peat management plan must be prepared to demonstrate how impacts on peat have been minimised. The public and governmental perception about the impact of construction sector activities on the environmental stability of peatland will be discussed in the Work-Package 2 of this study.

LDPs highlight the presence of the peat

The presence of peat is not uniform across the three local development plan areas that make up HC area. The West Highlands and Islands (WH&I) LDP cites 14 settlements, Caithness and Sutherland (C&S) LDP cites 3 settlements, whilst there are none in the Inner Moray Firth (IMF) LDP. The LDPs provide information on the total area of the settlement and housing capacity. The presence of surface peat area is then used to quantify the proportion of surface area and housing capacity 'limited by peat'. For example, of the 3 settlements identified in C&S, 74.6% of the total area set aside for housing development is compromised by peat of some depth; the corresponding figure for planned housing capacity is 67.8% (Table 1). In some cases, the influence of peat is inescapable, e.g. Lochinver, where all planned housing must contend with peat soils.

Housing development seems to encounter more difficulties in the West Highland & Islands settlements. Of the 14 settlements identified in WH&I LDP, 68.1% of the total area assigned to housing development is constrained by peat presence, equivalent to 63.8% of the planned housing capacity (Table 2). Hence, 1195 out of the planned 1873 housing units are limited by peat. Of three of the settlements (Staffin, Gairloch, and Ullapool), all housing is noted as 'limited by peat'.

The presence of peat is clearly noted in both WH&I and C&S LDPs and will impose a significant additional constraint on the design and construction, and hence viability of housing development in these locations.

Table 1. Settlements constrained by peat presence per settlement in C&S LDP. Based on Highland Council (2018)

Settlement	Total area (ha)	Limited by peat (ha)	% limited	Housing capacity	Limited by peat	% limited
Halkirk	11.4	3.5	30.7	63	35	55.6
Lairg	15.6	8.2	52.6			
Lochinver	48.5	44.6	92.0	24	24	100.0
Total	75.5	56.3	74.6	87	59	67.8

Table 2. Settlements constrained by peat presence per settlement in WH&I LDP. Based on Highland Council (2019)

Settlement	Total area (ha)	Limited by peat (ha)	% limited	Housing capacity	Limited by peat	% limited
Fort William	309.1	172	55.6	905	640	70.7
Mallaig	31.8	5.8	18.2	65	45	69.2
Spean Bridge and Roy Bridge	12.4	2.1	16.9	75	20	26.7
Broadford	266.3	253.5	95.2	107	70	65.4
Dunvegan	105.7	72.5	68.6	22	0	0.0
Kyleakin	26.7	24	89.9	28	2	7.1
Portree	123.7	95.6	77.3	366	195	53.3
Sleat	41	25.7	62.7	114	93	81.6
Staffin	4.1	2.2	53.7	10	10	100.0
Gairloch	30.6	9.4	30.7	27	27	100.0
Kyle of Lochalsh	62.75	4.7	7.5	43	36	83.7
Lochcarron	104.5	93.3	89.3	78	44	56.4
Poolewe	5.6	3.6	64.3	23	5	21.7
Ullapool	37.4	26.5	70.9	10	10	100.0
Total	1161.65	790.9	68.1	1873	1195	63.8

Interview with Planning Authority at Highland Council

In addition to researching available literature and council documents, an interview was conducted with Tim Stott, Principal Planner at HC, the outcome of which is contained in the following notes.

Housing within the West Highland area

There is no shortage of undeveloped land for affordable housing development within the West Highland area. However, physical, ownership, environmental and infrastructure capacity constraints severely limit the supply of larger housing sites that are physically, economically and environmentally capable of development – some of these constraints correspond to JHI interpretation as biophysically constrained.

For example, many parts of West Highland are physically and economically incapable of development because of gradient and flood risk. Of the land that is not constrained in that way, much of the remainder is too remote from facilities, employment and other infrastructure networks to be practicable for an affordable housing development. This sieving process of focusing on developable land then looks at ownership and crofting tenancy constraints. If a development is to happen then the landowner and/or crofting tenant needs to agree to its release for such a purpose. The large estate owners and crofting communities of the West Highland area, generally, only favour the release of land for development if it is of poorer agricultural quality. The exception to this is the release of better (in agricultural terms) land for single house developments where the loss of land is minimised and the owner/tenant has a degree of control on the new occupant (for example, a related family member can often obtain an affordable house plot for self-build in this way). Conversely the poorer agricultural land in crofting tenure, known as the Common Grazings, is more likely to be released for development. Almost always this land has poor ground conditions for building.

The search for larger, new-build, affordable housing sites (it is usually uneconomic for affordable housing agencies to undertake developments of less than 4-6 units) often ends up, within or close to existing West Highland settlements on land with challenging ground conditions. Either bedrock is too close to the surface and requires expensive blasting to create a flat and sizeable development area or more likely bedrock is too deep and overlain by peat deposits. Invariably these deposits are deep and extensive enough to make removal of the peat and import of a buildable fill the technically preferable solution for construction, a foundation solution referred to as ‘excavate and replace’. However, this solution has adverse environmental impacts and may entail significant development costs.

Private housebuilding in the West Highland area is far less constrained by peat because most private demand for new housing is accommodated in existing houses for sale or by single unit developments in the countryside or on the fringes of the smaller settlements. Larger “volume” private housebuilders have very little interest in the West Highland area because there is little or no profit margin in speculative schemes and better options are available elsewhere in Scotland. This is for a variety of reasons including the relatively higher site preparation costs, contractor labour costs, infrastructure network connection costs and finance costs associated with lower sales volume over a longer period in West Highland. The typical West Highland private house purchaser is buying a second, holiday or retirement home and is therefore drawn to those houses/plots with privacy and an attractive outlook. In the period 2000 to 2017 inclusive, 85% of housing development in the West Highland area took place on sites not specifically allocated in the Council’s local development plan. Almost all of this 85% was in the form of single housing unit developments.

In contrast, there are two large sites in Fort William that have long been earmarked for housing development within the Council’s development plan. The sites were allocated for development because they had fewer ownership and crofting tenure constraints than other alternatives in around Fort William. Moreover, they could be connected to road/sewer/water infrastructure networks at reasonable cost, flooding issues could be avoided and/or mitigated, they were not visually intrusive, and they were as close as possible to community, employment, commercial and public transport facilities to minimise car borne travel and its adverse environmental impact. Both are affordable housing developer led and are unlikely to contain any unsubsidised private housing element.

However, both have contended with challenging ground conditions, in particular a depth and extent of peat cover that will likely rely on excavate and replace. Both seek to reuse excavated peat within the site boundary or nearby for beneficial, restorative purposes.

WP1 findings

Whilst headline figures relating to a shortfall in house building, such as those introduced at the beginning of this document, are compelling, they are often aggregated figures that hide complex local situations over time. It must be born in mind that the housing need and new build situation in WH&I, where peat is a significant complicating factor in the design and construction of housing, is not simply a microcosm of the national picture. It is not even a scenario replicated within the three LDPs that make up HC. So, identification of new build requirements in terms of local housing need and demographic change and availability and workability of new sites is a complex calculation. The broader demographics and social need can be elucidated, but the LDP is only a partial statement of the potential for new build with a large proportion of new build being single plots not allocated in the Council’s LDP. We have noted that a range of factors, including biophysical constraints, second home or retirement purchase and crofting rights influence the supply and demand for new build. There is nevertheless an interest in alternative foundation options to better manage construction costs if not to bring hitherto unworkable locations into the calculation. In this way, larger “volume” private housebuilders may be enticed into the WH&I area.

Work-Package 2: Ecosystem, Environmental Impacts and Regulatory Framework

Peatland as ecosystem

Significance – role of peatland in climate change and the challenges set

Peatlands are a key asset in the drive to reduce annual carbon emissions due to their potential as a carbon sink. However, peatlands have historically been considered as wastelands which needed to be re-used for other, more productive, purposes. This is the reason why active bogs have been drained, afforested and grazed resulting in circa 80% of UK peatlands being partially degraded (Harrabin, 2020). When the level of degradation is advanced, the peat is exposed to the elements resulting in fragmentation of the bog and the progressive release of the carbon stocks (Lindsay et al., 2014). In 2017, emissions from agriculture and land use were 58 MtCO_2 of which 23 MtCO_2 were associated with emissions from degraded peatlands, equivalent to 5% of the UK GHG emissions (CCC, 2020a; 2020b). This situation may be worsened in the future as there is a high risk that degraded peatlands will be destroyed under the hotter and drier conditions predicted with climate change. Consequently, the policies for a Net Zero UK published by the CCC in the sixth carbon budget (CCC, 2020c) have proposed to ban rotational burning in 2020 and that up to 100% of upland peatlands and 60% of lowland peatlands will have to be restored by 2045 and 2050, respectively. These actions would aid in reducing UK-wide peatland emissions by 6 MtCO_2 by 2035 and around 10 MtCO_2 by 2050. Any case for construction must therefore be robust and demonstrate net positive benefits.

Scotland has its own Climate Change Act 2009 which includes a more ambitious 2045 target for a 100% reduction on 1990 emissions (Climate Change Scotland, 2009). The Climate Change Plan (CCP) presented by the Scottish Government established that the land sector in Scotland, i.e. agriculture, forests and peatlands, had passed from being a net carbon source in 1990 to become a net carbon sink in 1998 (Figure 8) (Scottish Government, 2018b). The plan sets out policies of different natures to increase the sequestration of emissions by means of specific actions in the Land Use & Land Use Change and Forestry (LULUCF) sector, including changes in peatland restoration and woodland planting programmes (Scottish Government, 2020a). Peatlands are known to cover around 20% of land in Scotland or 1.7 million ha (Bruneau and Johnson, 2014), equivalent to 1620 MtCO_2, which is larger than the combined presence of peat in Northern Ireland, England and Wales (0.96 million ha) combined. As for the case of the UK, it has been established that between 600,000 ha and 1 million ha of peat, i.e. 35-60% of peatlands in Scotland, are in degraded conditions attributable to previous land management decisions. If the degradation continues at the same rate, peat sites will switch from being a predominantly carbon sink to act as a source of GHGs. In 2017, degraded peatlands in Scotland emitted GHGs equivalent to 6 MtCO_2 (Scottish Government, 2018b).

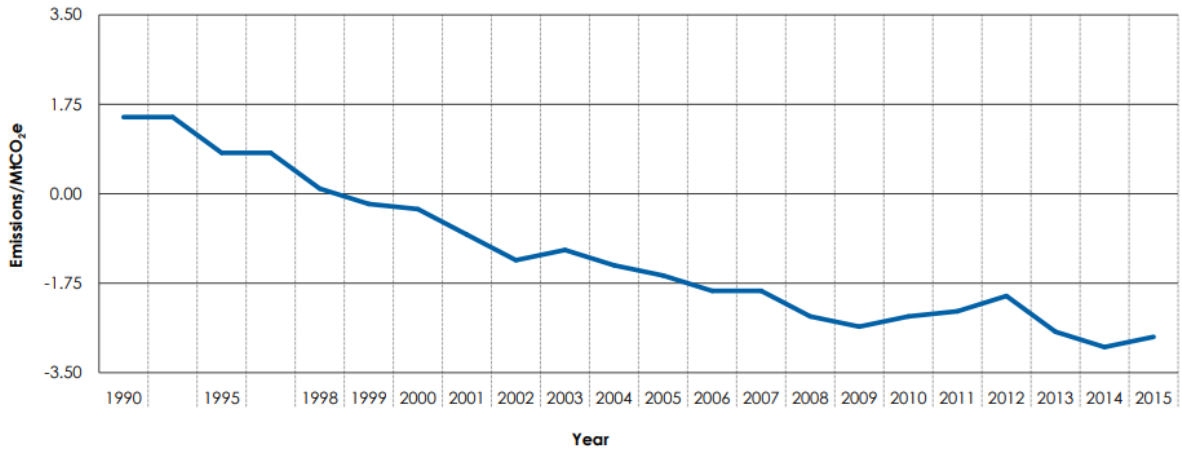


Figure 8. LULUCF historical emissions (Scottish Government, 2018b)

Fundamentals

Peat formation

Peat is the decomposed remains of plants, typically sphagnum moss, that have accumulated beneath the groundwater level of the growing acrotelm layers of the peatland profile. Under UK climate conditions, this occurs during seasonal water-logging conditions and the process is exacerbated by cold temperatures. Due to the lower mineral content of peat and its lesser density, most of the peat volume is occupied by water (Bruneau and Johnson, 2014). Bog peatlands are those that receive their water from precipitation and when they form across a hilly landscape they are known as blanket bog peatlands. Around 20% of Scotland's land surface area is covered by blanket bogs, which in turn is about 15% of the global total for this habitat, the largest proportion of which are found in the Highlands & Western Isles (Lindsay et al., 2014).

Peat degradation

If peat is not waterlogged, aerobic conditions give rise to a relatively rapid process of decomposition. A release of greenhouse gas (GHG) from dissolved organic carbon adjacent to streams and water bodies occurs leading to a significant negative environmental impact. The degradative state of the peatland has been characterised by Cummins (2011) into 5 categories according to vegetation, hydrological and developmental criteria. These are: active, degraded, bare, archaic and wasted (Cummins, 2011). An active and healthy peatland is mainly found where there is peat-forming because of the vegetation cover and a waterlogged and stable hydrological condition. If the water table falls, the vegetation fails, peat no longer forms and starts to degrade. The vegetation might be lost due to the natural weather conditions, in which case the peat can be described as bare. Or following other land use such as agriculture, in which case it is described as archaic peat. Peatland is degraded when it retains part of the natural vegetation cover; it is normally found in a state between active and bare peat. In a wasted peat, the peat-forming vegetation and a significant depth of peat soil have been lost.

Peatland restoration in Scotland

As a means of minimising the environmental impact of degraded peatlands, a Scottish Government-funded action has been coordinated since 2013 by NatureScot through the Peatland ACTION project restoring 10,000 ha of peatland per annum (NatureScot, 2020). The importance that the Scottish Government puts on peatlands can also be seen in the Scottish Budget 20-21, where an investment of £250 million was proposed over the next 10 years in peatland restoration (Scottish Government, 2020b). The peatland restoration contributes not only to reduce the carbon emissions but to mitigate flood risk whilst increasing the biodiversity in restored areas.

Peatland restoration projects (e.g. NatureScot Peatland ACTION) also aim at improving the water quality. This is because bare peat in a degraded state can end up in water ways, contributing to high organic loading and brown discoloured waters that has been proven to be environmentally and economically costly. Peat restoration would enhance the water quality before it reaches the catchment and thus it would reduce the need of excessive chemical treatment. As part of the new national land-use policy framework, water companies and owners of peatland within a Site of Special Scientific Interest will be obliged to restore peat under their ownership (CCC, 2020b). This is the case of Scottish Water in Scotland which has been actively engaged in peat restoration for removing dissolved organic content. There will then inevitably be a reluctance to permit activities that run counter to these advances.

Environmental impacts

The risks of constructing on peat

Peat is a soft, organic soil, difficult to access as the water table will be at or above the ground surface. Peat is well known for its poor mechanical properties: low strength and its high compressibility or tendency to deform under load. Consequently, geotechnical issues such as lack of bearing capacity or excessive settlement must be considered when building on any such soil. Ideally, building on peat would be avoided but in many parts of the world where peatlands cover a substantial area, e.g. Malaysia or Scotland, avoidance may not be an option or may incur additional costs.

Over the last 25 years the industry has made appreciable advances in methods of construction over peat. There is a body of work (Huat et al., 2014; Bell, 1999; Hobbs, 1986) covering the engineering properties of peat, which provides information in relation to testing its mechanical characteristics such as shear strength or deformation. A general agreement coincides that it is difficult to characterise the properties of this highly variable material. This is one of the reasons why there exists a wide range of soil improvement methods, each of which are assessed in terms of environmental, technical, cost and/or approval regimes. Considering and comparing some of these will be the objective of Work-Package 3 of this study. However, there is no single specific code or set of guidelines for construction on peatlands in Europe. Only Malaysia, where 8% of the land is covered by peat, has produced a specific document entitled "Guidelines for construction on peat and organics soils" (CRIM, 2015). That document contains maps with peat locations, classifications, testing methods, design and construction on organic soils as well as case histories of good practice. The guideline describes design criteria for the construction of embankments and fills on peat including methods for stability and settlement analysis.

Historically, excavate-and-replace, whereby the peat is removed down to a firm bearing stratum and replaced by a conventional mineral fill, has been regarded as the preferred method for construction on peat mantled sites. Introducing a new competent layer avoids the need to assess the mechanical stability of peat. However, construction activity on the peatlands was not without consequence and based on a number of factors such as (Lindsay and Bragg, 2004):

i) the high level of degradation shown by peatlands across the country and hence the higher risk of a possible increase in the number of landslides,
ii) the significant increase in the number of onshore wind farms on peat sites, and
iii) and general concerns raised about the environmental impact on carbon release due to current construction activities,

there appeared in 2006 the Peat Landslide Hazard and Risk Assessment (PLHRA) (Scottish Government, 2017).

Mechanical stability

The degradation of peat may destabilise peat lying on inclined ground resulting in peat landslides. These events can have catastrophic effects and have the potential to affect the biodiversity, peatlands habitats, carbon sinks and, in the last instance, the mechanical stability of new developments. Take for example, the DerryBrien bog slide, which occurred in 2003, and which affected the construction of a 71-turbine wind farm (Lindsay and Bragg, 2003). Just as wind farms and their associated infrastructure may be affected by or cause peat landslides, other infrastructure such as road networks, flood defences, power lines, residential areas and farmland may be affected.

Slope instability and landslide hazard assessments have typically followed a standard approach as detailed in BS5930 (British Standard, 2015). Previous investigations have demonstrated, however, that the geotechnical features of peat landslides differ from mineral soil landslides and that pre-conditions of failure are not properly accounted for by more conventional site investigation. This is due to the fibrous nature of the peat and its very high water content, which can be up to 1000% (Huat et al, 2014) as measured in geotechnical terms.

Peat Landslide and Risk Hazard Assessment

Peat Landslide Hazard and Risk Assessments (Scottish Government, 2017) was developed by the Scottish Government in 2006 and updated in 2017 to reflects contributions from new research and publications (SEPA, 2017a; NatureScot, 2016). Together with the guidelines for construction published in Malaysia (CRIM, 2015), the PLHRA is one of the few documents that considers best practice for evaluating the ground conditions of peatlands.

One of the main limitations when testing peat comes from deriving credible strength parameters from laboratory and field-testing methods. The PLHRA provides a series of procedures and analyses to consider as a means of obtaining a detailed site assessment of peat. A methodology is also presented in the guidance to assess the likelihood of a peat landslide and the associated risks based on previous studies in the field (Lee and Jones, 2013; Dykes and Warburton, 2007; Brunsden and Prior, 1984).

Although originally proposed for the construction of onshore wind farms, the PLHRA has become an official construction code to be followed as part of the peat management plan for any new developments on peat sites, including housing activities, that cannot avoid disturbing the soil. This is because the construction of deep excavations in peat sites, likely to take place when the excavate-and-replace foundation option is adopted at deep peats, can trigger landslides. For instance, a PLHRA needs to be incorporated to any planning application when proposed at locations with 2° slopes in blanket bogs or any gradient in raised bog environments.

Hydraulic stability

Construction of new developments on peatlands that entail the excavation of peat requires the drainage of water. Drainage is undertaken by pumping water away from the excavation. This results in a reduction in the level of the water table, loss of habitat and subsidence of the peat surface. The increase in soil respiration attributed to the lowering of water level has often been regarded as an instigator of carbon loss from the organic matter (Artz et al., 2012). The impact that drainage may have on organic soils is related to the depth of ditching, distance between ditches and the hydraulic conductivity of peat (Nayak et al., 2008). The reduction in the water level is greatest when close to the ditch. It increases with distance, the magnitude of the lowering being dependent on groundwater flow rates, permeability and the inherent strength of the peat, as may be determined by the degree of decomposition of the peat (Armstrong, 2020).

In addition to its contribution to mechanical performance, PLHRA (Scottish Government, 2017) identifies activity that alters natural drainage pathways and which can trigger peat landslides directly. For this, the PLHRA requires a detailed study of the site hydrology and geomorphology with the hydrological baseline understood to model the water table levels.

In addition to stability of the peat itself and associated environmental impacts, the design engineer must ensure the stability and serviceability of the planned structure. This means detailed consideration of the interface between the ground and the structure – the foundation. In the next section, a summary of foundation options is given. A more detailed study and appraisal of different foundation options is given in the report on work package 3.

Foundation construction on peatlands

Roads, housing or windfarm construction on any soil 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). This study considers 7 different foundation options within the foundation types. The options are: *Excavate-and-Replace (E&R), trench fill, floating solutions, mass stabilisation, preload-and-surcharge, and piling (both conventional (concrete/steel) and timber)*.

The most important aspects of the impact of the foundation option on the peat are introduced in this section. A more detailed and comprehensive appraisal (technical, environmental, economic and logistical) of each of these foundation options was undertaken in Work-Package 3 of this report. A distinction is made in this report between 'impact on peat'; total carbon loss associated with the organic matter, and the 'embodied carbon'; referring to carbon emissions coming from the production, transport and installation of materials used with each option.

Excavate-and-replace

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 competent fill to provide a suitable formation. However, the excavation process risks drying sections of the peatland with the associated detrimental effect on the carbon stored within the peat (Munro, 2004). Drained peat allows stored carbon to readily decompose due to the aerobic conditions created. The total amount of GHGs emitted by a drained site will depend on factors such as the depth to water level, peat depth, temperature, extent of drainage and hydraulic conductivity of the soil. The assessment of the drainage extent around the site construction is critical since it strongly influences the total volume of peat impacted by the construction of the development. For this, sufficient measures are to be obtained at each site to describe the hydrological features of the area, apart from a hydrological model to simulate the likely changes in peat hydrology. As a result, the direct emissions associated with the adoption of excavate-and-replace are considered to be significantly high given the high volumes of peat replaced by competent fills. Due to the foreseeable loss of soil organic matter, peat management, peat restoration plan and post construction habitat management plans would then have to be considered in developments that propose to excavate-and-replace peat, as found in the peatland survey (SEPA, 2017b).

Trench fill foundation

Trench fill foundation is a type of shallow foundation where the peat/soil is excavated to a certain depth, i.e. to a competent load bearing-layer, and it is filled with concrete creating a strip of concrete around the area of the property (Munro, 2004). This foundation option has been used in Scotland to provide a stable building founded on (reinforced) ground/ring beams, in turn bearing on rockhead (McIvor, 2021). In terms of environmental impact, this option is found amidst the excavate-and-replace and the peat-left-in-place techniques. Although there is a significant reduction in the amount of peat excavated, peat is partially disturbed, and it may lead to the release of carbon emissions from the organic matter. Moreover, there is also an associated embodied carbon associated with the production, transport and installation of the cementitious materials needed to fill the trenches.

Peat-left-in-place options

In some cases, excavate-and-replace in peat soils may be too expensive due to factors such as peat depth, cost of backfill material and availability of peat disposal areas. Peat-left-in-place foundation options could be used instead.

Floating solutions

Floating solutions have been commonly used across Scotland to build "floating" roads on top of the peat relying on the strength of the in-situ peat for its support. Modern construction practice generally uses a geosynthetic layer to be placed on the surface of the peat before the road is constructed to give a working platform for the roads and provide separation between the road and the peat below. Compared to excavate-and-replace, peat-left-in-place options such as this, reduce emissions associated with the loss of organic matter. However, other environmental impacts, from the production and transport of geogrids and aggregates used for the construction of the floating road, must be accounted for. Work by NatureScot indicated that even after these other effects are included, carbon emissions and costs are lower than excavating and replacing the soil (NatureScot, 2015).

Mass stabilisation

Mass stabilisation of peat has become increasingly popular and is extensively used in different parts of the world including Japan and Scandinavia. This option works by injecting suitable dry cementitious and pozzolanic binders into the ground that are mechanically mixed into the peat by means of a mechanical tool. As a result, it creates a homogeneous mass; either for the whole peat layer or in the form of deep columns, which hardens via curing over time strengthening the ground and reducing any potential settlement. Environmental considerations favour the use of mass stabilisation because its use reduces the need to excavate the peat and avoids any subsequent drainage effects of the surrounding peat. Previous laboratory tests have demonstrated that stabilised peat not only holds its carbon but also absorbs additional CO_2 from the atmosphere and the peat by means of the binders injected in a process referred to as "carbonation" (Duggan, 2016). Moreover, the option is known for also reducing the release of methane observed in normal conditions (Juha et al., 2018). The main environmental impact is associated with the production of binder materials. Although cement has been the most used pozzolanic binder due to its greater potential for strength, other by-products of industrial processes are proposed as alternative binders including granulated blast furnace slag (GGBS), fly ash or recycled gypsum. These by-products are known to be more environmentally friendly when compared to cementitious materials. Alternatively, fillers such as fine silica sand or limestone can be added to increase the number of soil particles, fill the void space, reduce the amount of binders needed and the embodied carbon associated with its production. Replacing the stabiliser with inexpensive fillers can also save costs (Axelsson, 2002).

Preload-and-surcharge

Preload-and-surcharge is a method of improving the strength of the soil by applying a load in excess on top of the peat to trigger the settlement of the soil until it reaches the predicted value. Once this is reached, the excess load is removed. To accelerate the settlement, surcharge (an additional load) is commonly added to the process (Poon et al., 2020). This is a peat-left-in-place technique and, unlike mass stabilisation or trench fill options, cementitious materials are not needed. Instead, large amounts of surcharge fill, and the associated embodied carbon of its transport and installation, may be needed. Stockpiles of construction materials may be used otherwise as preloading surcharges and thus reduce the environmental impact (Munro, 2004).

Piling

The main form of piling on peatlands that has been used in Scotland is for road construction where deep soft soils, like peat, exist and settlement control is critical. Driven precast concrete piles or continuous flight auger piles have been installed to depths of up to 30 m (Munro, 2004). For the installation of the piles, a suitably designed piling rig support platform is mandated, where a geosynthetic reinforced load transfer platform tends to be the most popular. These are composed of a grid of piles with pile caps which is overlain by a/two layers of geotextiles with the granular embankment constructed on top. In terms of direct carbon emissions, little or no peat is removed. Emissions come from other sources, such as the construction of the load platform and the need to transport heavy piling machinery as well as the production and movement of aggregate fillers and geosynthetics. Calculated carbon emissions are estimated, however, to be lower than with excavate-and-replace techniques (Duggan, 2016). The main environmental impact is associated with the production of precast concrete or steel piles and its transport to the site, which can be hundreds of kms depending on the location.

Alternatively, timber piles have gathered interest over recent years by offering a more sustainable design. They are economical, easy to transport, handle and are particularly suited for locations with access difficulties. Moreover, Scotland has a large forest resource of conifers such as Douglas fir, Larch, Norway spruce and Sitka spruce that could be used for piles (Davies, 2016). In this regard, there would not only be a reduction of carbon emissions by replacing steel or concrete piles by timber, but also the sequestration effect of re-using the material when introducing into the soil. Carbon emissions would still need to be considered for the design of the load platform and the use of piling machinery, but these are estimated to be lower due to the lower weight of timber over concrete/steel.

Regulatory framework

Scottish Planning Policies

The Scottish peatlands as both an important habitat for wildlife and a significant carbon store makes them one of the most valuable physical assets in the country. Unfortunately, they have not always been viewed as such and peatlands have been considered wastelands in the past, leading to a degradation of over 35% of peatland in Scotland. Both the public and governmental perception on the economic and environmental value of peatlands changed after the Climate Change Act (CCA) (2008).

An increasing awareness of peatland's value can be found within the narrative of the National Planning Framework (NPF) together with the Scottish Planning Policy (SPP) and the Local Development Plans (LDPs). Whilst NPF refers to the spatial planning of the Government Economic Strategy and the plans for development in infrastructure, the SPP focuses on the preparation of development plans and material consideration in planning decisions at a national scale. National planning policy is then locally reflected in every LDP.

The first NPF was published in 2004 and it provided guidance for the development of land use in Scotland until 2025 (Scottish Government, 2004). Despite discussing elements of sustainable development on Scottish lands, the document did not include any statement regarding the impact of peatlands on the development of new housing. After the CCA 2008 was enacted, the subsequent NPFs highlighted for the first time the national importance of peatlands given their role as carbon reservoirs (Scottish Government, 2010a). The third NPF (2014), with a 2035 target year, went one step beyond and established the need to restore peat sites and the creation of a National Peatland Plan to protect and enhance the multiple benefits of this resource (Scottish Government, 2014b).

The national planning policies contained in the SPP experienced the same change after the CCA 2008 became law. Whilst the SPP in 2006 did not include any policy in relation to the development plans on peat (Scottish Government, 2006), these would be included for the following versions (Scottish Government, 2010b, 2014a). In the latter versions, the need to assess the likely effect of new developments on carbon emissions and that any new construction should aim to minimise their release was highlighted. Furthermore, it was established that local policies should protect peatlands and only permit commercial development in areas suffering historic, significant damage, where the restoration value is low, or where restoration is impossible. Hence, these became the first planning policies in Scotland that limited building activities on peatlands.

Policy in Highland Council region

In the Highland-wide LDP (HwLDP) (2012), local planning policies were set to protect peatlands in the HC region. One of them is Policy 55, which states that development proposals should demonstrate how they avoid unnecessary disturbance, degradation or erosion of peat (Highland Council, 2012). It states that peat disturbance will not be permitted until it is shown that adverse effects are clearly outweighed by social, environmental and economic benefits arising from the development.

Consequently, Policy 55 in the HwLDP was created in accordance with the guidelines proposed by NPF 2014 and SPP 2014 but with a more restrictive approach; to avoid developments on peatlands unless properly justified. If a development on peat was unavoidable, a Peat Management Plan (PMP) is to be presented to demonstrate how the impact on peat has been minimised or mitigated. A PMP must be created in collaboration with key consultees including SEPA and NatureScot, who provide support at the local development plan stage.

NPF4, expected in 2021, will also incorporate the new SPP so that spatial land use and thematic planning policies will be addressed in one place. It will have the status of the development plan for planning purposes, having a stronger role in day-to-day decision making. Under the NPF4 position statement (Scottish Government, 2020b), it is stated that the new planning policies will support phasing out the use of horticultural peat and restrict construction developments.

Planning guidance for wind farm and housing applications on peat

Wind energy developments are often proposed in the HC region in areas where peat is present. The number of windfarm applications on peatlands across Scotland has substantially increased over the last decade (Artz and Chapman, 2016). This was encouraged by the Climate Change (Scotland) Act 2009 to minimise any dependence energy collected from carbon fossil fuels which has led to an almost 100% of electricity demand obtained from renewable sources in 2020 (Scottish Government, 2020a).

Given the high number of new commercial developments, the Scottish Government and HC have published documents, e.g. "Good Practice during Windfarm Construction Guidance", that account for the key considerations when planning construction on peat sites. Amongst the main measures, the excavation of deep peats should be avoided given that it would result in the excavation of amorphous peat, which is difficult to handle or store effectively. Mitigation of these effects may otherwise include construction methods such as the use of floating tracks or piling turbine foundations. These may also take the form of habitat restoration or habitat improvements, either in areas of the site not being developed or other peatland sites (Highland Council, 2017b).

Similar good practice guidance does not exist for housebuilding activities which may be attributed to the smaller number of applications compared to the large number of annual windfarm construction applications. However, there are a series of documents (listed below) which have been created for consideration when proposing any new developments on peat. The main guidance from SEPA can be summarised as an instruction to minimise waste arisings and to ensure the environmental stability of peatlands. A policy of a prevention, re-use and recycling process, in that order, is set out (SEPA, 2017).

Any construction on peatland should have regard to the following key publications:

- Calculating Carbon Savings from Wind Farms on Scottish Peatlands - A New Approach,
- SEPA's Regulatory Position Statement – Developments on Peat,
- Good Practice during Windfarm Construction Guidance,
- Peat Hazard and Risk Assessment Guide,
- Development on Peatlands: Site Surveys,
- A Land Use Strategy for Scotland, 2016-2021,
- Assessment of Peat Volumes, Reuse of Excavated Peat and the Minimisation of Wate,
- Scotland's National Peatland Plan: Working for our future.

Wind farm and housing activities in HC region

The fact that windfarm developments save significant amounts of carbon emissions when replacing other fossil fuel sources justifies the emissions associated with disruption of the peatland. In addition to this, the high budgets of wind farm constructions enable the development of economically costly and time-consuming PMPs which can demonstrate the mitigation of peat disturbance by restoration projects. This is for instance the case of Cloiche Wind Farm, located towards the south-east of Fort Augustus, which comprises of 36 turbines with a total capacity of 150MW. As according to the PMP, net emissions account for c400 kT CO_2, which results in an overall carbon payback-time between 3 and 10 years, depending on the fossil fuel considered (SSE, 2021). It is against just such a positive renewable resource backdrop that wind farm applications are judged and typically approved.

On the other hand, only two major housing developments on peatlands in the HC region have been submitted over the last 5 years (Highland Council planning portal, 2021). The budgets for housing construction are tighter than wind farm projects and hence with fewer resources to develop a PMP. This, in addition to the higher foundation costs for peat, adds to overall building costs, squeezing already tight financial margins.

The carbon calculator

In 2008 Smith et al. presented the "Carbon Calculator", with a web-based version since 2016, to calculate the impact of wind farm developments on the soil carbon stocks held in Scottish peatlands (Scottish Government, 2018c). This is the first official documentation to quantify the impact of new developments on the carbon stability of peatlands.

To calculate the carbon emissions attributable to the removal or drainage of the peat, mainly due to excavate-and-replace technique, emissions occurring if the soil had remained in situ and undrained are subtracted from the emissions occurring after removal. The extent of the area affected by drainage around each construction at the site strongly influences the total volume of peat impacted by the development. On the other hand, restoration of the site could minimise carbon loss, limiting carbon dioxide emissions to the time before the habitat and hydrological conditions are restored. The amount of carbon lost is then calculated from the annual emissions of methane and carbon dioxide, the area of drained peat, and the time until the site is restored.

Despite the importance of the carbon stability of peatlands in Scotland, this approach is not currently followed by the land developers to propose the planning construction of new housing on peatlands (Stantec, 2019). Only the total volume of soil removed or re-used from peatlands is being evaluated as according to the "Assessment of Peat Volumes, Reuse of Excavated Peat and the Minimisation of Wate" (Scottish Government, 2012). However, the change in water table and the impact of drained peat on the overall GHGs emissions are not being considered unlike it occurs with the planning construction of windfarms. This indicates that the total environmental impact of housebuilding activities on peatlands, if any, may be underestimated. As a means of better estimating the impact of excavate-and-replace techniques on the carbon stocks, the "carbon calculator" shall be also used by land developers that seek to propose housing developments on peat sites. This has been proposed by the Highland Council as a response to the National Planning Framework 4 (Highland Council, 2020).

WP2 findings

This work-package has highlighted the role of peatland as a carbon reservoir, but one that without proper management or control may become a carbon source. Construction on the peat has the potential to create such a source and so as background to the wider ranging foundation option appraisal that makes up WP3, this work package has set out the key features of the interdependencies that exist between construction, foundation and the underlying peat and their collective impact on the environment. We have noted that 35-60% of peatlands in Scotland are in degraded conditions. If degradation continues at the same rate, peatland will switch from being a carbon sink to act as a source of GHGs.

There is no single specific code or set of guidelines for housing construction on peatlands in Europe despite the abundance of peat found in the continent. Given the high number of onshore wind farms in Scotland, a best practice guidance, Peat Landslide Hazard and Risk Assessments (PLHRA), was created for identifying, mitigating and managing possible landslides. Good practice guidance does not exist for housebuilding activities. However, the PLHRA has become an official code to be followed as part of the peat management plan for any new development on peat, including housing activities, that cannot avoid disturbing the soil.

The favoured foundation option for any form of construction development in Scotland has been to excavate the peat and then replace it with a competent fill to provide a suitable formation, however, the carbon emissions associated with this technique are very high. Other forms of foundation, e.g. peat-left-in place techniques, such as *mass stabilisation, preload-and-surcharge, or piling*, have the potential to minimise the excavation and drainage of peat.

Work-Package 3 - Foundations on peat. Options appraisal and adaptability

Introduction to work package

The aim of work-package 3 (WP3) is to consider foundation options for domestic developments on peatland in Scotland in terms of current local practice and with reference to overseas experiences. The assessment was undertaken to identify existing foundation options and alternatives, as a means of supporting the responsible use of peat sites for housing development.

Foundation options are first considered in isolation, i.e. in the kind of ground profile to which they are best suited. Next, the adaptability of options to different ground conditions and loading scenarios is considered. The options appraisal is developed within the context of 4 tables. The adaptability of options is illustrated through selected visualisations. This work package contains the main outcome of the Phase 1 of this project.

Foundation types and options

Traditionally, there are three types of foundation solution for construction on peat, the fundamental principles of which can be thought as: 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). This study considers 7 different foundation options within the foundation types, as visualised in Fig. 9. The options are: *Excavate-and-Replace (E&R), trench fill, floating solutions, mass stabilisation, preload-and-surcharge, conventional (concrete/steel) piling and timber piling*.

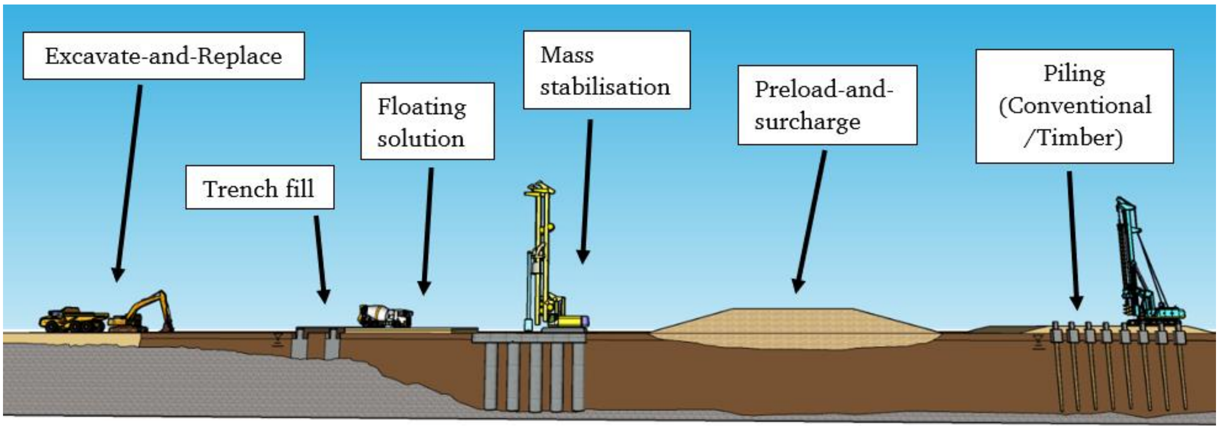


Figure 9. Foundation options for construction on peat

National and international experience

Each of these techniques have been used for civil engineering constructions on conventional ground. Some transfer readily to use as foundations on peatlands; others call for more detailed consideration and/or expert input. *Excavate-and-replace* is the default form of housing foundation on peatlands in Scotland (DAM, 2019; Stantec, 2019) whilst *floating solutions* are commonly adopted for the construction of access roads on wind farms (NatureScot, 2015). Techniques such as *trench fill and conventional driven piling*, have been used in Scotland for housing foundations when it was required to ensure the stability of nearby buildings (Munro, 2004; McLeod, 2021). *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) and Japan (Juha, Leena, and Pyry, 2018). It is becoming established in the UK (ICE, 2020). The technique has been proposed in Ireland for some projects in peat, but it has not been commercially deployed due to the large amounts of binder (e.g., cement) required (Duggan, 2016).

Since the Romans, timber piling was the main form of foundation for building construction in Northern, Central and Eastern Europe until the Second World War, when concrete piling replaced them as the main foundation option due to its higher durability (Klassen and Creemers, 2012). In Indonesia, the use of bamboo and timber pile raft system, known as "cerucuk", has been used until now based on their availability and low cost (Rahardjo, 2005). Forms of geotextile bamboo/timber fascine mattresses are used in Malaysia to enable the embankment construction over deep peats (CRIM, 2015). Although there is limited information on the design considerations for using *timber piling* on peat (Snider and Iordache, 2017; Gould, Bedell and Muckle, 2002; MacFarlane, 1969), they are commonly used for the construction of house and building foundations over soft soils, e.g. clays, in USA (SPTA, 2016), Canada (Canadian Foundation Engineering Manual, 2006) and Netherlands (NNI NEN 5491, 1999).

Options appraisal

Explanatory notes: Reading the tables

The options appraisal is elaborated within the context of the following 4 tables:

- Table 3. Options matrix and RAG appraisal
- Table 4. Criteria definitions
- Table 5. Advantages and disadvantages
- Table 6. Strengths and barriers to implementation

Options matrix and RAG appraisal

The 'Red/Amber/Green' (RAG) appraisal is the outcome of a desk study and interviews with key stakeholders. The 7 different foundation options are considered in relation to 12 assessment criteria. These criteria are grouped into 4 criteria categories: Geotechnical, Environmental, Logistical and Other. Assigning a RAG status to each option/criterion combination allows for a visual appraisal of each foundation option across the 12 criteria. RAG status is interpreted as follows:

Red (R): is a NEGATIVE attribute of the foundation option in question. It implies that it may present difficulties with regards to stability or settlement (geotechnical), excessive carbon emissions (environmental), lengthy construction times (logistical), and/or no significant prior experience. For example, stability of a *floating solution*, road or platform, will be dictated by the properties of the underlying soils and should be avoided for any infrastructure that is vulnerable to settlement.

Amber (A): is an attribute of the foundation option in question that, without further knowledge or specification, e.g. information on ground conditions, cannot be assigned to either R or G status. For example, *preload-and-surcharge* are well known techniques for the management of settlement and bearing capacity in conventional soils, but their effectiveness depends on a number of factors: the extent of the area to be preloaded, depth of peat, availability of surcharge load and time available for secondary settlement.

Green (G): is a POSITIVE attribute of the foundation option in question. For example, settlement is generally not a problem with *excavate and replace* because highly compressible peat is replaced by a much stiffer mineral fill.

Criteria definitions

This table elaborates on the 12 appraisal criteria used to evaluate the 7 foundation options.

Advantages and disadvantages

This table summarises the main advantages and disadvantages of each foundation option. Additional detail about the rationale underlying the RAG grading is provided.

Strengths and barriers to implementation

This table emphasises some of the practical positive features of the 7 foundation options and highlights key unknowns or current barriers to implementation. Barriers to implementation may provide opportunities for further investigation.

Table 3. Criteria matrix for preliminary RAG appraisal of foundation options

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)	Green	Green	Amber	< 3	Red	Red	Red	Amber	Green	Green	Green	Green
Floating solution	Red	Red	Amber	> 1.5	Green	Green	Amber	Green	Amber	Amber	Green	Red
Preload-and-surcharge	Amber	Amber	Amber	No limit	Green	Green	Green	Green	Amber	Green	Green	Red
Mass stabilisation	Green	Green	Red	< 20	Amber	Amber	Amber	Green	Green	Amber		Green
Trench fill	Green	Green	Amber	1 - 3	Amber	Amber	Amber	Amber	Green	Amber	Green	Red
Piling (Concrete/ Steel)	Green	Green	Red	> 3	Green	Green	Red	Green	Green	Amber	Green	Red
Piling (Timber)	Green	Green	Red	3 - 10	Green	Green	Green	Red	Amber	Green		Red

[1] Gives an indication of some of the countries where the techniques are commonly used (i.e. international experience).

Table 4. Criteria definitions

Categories	Criteria	Criteria definitions for Options Matrix
Geotechnical	Bearing capacity	Bearing capacity is the maximum foundation pressure that a soil can withstand before failure occurs. May be superseded in relevance to the stability of a structure by settlement.
	Settlement	Settlement is the volumetric reduction of a soil due to change in load (usually referred to as consolidation settlement) and over time (secondary settlement) Secondary settlement is much greater in peat than in mineral soils). Differential settlement, where settlement magnitudes differ over the site due to differences in peat properties, depth, and loading, is most damaging to a structure.
	Temporary works	Temporary works are additional works required by some techniques (mass stabilisation, piling) to allow site operations, e.g. working platform, machinery, transport of materials, cement curing, soil consolidation. A working platform may be required using geogrid and select fill.
	Peat depth	Peat depth over which the foundation option in question would be considered technically viable. A depth of 3 m is significant as it is at depths greater than this that piles become viable.
Environmental	Impact on peat	Impact on peat is the level of disturbance, and the total carbon release of the organic matter, that the adoption of a technique would have upon the peat. Distinction is made between techniques that propose the total removal of peat and replacement with aggregate fill (Red), e.g. Excavate-and-Replace; techniques where some material is excavated, e.g. trench fill (Amber); and the rest of the foundation options, where the soil disturbance is minimal (Green).
	Impact on hydrology	Impact on hydrology describes the level of impact that the foundation option may have on the ground water regime[2].
	Embodied carbon	Embodied carbon refers to the impact that the adoption of the foundation option would have on the carbon release associated with excavation and mobilisation costs, and production of the construction materials used.
Logistical	Approval	Approval is the likelihood that the foundation option gets approved based on regulatory, technical and environmental grounds.
	Durability	Durability is the capacity of the foundation option to maintain its serviceability state for the life of the foundation, e.g. timber in oscillating water table conditions would be susceptible to decay.
	Cost	Indication of magnitude of costs gathered. Mostly anecdotally from specialist contractors.
Other	Experience	Previous experience of using the foundation technique in the UK. Also indicates examples of international contributions/use of the corresponding foundation technique. Norway 🇳🇴, Japan 🇯🇵, Finland 🇫🇮, Sweden 🇸🇪, Canada 🇨🇦, USA 🇺🇸, Netherlands 🇳🇱
	Adaptability	Adaptability reflects the potential for a foundation option to be applied regardless of loading scenario, i.e. house foundation and adjacent infrastructure).

[2] NatureScot, 2020

Table 5. Advantages and disadvantages

Options	Adv./ Disadv.	Geotechnical	Environmental	Logistical	Other
Excavate-and-replace (E&R) Peat is excavated and replaced by a competent fill	Adv.	Good bearing capacity. Little settlement over the lifetime of the foundation		Proven, practical solution. Durable. Most cost-effective solution.	Well known technology. Adaptable to different load scenarios.
	Disadv.	Not practical in peat at depths >3m without forming bund walls. Requires large quantities of imported fill. Difficult excavation below the water table.	Expected restoration/peat management. Peat excavation results in soil disturbance and carbon release. Soil drainage affects local hydrology increasing carbon emissions.	At odds with zero carbon, net zero, foundation and hence not preferred option.	
Floating solution Geogrid reinforced layer of fill placed above soft layer	Adv.	Can be used on deep peat. Reduced fill requirement compared to E&R.	Little disruption to groundwater hydrology. Limited site disturbance.	Proven solution, specifically over deep peats.	Often used solution for access roads in UK.
	Disadv.	Relative low bearing capacity. Total and differential settlement may be significant. Geogrid cannot be cut by subsequent excavations.	Requires the use of high-quality geomembrane and aggregates.	Less durable than E&R. Incompatible with house foundation requirements.	Not useful for different load scenarios - building/services
Preload-and-surcharge Temporary loading of foundation soils	Adv.	Increases bearing capacity and minimise working settlement.	Avoids removal of peat. Stockpiles of construction materials can be used as preloading surcharges.	Proven solution. Use in peat less frequent but could be approved.	Often used in UK for road construction.
	Disadv.	Advanced ground investigations to understand consolidation and increase in loading capacity	May require large amount of surcharge fill and import then removal costs.	Site investigations and preloading/surcharging can extend project construction times.	Not useful for different load scenarios - building/services
Mass stabilisation Addition of cementitious binder to form stiffened ground	Adv.	Good bearing capacity. Minimal settlement. May be used in shallow and deep soils.	Carbonation of pozzolanic binders is net consumer of carbon. Limited site disturbance.	Durable. Ready approval.	Experience of use increasing across Europe. Adaptable to different load scenarios - building/services
	Disadv.		Significant embodied carbon of cementitious materials. Introduction of hydrological barrier.	Site investigations and testing can extend project construction times. High cost/specialist contractor. Normally limited to large projects	Less experience on peats in the UK.
Trench fill Trench filled with concrete down to firm layer	Adv.	Good bearing capacity. Minimal settlement. Alternative to piles for shallow depths.	Lower impact on peat than E&R.	Proven solution. Durable. Ready approval.	Commonly used in peats in Scotland.
	Disadv.	Instability issues of side walls of trenches. Depth limited to 3m.	Marginal site disturbance. Disrupts soil local hydrology. High embodied carbon due to cementitious materials.	More expensive than E&R. Only used for heavier loads (house foundations).	Not useful for different load scenarios - building/services
Piling Conventional piles (steel/concrete) driven to firm layer	Adv.	Good bearing capacity. Minimal settlement. No additional time for curing or surcharge effects.	Avoids excavation and disruption to soil hydrology.	Proven technology. Durable. Ready approval.	Commonly used in the UK.
	Disadv.	Requires working platform for plant/equipment. Only practical in depths > 3m. Differential settlement with adjacent infrastructure and ground.	High embodied carbon due to use of concrete/steel. High transport costs.	Design/installation more complex and overall costs higher than E&R.	Less experience on peats. Not useful for different load scenarios - building/services
Piling Timber piles driven to firm layer	Adv.	Good bearing capacity. Minimal settlement. No additional time for curing or surcharge effects. Easier design constraints.	Avoids excavation and disruption to soil hydrology. Can be a zero-carbon foundation when using locally sourced timber species.	Proven solution. Easier to handle, transport, and install than conventional materials. Easier environmental justification.	International experience
	Disadv.	Requires working platform for plant/equipment. Only practical in depths > 3m. Geotechnical design not widely known. Dependent on anaerobic conditions		Durability poor if timber above water table. Lack of awareness of local species durability. Challenging financial justification.	Little UK experience. Not useful for different load scenarios - building/services.

Table 6. Foundation options: Strengths & Barriers to implementation

Options	Strengths and barriers to implementation
Excavate-and-replace (E&R) Peat is excavated and replaced by a competent fill	Historically the default option[3]. Significant environmental impact due to soil disturbance, carbon release and impact on soil hydrology[4]. May no longer be an option or difficult to justify under zero carbon foundations policy[5].
Floating solution Geogrid reinforced layer of fill placed above soft layer	Widely used for access roads[6]. Not suitable for building foundation. Barriers for use under infrastructure when introducing drainage/below ground services.
Preload-and-surcharge Temporary loading of foundation soils	Improvement in bearing capacity may be small under practical (low) surcharging loads. Long-term settlement phenomena may not be well understood. Option difficult to apply under heavier loads, - buildings. Restrict its use to infrastructure and surrounding ground improvements.
Mass stabilisation Addition of cementitious binder to form stiffened ground	Requires thorough ground investigation and specialist plant/machinery to install[7]. Allow for design by specialist contractor. Mobilisation may make option uneconomic for small projects - single dwelling. Columnar stabilisation should alleviate concerns over disruption to groundwater flow/drainage. Alternative binders to improve environmental credentials such as Granulated Ground Furnace Slag (GGBS), fly ash or gypsum[8]. Can treat very deep peats and suitable for both building and infrastructure.
Trench fill Trench filled with concrete down to firm layer	Gives firm bearing layer. Able to bridge pocketed peat. Alternative for use in depths of 1-3 m, where piling is not an option. Trench/walls may disrupt groundwater flow/drainage. Trench side walls stability can be a problem. Alternative binders to improve environmental credentials. Does not deal with adjacent ground.
Piling Conventional piles (steel/concrete) driven to firm layer	Cannot be used at peat depths < 3m. Interaction of pile with peat not well understood, although assumption of solely end-bearing performance would bypass the lack of knowledge[9]. Requires working platform for rig which brings raw materials for excavate-and-replace option onto site. Does not deal with adjacent ground.
Piling Timber piles to driven to firm layer	As for conventional piles, although cutting/sizing can be done on site[10]. More work required to identify and characterise the performance of locally sourced timber species[11], durability under periodic submergence under water table, and use of preservative solutions on the peat environment[12] [13]. Does not deal with adjacent ground.

The information provided in Table 6 is based on an extensive literature review with contributing sources referenced using the Vancouver system. These references are given in brief form in the footnote to this table; full references can be found in the Harvard style main reference section.

[3] Munro, 2004
[4] Nayak et al., 2008
[5] Scottish Government, 2020c
[6] NatureScot, 2015
[7] Axelsson, Johansson, and Andersson, 2002
[8] Duggan, 2016
[9] Tomlinson and Woodward, 2015
[10] SPTA, 2016
[11] Reynolds, 2003
[12] BS EN 599-2, 2016
[13] WPA, 2020

Adaptability (or a single technical solution)

The options appraisal considers each foundation option in isolation and located in the kind of ground profile to which they are best suited. However, inevitably, choice of foundation option must be made with other project requirements in mind, i.e. connection to services, geotechnical performance of adjacent (more lightly loaded) structures, e.g. garages, roads, and temporary/access works.

The combination of variable applied loading with variable soil depth and properties, i.e. strength and compressibility, is challenging enough for foundation design in conventional soils (O'Brien and Burland, 2012). Soil properties are notoriously variable. The problem is exacerbated in peat soils with peat in forms ranging from fibrous to amorphous (Huat et al., 2014) and long term issues may arise - roads, sewers, manholes or pipelines. Secondary settlement in peat can be of the order of 10 to 100 times that in firm clay (Mesri and Ajlouni, 2007).

The issue of peat properties and classification and the geotechnical mindset are elaborated below.

Although the peat will be subjected to lower pressures from services and infrastructure than from house foundations, medium-to-long term issues may arise due to secondary settlement and its impact on roads, sewers, manholes or pipelines. Secondary settlement rates in peats can be of the order of 10 to 100 times that in firm clay grounds (Mesri and Ajlouni, 2007), depending on the type of peat.

Peat classification: Fibrous vs amorphous peat

According to the American Society for Testing and Materials standard (ASTM), peat is classified based on its fibre content, ash content and the acidity of the soil (ASTM, 1990). Peat classification systems such as the von Post (Von Post, 1922) and Radforth (Landva and Rochelle, 1983) are commonly used to standardise the description of peat conditions. The von Post scale accounts for the fibre content and degree of decomposition of peat. It identifies fibrous peat as containing over 66% fibre, corresponding to groups H1-H4 with a relatively low degree of decomposition. Amorphous peat with less than 33% fibre, corresponds to H8-H10 on the von Post scheme with a high degree of decomposition. The term pseudo-fibrous peat with 33-66% fibre is used to describe an intermediate degree of decomposition (H5-H7).

Perhaps the most significant feature of peat soils, and one that underscores the choice of excavate and replace as the most common foundation solution is the presence of fibrous peat. Macfarlane and Radford (MacFarlane, 1969) established that the engineering behaviour of peat can be grouped broadly into fibrous and amorphous granular. The presence of fibres leads to an inherent anisotropy making difficult, although possible, the use of conventional field tests and the subsequent interpretation of peat mechanical parameters. With very little load-carrying capacity and extreme compressibility, fibrous peat is generally removed.

However, as with more conventional soils, the change from fibrous to amorphous peat is a gradual one and, on some occasions, this occurs in relatively short distances. This makes the design of a foundation option on peatlands especially difficult as engineers would need to calculate the geotechnical capacity of the construction according to a material with highly variable strength properties.

The geotechnical mindset

There is ample evidence of the challenge of foundation design in conventional soils. O'Brien and Burland (2012) in the ICE Manual of Geotechnical Engineering state that "geotechnics is a difficult subject and is regarded by many engineers as a kind of black art. It is true that it (the ground) is much more complex than the more classical structural materials of steel, concrete and even timber with which most engineers are familiar".

The need to obtain an adequate knowledge about the ground profile is highlighted in the literature (Tomlinson, 1986). Typically, this can be achieved for single or two storey dwellings without the need for boreholes; local knowledge may be adequate. Only if troublesome conditions are found, and at this point Tomlinson cites layers of peat, would it be necessary to expand the ground investigation.

Foundation design is then a challenging process in which an understanding of soil behaviour – the analysis – is combined with a working knowledge of the geometry, loading conditions and the material properties of the soil profile (Potts et al., 2002). Moreover, the analysis and material properties must account for behaviour in the present, i.e. the immediate response to loading, and for the working life of the foundation. For these reasons, we cannot overstate the importance of an adequate ground investigation.

The foundation engineer must then find a solution that meets a range of loading scenarios. This may not be possible with a single technical solution at an economic cost. Rather the engineer must seek a compromise. In the absence of site-specific information, it is neither possible nor prudent to advocate one option or combination of options over another. However, it is possible to report on some of the specific challenges faced by housebuilders constructing on peat in Scotland. To illustrate these challenges and the inherent variability of ground conditions a series of profile and options visualisations is presented.

Peat profile A: Pocketed peat - Skye and Fort William

As a result of an interview with Iain McIvor (IM), director of investment at Lochalsh and Skye Housing Association, we were alerted to the specific circumstances faced by developers seeking to build in Portree and other areas on the West Coast such as Wester Ross (McIvor, 2021). Portree has already been highlighted in WP1 as a planned settlement location the development of which is limited by the presence of peat. IM described a soil profile as illustrated in Fig. 10, where solid geology is undulating or pocketed creating alternating exposures of rock outcrop with adjacent pockets of peat up to 3 m depth. Foundation solutions have relied upon a combination of trench fill and/or excavate and replace for buildings, with floating platforms for infrastructure. This is because these provide for a stable building founded on (reinforced) ground/ring beams, in turn bearing on rockhead. Similar conditions have been proved in Fort William, at Upper Achintore (Stantec, 2019) and Blar Mhor sites (DAM, 2019).

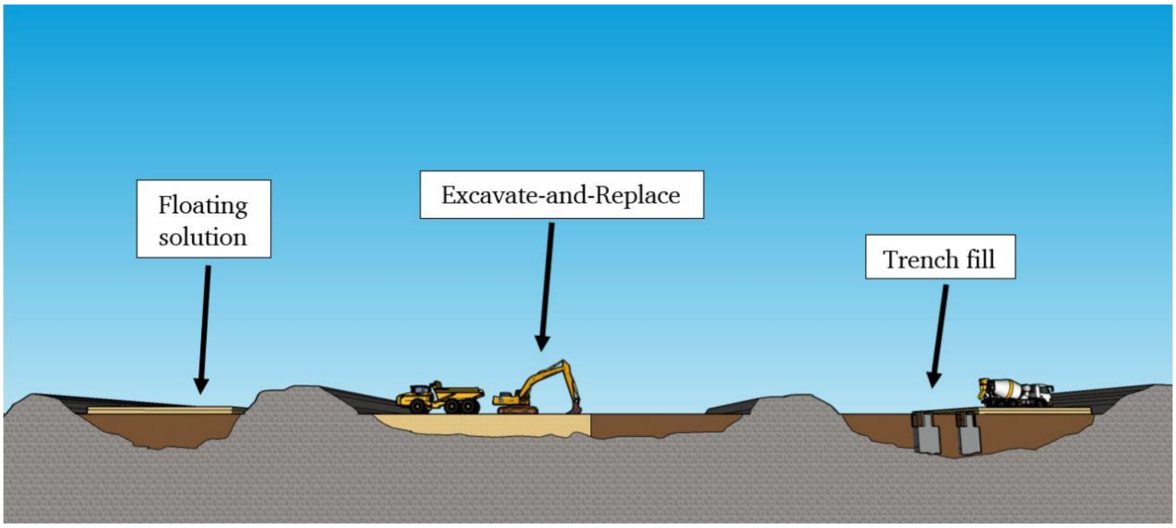


Figure 10. Peat profile A: pocketed solid geology (Portree and Fort William)

Peat profile B1: Deep peat with buildings on piles
Figure 11 shows a building on piles in deep peat. This illustration does not correspond to a real case study but a representation of the different elements that might need to be considered for housing development on peatlands. A working platform is required to support the machinery and install the timber driven piles as well as for the construction of the house. There remain durability concerns for timber piles (WPA, 2020), hence pile caps are shown here, the purpose of which is to avoid cycles of wetting and drying on the pile head (Reynolds, 2003). Access roads may be amenable to *floating solutions.* The success of direct placement on amorphous peat and floating roads would be predicated on settlements being within tolerable limits. As already noted, settlement rates in peat and be up to 100 times those found in firm clay (Mesri and Ajlouni, 2007). Drainage and infrastructure alignment then become critical indicators of the viability of foundation option choice.

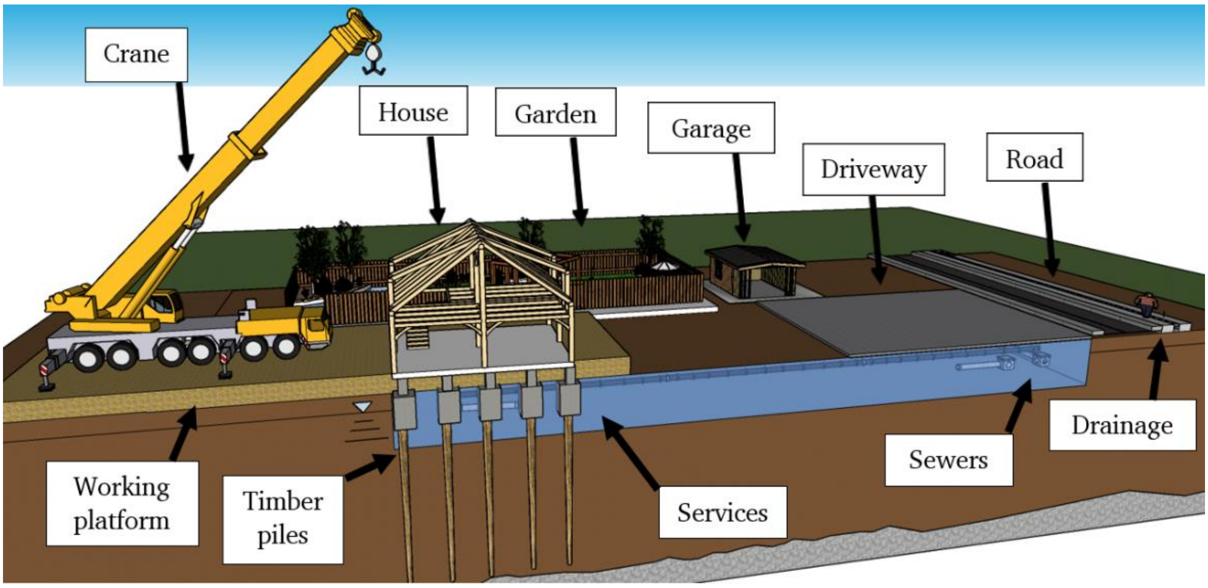


Figure 11. Peat profile B1: Deep peat with building on piles

Peat profile B2: Deep peat with mass stabilisation
As in the case of the previous illustration, Figure 12 does not correspond to a real case but a representation of the various elements that might need to be considered for housing development on peatlands with mass stabilisation for the whole peat layer, rather than piles. Figure 12 shows a site with deep peats at which all load bearing areas, i.e. house and adjacent infrastructure, are stabilised by the construction of a 2-3 m thick mass-stabilised platform by the addition of a binder. This might be sufficient with amorphous peats. Services and sewers may be incorporated within the stabilised platform and thus keep settlements within tolerable limits. Deep columns, mass stabilisation introduced to a certain depth instead of the whole peat layer, might be deployed to support the platform with poorer ground conditions by transfer of load to lower strata. However, the costs involved in site investigation, design and mobilisation may make this option uneconomic for small projects, e.g. single dwelling.

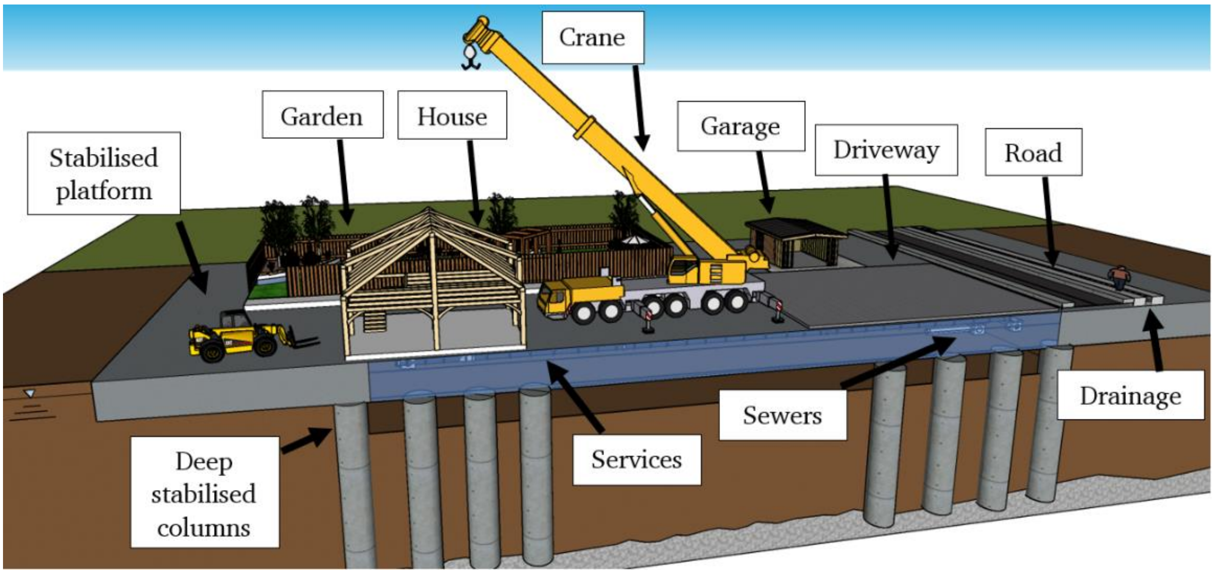


Figure 12. Peat profile B2: Deep peat with mass stabilisation

WP3 Findings

This work package has developed a RAG analysis of 7 options for foundations in the peat (Table 3). The analysis has been based on a selection of assessment criteria, chosen to reflect the (geo)technical, environmental and logistical context of domestic construction on peatlands. The criteria are defined in Table 4. The advantages and disadvantages (in the context of each criterion) for each foundation option are highlighted in Table 5. Table 6 summarises known strengths/barriers to entry or knowledge gaps of each option. The information held in Tables 3 – 7 is based on our assessment of both literature review and personal communications with private and public sector stakeholders.

It is the combination of Tables 4 – 7 that frame the proposed allocation of RAG colour in Table 3. The following observations can be made:

Excavate and Replace: shows 3 red RAG criteria, all of which are environmental. E&R reveals good technical and logistical performance, which goes a long way to explain its continuing use.

Mass stabilisation: Only this foundation option has the inherent capability to deal with different load regime, but its use is likely to be restricted, because of costs, to larger scale development.

Timber piles: Offer an advance on conventional piles (better environmental and cost performance) but at this stage issues of durability and inexperience remain.

Post-script on environmental performance

Whilst for the purposes of this work package environmental performance has been assessed in the same way as the technical and logistical performances, it is likely that environmental constraints will impose increasingly stringent peat protection measures. Consequently, the RAG status of 'approval' and 'cost' drivers underpinning foundation options may shift significantly. However, such a forward-looking analysis is beyond the scope of this project.

Work Package 4: Gateway to Phase 2

Phase 1 is a wide-ranging feasibility study devised to anticipate the practicalities and scope for a wider programme of field trials (Phase 2). Phase 1 sought to identify:

- the scale of the foundations on peat issue (WP1), environmental ramifications (WP2) and technical options appraisal (WP3), the culmination of which is,
- a library of relevant documents and,
- selected insights, in particular, the strengths and weaknesses of foundation options by a structured RAG appraisal. The appraisal captures a number of commonly held assumptions about foundations on peat:
  - Excavate and replace – scores poorly in RAG for environmental criteria but good for logistical criteria and adaptability.
  - Mass stabilisation – scores well for depth but has significant cost and temporary works impact.
  - Piles – conventional vs timber – durability of timber may be a problem and further investigation is required to understand the performance of locally sourced timber.

There may be a 'pivot' point at some stage in the options appraisal, and this will inevitably affect the RAG appraisal of some of the foundation options. For instance, costs may become a secondary factor given,

i) public interest is resurgent (already seen during this project) in the protection/restoration of peatlands,
ii) recent legislation on peat compost and,
iii) net zero foundation may be looming,

in which case the options appraisal may require recalibrating, e.g. feasibility of mass stabilisation, veto on excavate and replace, or any option that is red in environmental criteria.

However, there are still too many uncertainties to consider the creation of a geotechnical design guide. The outcomes from WPs 1-2-3 should underpin the planning of 'Phase 2 (or 1b)'. This phase needs to be **under the guidance of a multidisciplinary consultant / commercial / design led team** (as opposed to an overarching academic project). The stakeholders should:

- identify a proposal and site,
- recruit a project team, which can
- call on academic support as appropriate.

Hence, this study recommends that **Phase 2 should be more focused on site-specific appraisal.** For instance, looking into the planning proposal for the development of affordable housing compromised by peat in the Highland Council region. Phase 2 team could then work on a particular ground scenario and focus on a reduced set of design issues. Laboratory and in-situ testing can then be undertaken to reveal in detail the ground profile and material properties. <u>A series of design recommendations are thus elucidated from a site-specific case study to articulate how a design guide might emerge.</u>

Workshop, Dissemination & Phase 2

In the interests of gauging interest, expertise, and willingness to participate in Phase 2, a dissemination workshop took place in June 2020.

The broad aims of the workshop were to preview the main outputs from the project and to consider next steps. The workshop was planned and led by Dr Andrew Nurse (CSIC) as a brainstorming/planning activity.

Because of COVID-19 the brainstorming/planning took place using an on-line flip-chart/post-it note planning tool – MIRO. There were 14 participants in the workshop, mostly steering group members.

The agenda was as follows:

Workshop Agenda

1. Welcome and Introductions (5 mins)
2. Brief overview of WP3 Solution Options and Next Steps by ENU (10 mins) – *slides attached*
3. Introduction to Miro with Ice Breaker (10 mins)
4. Phase 2 Activities
    - Brainstorming - SWOT Analysis (15 mins + 5mins comfort break)
    - Scoping - MOSCOW Analysis (15 mins)
    - Phase 2 - Workstreams (15 mins)
    - Anything Else (5mins)
5. Summary (5 mins)

The link to the on-line collaborative Miro board is here:

https://miro.com/welcomeonboard/Z0lXV2VHaDR2aWxObDR6b2ZSalk4VnMxam5YQWpPVVVLYlVPTDlTNTZDMzRsa1BibWxjb3dVd1ZiSXFPd3JPTHwzMDc0NDU3MzQ4NDcxNjUxNjE3

(last accessed 8 July 2021)

Copies of the MIRO 'flip chart and post-it note' boards can be found in Appendix A, wherein ideas relating to the three main agenda items: Brainstorming; Scoping; and Workstreams are collected. On-line access allows zooming into the boards to help reading of post-it notes.

The MIRO boards constitute a valuable collection of recommendations and advice from the workshop participants highlighting opportunities for development and for the mobilisation of resources as part of Phase 2.

A summary of planned Phase 2 activities is presented in Fig. 13.

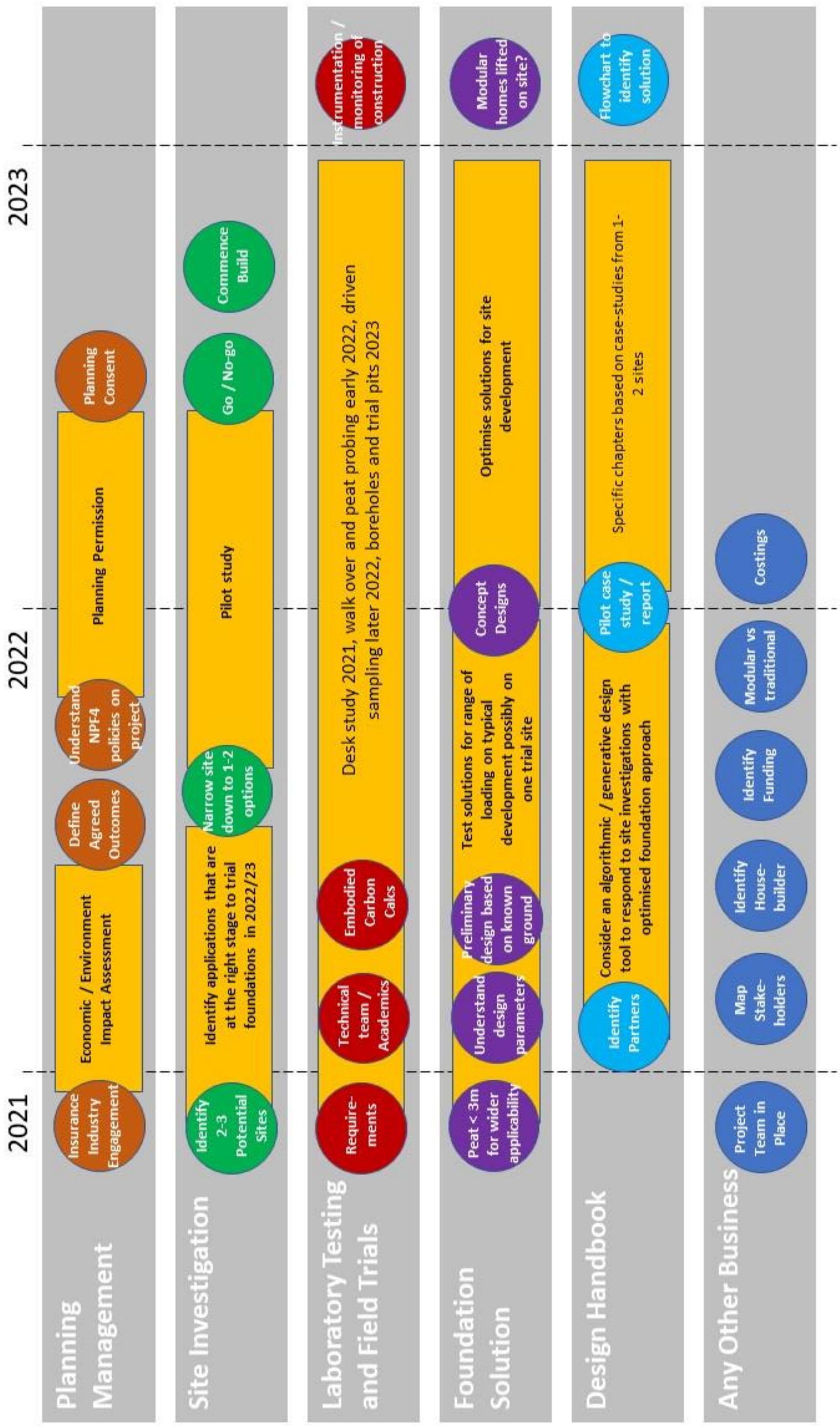


Figure 13. Schedule of activities for Phase 2

Abbreviations

CCA	Climate Change Act
CCC	Committee on Climate Change
CCP	Climate Change Plan
C&S	Caithness and Sutherland
GHGs	Green House Gases
E&R	Excavate & Replace
HC	Highland Council
HMA	Housing Market Area
HNDA	Housing Need and Demand Assessment
HwLDP	Highland Wide Local Development Plan
IMF	Inner Moray Firth
JMI	James Hutton Institute
LDPs	Local Development Plans
LULUCF	Land Use & Land Use Change and Forestry
NPF	National Planning Framework
NRS	National Records of Scotland
PMP	Peat Management Plan
PLHRA	Peat Landslide Hazard and Risk Assessment
RAG	Red / Amber / Green
SEPA	Scottish Environment Protection Agency
SPP	Scottish Planning Policy
WH&I	West Highlands & Islands

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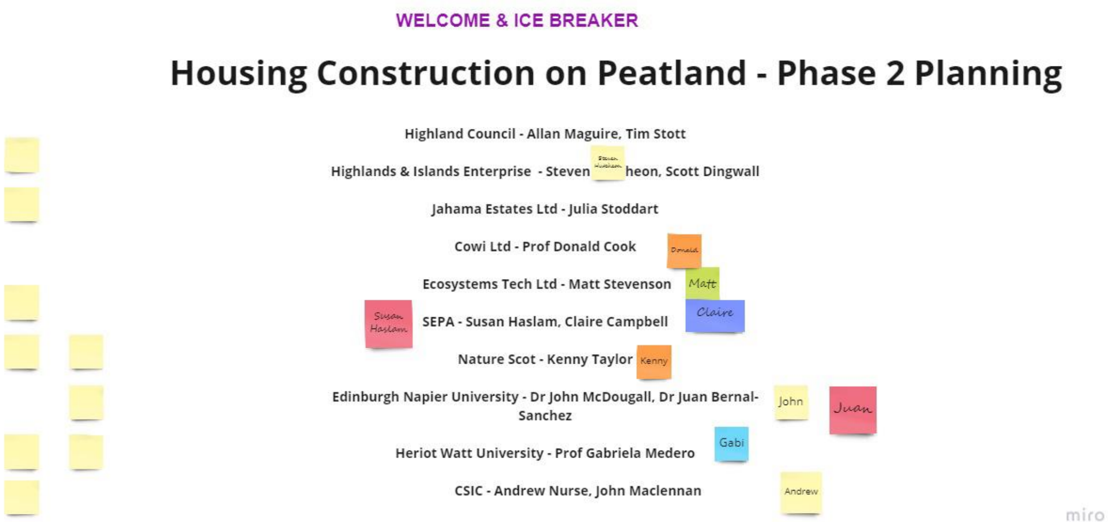
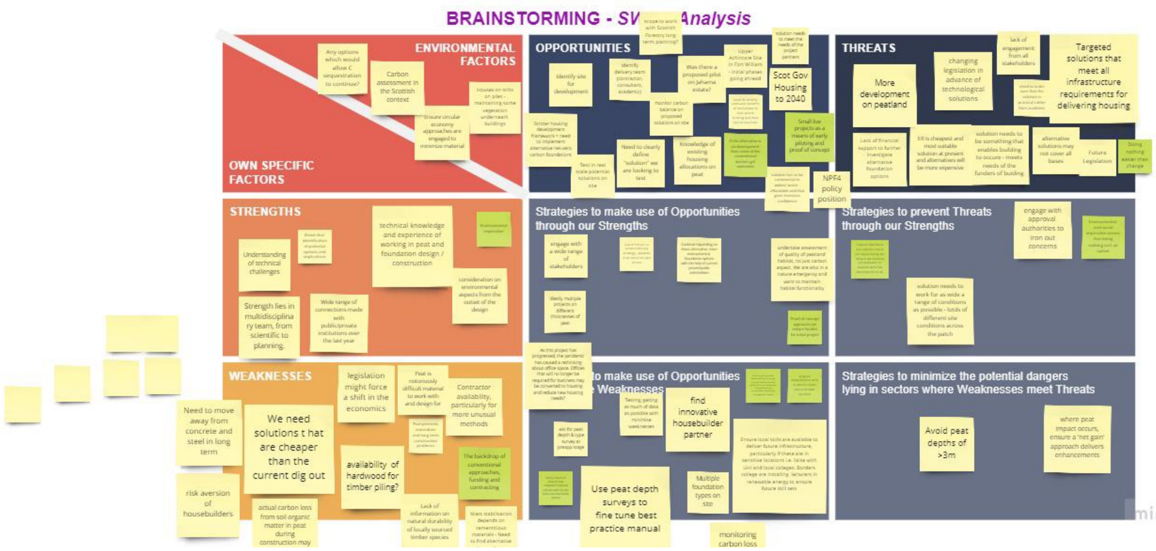
Appendix A: MIRO Edit Boards

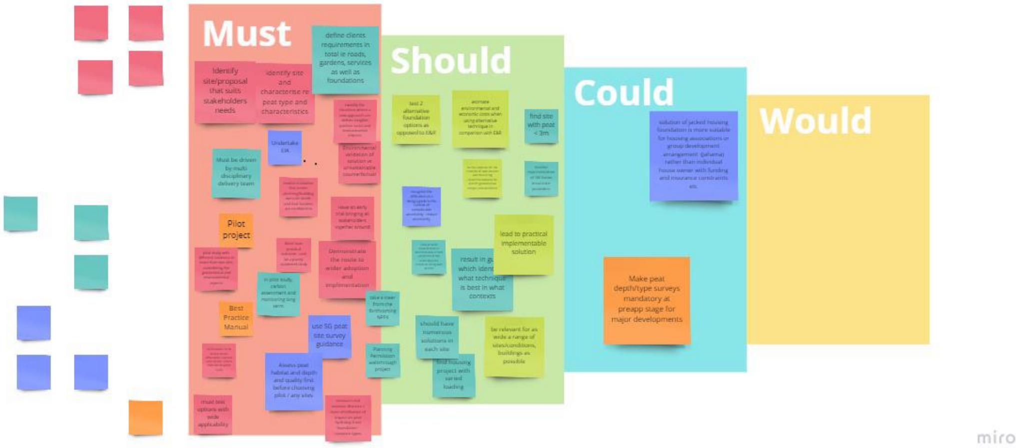
See also (last accessed 8 July 2021):

https://miro.com/welcomeonboard/Z0lXV2VHaDR2aWxObDR6b2ZSalk4VnMxam5YQWpPVVVLYlVPTDlTNTZDMzRsa1BibWxjb3dVd1ZiSXFPd3JPTHwzMDc0NDU3MzQ4NDcxNjUxNjE3





SCOPING - *MOSCOW Analysis*



PHASE 2 - WORKSTREAMS