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Authors(s)	Evans, Chris, Artz, Rebekka, Moxley, Janet, Smyth, Mary-Ann, Taylor, Emily, Archer, Emily, Burden, Annette, Williamson, Jennifer, Donnelly, David, Thomson, Amanda, Buys, Gwen, Malcolm, Heath, Wilson, David, Renou-Wilson, Florence
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Implementation of an Emissions Inventory for UK Peatlands

Chris Evans, Rebekka Artz, Janet Moxley, Mary-Ann Smyth, Emily Taylor, Nicole Archer, Annette Burden, Jennifer Williamson, David Donnelly, Amanda Thomson, Gwen Buys, Heath Malcolm, David Wilson, Florence Renou-Wilson

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CEH contact details Professor Chris Evans

Centre for Ecology & Hydrology, Environment Centre Wales, Deiniol Road, Bangor, Gwynedd, LL57 2UW

t: 01248 374500
f: 01248 362133
e: cev@ceh.ac.uk

Approved by Heath Malcolm

Signed

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SUMMARY AND KEY FINDINGS

This report summarises work undertaken on behalf of the Department for Business, Energy and Industrial Strategy (BEIS) to develop and implement a new method for reporting greenhouse gas (GHG) emissions from peatlands in the UK's emissions inventory. The work builds on the Intergovernmental Panel on Climate Change (IPCC) 2013 Wetlands Supplement, by providing empirically-based and UK-specific 'Tier 2' estimates of emissions from a representative range of peat land-use and condition categories. It collates consistent spatial information on peat extent and condition from each of the four UK administrations, as well as the most peat-rich Crown Dependencies and Overseas Territories (Isle of Man and Falkland Islands respectively). These data were used to assess the overall extent and condition of UK peatlands; to estimate change in condition over the period from 1990 to 2013; to implement the first UK-wide inventory of peatland GHG emissions over this period; and to project future peat-derived GHG emissions through to 2050 based on a set of five illustrative scenarios. Key findings were:

- Based on updated figures obtained during this project, the UK's peatlands are estimated to occupy a total area of around 3.0 million hectares (12.2 % of the total UK land area). Another ~280,000 ha of peat are believed to be present in the Falkland Islands (around one quarter of the land area).
- Of the UK's total peat area, approximately 640,000 ha (22%) is estimated to remain in a near-natural condition. This area of near natural bog and fen is believed to be continuing to act as a significant net sink for CO_2, of approximately 1,800 kt CO_2 yr^{-1}. This CO_2 sink is however counterbalanced by similar emissions of methane (CH_4) when its greater 100-year Global Warming Potential is taken into account making near-natural peatlands close to carbon neutral. Over longer time-horizons, natural peatlands have a strong net cooling impact on climate, due to the longer atmospheric lifetime of CO_2 compared to CH_4. While near-natural bogs are very small net GHG sources, for near-natural fens, CO_2 uptake exceeds CH_4 emission on a CO_2-equivalent basis making them a very small net GHG sink. However the areas that could be definitely mapped as near-natural fen from available data were small.
- A further 1,213,000 ha (41%) of the UK peat area remains under some form of semi-natural peatland vegetation, but has been affected to varying degrees by human activities including drainage, burn-management, and livestock grazing. This has led to drying of the peat, loss of peat-forming species and erosion, converting these areas into net GHG sources. Although the emissions per unit area of modified peatland are relatively low, their great extent makes them significant contributors to overall UK peatland GHG emissions (~3,400 kt CO_2e yr^{-1}, 15% of total emissions).
- Arable cropland occupies just 7% of the UK's peat area, but has the highest GHG emissions per unit area of any land-use, with high rates of both CO_2 and N_2O emissions as a result of drainage and fertilisation. As a result, cropland is estimated to emit ~7,600 kt CO_2e yr^{-1}, 32% of total UK peat GHG emissions. Around two thirds of the cropland area is on 'wasted' peat (shallow residual organic soils where much of the original peat has already been lost), predominantly in the Fenlands of East Anglia. The true extent and rate of GHG emission from wasted peatlands is not well quantified, making this component of the total cropland emission particularly uncertain.
- Peatlands converted to Grassland occupy a further 8% of the UK's peat area, and emit ~6,300 kt CO_2e yr^{-1}, 27% of total UK peat emissions. Drained intensive grasslands in lowland areas are the primary source of these emissions.
- Around 16% of the UK peat area is covered by woodland, the majority of which is drained conifer plantation. The UK inventory currently applies a model-based ('Tier 3') approach to inventory reporting for forests, but data collated for this study were used to derive empirically-based 'Tier 2' emissions estimates for comparative purposes. Both the area estimates and emissions factors associated with afforested peatlands are uncertain, and the Tier 2 emission factors cannot take into account factors such as the age of forest, differences between tree species or forest management practices. However

the Tier 2 emission estimates suggest that peat under forestry in the UK could be emitting around 4,600 kt CO_2e yr^{-1} (20% of the UK total). This figure does not take into account CO_2 uptake into tree biomass, or the after-use of harvested timber.

- Industrial peat extraction for horticultural use occupies a comparatively small proportion of the UK's peat area (~4,600 ha). A much larger area (mainly in Northern Ireland and Scotland) has been affected by current or historic domestic peat cutting for fuel (~145,000 ha), and the resulting modification of vegetation and hydrology is thought (in the absence of subsequent restoration) to have converted these areas into sustained GHG sources. The combined total GHG emission from extracted areas of ~1,200 kt CO_2e yr^{-1} derives mainly from these domestic extraction areas, despite the higher emissions per unit area of industrial extraction sites.
- In total, the UK's peatlands are estimated to be emitting approximately 23,100 kt CO_2e yr^{-1} of GHG emissions. This emission is sufficient to convert the UK LULUCF inventory as a whole from a net GHG sink into a net GHG source.
- There are large inter-regional variations in the main sources of peatland GHG emissions. In Scotland, with the largest total peat area, the largest sources are modified blanket bog and forests. In England, the smaller (and partly wasted) peat area makes a larger overall contribution to total UK emissions, as a result of intensive arable and grassland cultivation, predominantly in lowland areas. In Northern Ireland, intensive grassland in the lowlands and domestic peat extraction in the uplands are major sources, and in Wales sources include intensive and extensive grasslands and modified bogs. It was not yet possible to develop an inventory for the large area of peat in the Falkland Islands, but a significant proportion of this area is thought to be modified by grazing, erosion and fire.
- Since 1990, an estimated 95,000 ha of UK peatland have been subject to some form of active restoration intervention, of which around 70,000 ha has involved some form of re-wetting. These activities have occurred in all of the UK administrations, with the majority having taken place in areas of modified blanket bog. Some re-wetting and restoration to peatland vegetation has also occurred in areas of plantation forest, cropland, grassland and peat extraction. In total, these activities are estimated to have generated an emissions reduction since 1990 of 423 kt CO_2e yr^{-1}. It is likely that other unrecorded restoration activities, land-use changes and management activities (for example as part of agri-environment schemes) have had an additional influence on peatland emissions, but available data were insufficient to allow these changes to be reported.
- The emissions estimates obtained during this project represent a major (more than tenfold) increase in the total peat-derived emissions captured in the current UK inventory. This reflects a significant development in the IPCC methodology following publication of the 2013 Wetland Supplement, which allows for more complete reporting of peatland emissions than was previously possible. This new approach by IPCC has led to much more detailed reporting of peatland emissions in the LULUCF inventory, incorporating improved data on peat condition including the extent of peat mapped; peat condition classification and mapping; estimated emission factors; treatment of wasted peats; and methodology applied to forest on peat.
- Future emissions projections to 2050 based on a set of illustrative scenarios suggest that currently legislated peat restoration measures (mainly the phasing out of peat extraction in England) will have limited impact on emissions, but that current levels of ambition on peat restoration in all four countries could deliver over 4 Mt CO_2e yr^{-1} of emissions reductions by 2050. A more ambitious restoration scenario, including removal of 50% of forest planted on peat since 1980, could deliver over 8 Mt CO_2e yr^{-1} of emissions abatement. However none of our scenarios incorporated large-scale cessation of drainage-based agriculture on lowland peat, which (as it accounts for 60% of all current emissions) placed effective limits on the degree of emissions abatement that could be achieved.

In summary, although around 70% of UK peatlands retain some form of semi-natural vegetation cover, over three quarters are in a modified state, ranging from relatively minor changes to vegetation cover and hydrology, through to the complete replacement of wetland vegetation by arable and horticultural crops, agricultural grasses and non-native conifers, with accompanying deep drainage. As a result, UK peatlands have transitioned from modest historical net GHG sinks (an estimated pre-anthropogenic sink, based on 100 year Global Warming Potentials, in the region of 0.25 Mt CO_2e yr^{-1}) into large emission sources (exceeding 23 Mt CO_2e yr^{-1}). The contrast between these two values highlights that the priority for peatland management should be to reduce current high emissions; it is unlikely that so-called 'negative emissions' from peat formation will be able to offset emissions from other sectors.

Widespread and ongoing peat restoration across the UK has contributed to a reduction in total emissions, but to date the majority of restoration has taken place within modified upland bogs, which produce modest emissions sources per unit area, rather than categories with higher Tier 2 emission factors per unit area such as cropland, lowland grassland and plantation forest. Addressing continued emissions from these areas could provide a high degree of emissions abatement, but would face significant logistical and socio-economic barriers. Mitigation measures that reduce emissions from cultivated peatlands without leading to large-scale loss of income to farmers and landowners, or to a decrease in UK food security, thus represent a key scientific and policy challenge. In the meantime, the continued restoration of modified upland bogs, notably higher-emitting categories such as actively eroding areas and heavily degraded former domestic peat cutting sites, may represent more tractable options for emissions reduction.

Whilst many individual components of the peatland emissions inventory remain uncertain, due to limitations in the number of primary measurement studies and difficulties in translating available soils and land-cover data into reliable peat area and condition estimates, the data and methods set out in this report provide the basis for initial inclusion of peatlands in the UK emissions inventory. To support the future development of this inventory, there is a need for new field-scale measurements of GHG fluxes from under-studied peatland types, and for the development of consistent, UK-scale condition mapping and monitoring approaches, potentially based on new earth observation data.

1 INTRODUCTION

Peatlands are a globally important carbon store, holding around one third of all carbon in soils– more than is held in all living vegetation – in just 3% of the land area. In their natural state, peatlands continuously sequester CO_2 from the atmosphere, transferring it into organic matter which can remain stable for millennia provided that waterlogged conditions are maintained. Over the course of human history, however, peatlands have been utilised to provide food, fibre and fuel, processes which commonly involve drainage and which lead to the oxidation and loss of stored carbon. As peatland utilisation has accelerated through the industrial period, and expanded to tropical countries in recent decades, CO_2 emissions from peatlands have increased dramatically, and are now estimated to contribute around 3.5% of all anthropogenic greenhouse gas (GHG) emissions globally (IPCC, 2013). If all of the carbon held in peatlands were oxidised, it would raise atmospheric CO_2 concentrations by approximately 75%, with catastrophic consequences for global climate.

Despite its comparatively small area, the United Kingdom (UK) has a high proportional peat area of around 12% (Bain et al., 2011), and is among the top twenty countries globally in terms of total peat cover (Joosten, 2010). It has particularly large areas of upland blanket bog, a globally rare habitat associated with high-rainfall oceanic regions (Gallego-Sala and Prentice, 2012), of which an estimated 13% of the global total occurs in the UK (Bain et al., 2011). Although blanket bog comprises around 85% of the UK peatland resource, substantial areas of lowland raised bog and fen peat are present in all four UK countries. Further areas of peat occur in a number of the UK's Overseas Territories and Crown Dependencies, notably the Falkland Islands. Large-scale drainage and conversion of lowland peatlands for agriculture in the UK began in the East Anglian Fens in the 17th century, but increased in extent and effectiveness following the establishment of electrical pumped drainage in the 20th century, creating highly productive farmland for arable, horticultural and livestock agriculture in areas such as the East Anglian Fens and Somerset Levels. In the uplands, blanket bogs have been cut for fuel and burned with the aim of enhancing grazing quality for centuries. In the post-war period, large areas were drained and planted with non-native conifer species to increase timber supplies, and many areas of open moorland were drained ('gripped'), often supported by agricultural subsidies. In some areas, land-use activities such as ploughing, grazing, and vegetation burning may have contributed to the onset of peat erosion, while industrial peat extraction for horticultural use continues in many locations. In recent years, recognition of the conservation and ecosystem service value of the UK's peatlands (Smith *et al,* 2013), including their importance as carbon stores, has led to significant investment in restoration of degraded peatlands, notably in the uplands.

The variety and extent of human modification of the UK's peatlands is thought to have caused significant GHG emissions, many of which are ongoing. The UK's inventory of GHG emissions and removals from Land Use, Land Use Change and Forestry (LULUCF) is compiled using methodology laid out by the Intergovernmental Panel on Climate Change (IPCC). The 2006 IPCC Guidelines provided a framework for reporting a limited range of emissions from peatlands, specifically direct CO_2 and N_2O emissions arising from peat extraction activities, and drainage of cropland and agricultural grassland. The 2006 Guidelines allowed the LULUCF Inventory to capture only a small fraction of emissions from UK peatlands, and this estimate was based on limited empirical data. The IPCC methodology for emissions estimation uses Activity Data (usually areas of land in a particular condition for LULUCF emissions) and Emission Factors (EFs) which give emissions per unit of activity. The IPCC regards it as good practice for emissions estimates to relate as closely as possible to local conditions, but recognises that this may not always be possible. Their methodology therefore provides for three Tiers of calculation of increasing complexity. Tier 1 methodology using default EFs provided by IPCC, Tier 2 methodology uses country-specific emission factors based on national data, and Tier 3 methodology uses more complex models to reflect more detailed variation in conditions within a country.

Recognition of the importance of peatlands and other wetlands for global LULUCF emissions led the Intergovernmental Panel on Climate Change to publish a 2013 supplement to their previous (2006) guidelines on emissions reporting (hereafter referred to as the 'Wetlands Supplement') which provided default 'Tier 1' guidance and emission factors to allow calculation of GHG emissions and removals associated with a wider range of drained and re-wetted peatlands. The Wetlands Supplement Tier 1 EFs were based on the best available published data, and classified peatlands into broad climate regions (boreal/temperate/tropical), peat types ('nutrient-rich' fen peat, and 'nutrient-poor' bog peat) and land-use categories. Although a full suite of greenhouse gases were considered, as well as on-site (direct gaseous) and off-site (indirect, e.g. waterborne) emissions, the degree to which emissions could be stratified in relation to peat type and condition was limited both by data availability, and by the need for Tier 1 methods to be sufficiently simple to enable their widespread application. From a UK perspective, key limitations were the absence of any separate treatment of blanket bogs, despite known differences in their ecological function compared to other peatland types, and the lack of Tier 1 emission factors (EFs) for peatlands that had been modified by activities such as draining, burning or grazing, but which retained a 'semi-natural' cover of peatland-associated plant species. The use of a broad 'temperate' climate zone also meant that many of the primary field data used to develop Tier 1 EFs were located in drier continental regions, the applicability of which to the more oceanic conditions of the UK is questionable.

This report describes the implementation of a 'country-specific' Tier 2 emissions reporting approach for UK peatlands, building on the methodology set out in the IPCC Wetlands Supplement, and intended for implementation as part of the overall UK emissions inventory. The following sections describe:

i) The collation and analysis of existing and new measurement data to develop Tier 2 EFs for the broad range of peat condition categories present in the UK;

ii) The development of methods to quantify current status and change in peat condition over the 1990 to 2013 period, based on a new 'unified' map of peat extent for all four UK countries, collated spatial land cover and peat condition datasets, and records of peat restoration and management activities;

iii) The implementation of a first full emissions inventory for UK peatlands; and

iv) The projection of peatland emissions to 2050 for an illustrative set of future management scenarios.

Note that the IPCC Wetlands Supplement also provided outline methods to report emissions from other wetland types, including coastal wetlands and inland wet mineral soils. The potential implementation of reporting for these wetlands types in the UK was considered during the project, but is reported separately as Burden et al. (2016).

2 EMISSION FACTORS

2.1 Method

The IPPC's Tier 1 emission factors (EFs) are based on field data from across the temperate climate zone, including some regions that are climatically or ecologically dissimilar to the UK. The level to which EFs could be stratified was also limited, both by data availability and by the need to develop a generic and easily applicable methodology to support emissions reporting by a wide range of countries. Furthermore, the UK is globally unusual in possessing large areas of peatland (particularly blanket bogs) that have been modified by human activity, but which either remain undrained (e.g. peatlands modified by grazing or burn-management), or retain what can be broadly termed semi-natural vegetation despite the presence of drainage ditches. Since the IPCC Wetlands Supplement made no provision for modified but undrained peatlands, and all drained peatlands were assumed to have been converted to another land-use type (the closest analogous category to drained semi-natural bog being 'drained, nutrient-poor grassland'), it was necessary to develop Tier 2 EF categories to capture the impacts of these important peat condition categories in the UK inventory.

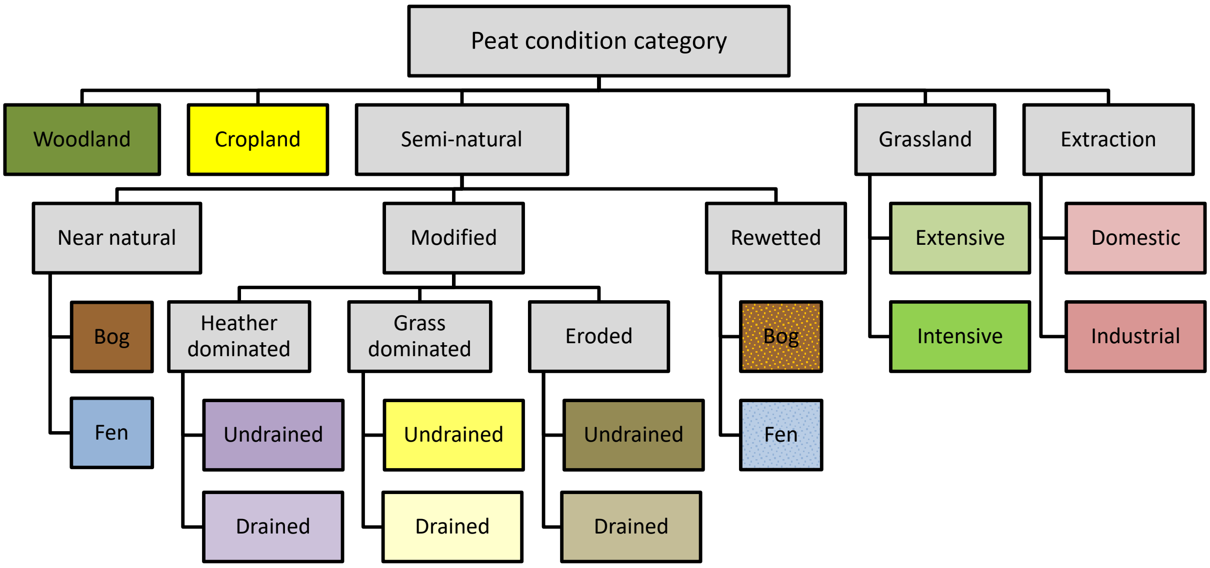

***Figure 2.1**. Final land cover hierarchy used for Tier 2 calculations. Coloured cells have assigned Tier 2 emission factors, grey cells represent higher-level categories encompassing two or more sub-categories. Note that this classification is not considered to be fully comprehensive in that it does not encompass all potential peat condition categories, as some categories either lack widespread representation in the UK (e.g. pristine peatlands) or sufficient measured data to derive a separate EF (e.g.* Molinia*-dominated blanket bog, nutrient-enriched fen). Some categories encompass multiple categories for which separate EFs could not be derived (e.g. conifer and broadleaf woodland). With the exception of the near-natural and re-wetted categories, it was not possible to derive separate EFs for bog and fen peat; see text for details of EF derivation.*

The final classification scheme used for UK Tier 2 EFs is shown in Figure 2.1. This scheme was developed from discussions with BEIS, Defra, the devolved administrations and country conservation agencies, and subsequently refined in order to define condition categories which i) encompassed a sufficient number of field studies to enable a Tier 2 EF to be derived, and ii) were sufficiently well mapped by the various spatial datasets available to the project (See Section 3) to enable activity data to be obtained. To maximise the applicability of the Tier 2 EFs, whilst also aiming to obtain a sufficient number of data points, we constrained the data sources used to climatically similar (humid temperate) regions based on the Köppen-Geiger global climate zone classification (Rubel and Kottek, 2010) and to comparable vegetation types (Figure 2.2).

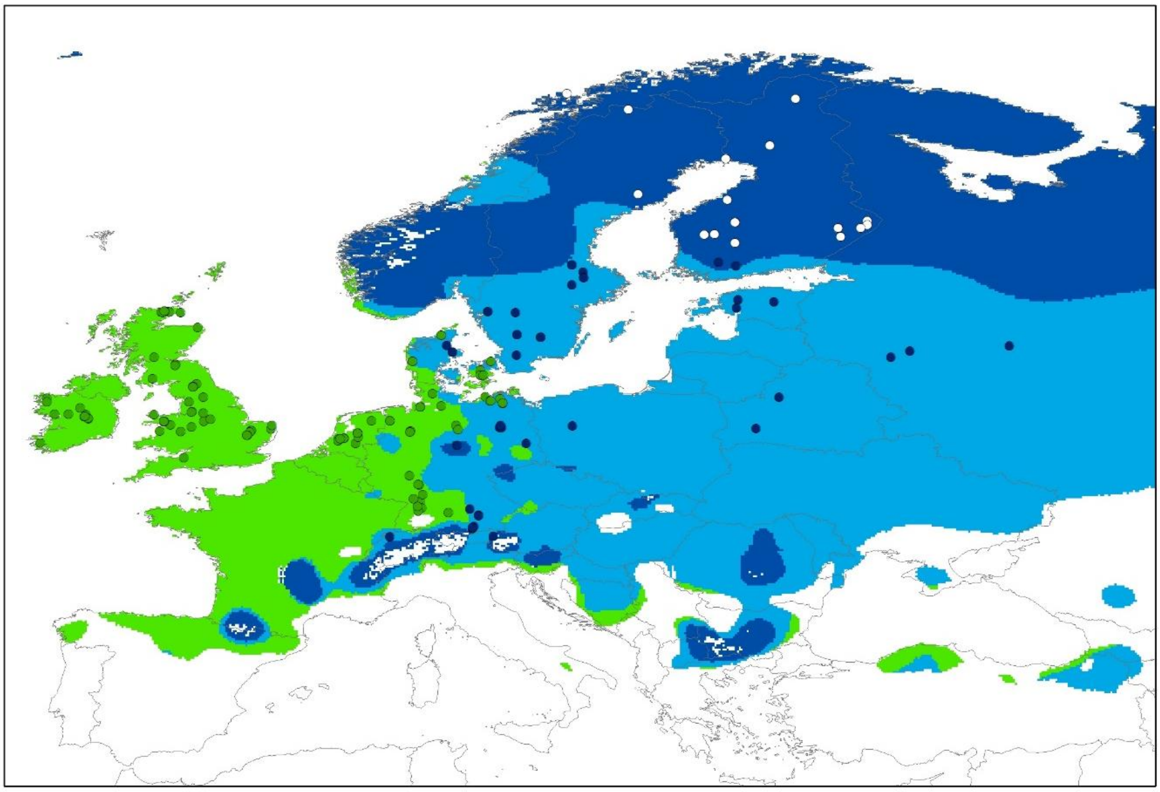

Figure 2.2. *Map of the assignment of climate zones to relevant publications retrieved from the 2013 IPCC Wetlands Supplement Tier 1 calculations, and additional publications since 2013 in this report. Studies were included in the Tier 2 calculations (dark green symbols) if they fell within the light green (oceanic temperate) climate region, and had comparable vegetation. Data from studies in the continental temperate and boreal climate zones (blue and white symbols respectively) were not included. One additional site from New Zealand was also included from outside the region shown.*

The IPCC Wetlands Supplement (IPCC, 2014) provided the base dataset for this analysis, and as many publications cited in this analysis as could be retrieved were used in our analysis. A significant number of new GHG flux studies, especially for drained and re-wetted blanket bogs, have become available since the 2013 publication cut-off date of the Wetlands Supplement, and were included in the analysis based on a combination of literature searches and approaches to individual researchers. In total, 2232 individual observations from 214 sites of direct CO_2, CH_4 and N_2O losses, as well as other emission pathways (such as DOC and POC leaching, and burnt or harvested biomass) from 300 publications were included in the meta-analysis. Data from 68 continental temperate, 29 boreal and a further 7 oceanic sites with vegetation types that would not be relevant to UK blanket bogs were excluded from Tier 2 EF derivations. We also omitted data from subsidence-based or long-term average carbon accumulation-based studies, on the basis that these approaches calculate an average emissions value across timescales of decades and are not therefore necessarily representative of present-day emissions, particularly in sites where management has become more intensive within the last century.

This process resulted in data from a total of 110 'oceanic' sites (1207 individual observations) remaining for analysis. Note that this included 15 UK sites from the recently completed Defra Lowland Peat project (Evans et al., 2017), as well as unpublished data provided by Andreas Heinemeyer (University of York) and Matt Saunders (Trinity College Dublin). Experiments located within the primary sites were treated as nested treatments or microsites/microforms, rather than individual observations. This approach was taken because a large proportion of publications reported fluxes from different peatland microforms within the same peatland body (e.g. hummock, hollow, lawn etc.); experimental plots within the same general geographical area (e.g. burnt versus unburnt); or plots that were geographically close together and hence climatically quite related. This approach weights data from more geographically spread data points more highly than sites close together. For sites with multiple years of observation, we took the long-term average of multi-year observations, but assigned a higher weight to such studies according to the number of years of observation. Finally, all data were coded to the land-use categories shown in Figure 2.1. This was a non-trivial task, due to potential interpretation issues across different countries and inconsistent and/or incomplete descriptions of study sites in different publications, hence we communicated with a small proportion of the authors of publications included in this study to cross-check the classifications used.

The draft Tier 2 emission factor means and their standard errors were estimated using random effects meta-analysis with random effects for the study (primary location) and the site (specific experimental treatment, microsite or vegetation type). In the majority of multi-annual studies, data from individual years were available and this allowed the variation between years within sites to be estimated as well as the variation between sites. However, for some sites only an average value over a number of years was available. In order to allow for this, we used as weights in the analysis the number of years of measurement data contributing to the values, e.g. 1 for a single year observation, and 5 for a 5-year observation. Use of weights in the analysis relates only to the variance contribution from the residual (between years within sites) variance, and is not applied to the contribution from the site effect (i.e. an observation with weight 2 is treated as an average of 2 observations within a site, not an average of 2 observations from different sites). Calculations were performed separately for each land cover *x* emissions class.

The statistical robustness of the draft Tier 2 factors was assessed against Tier 1 values using a relatively simplistic assessment due to the generally low number of observations. Draft Tier 2 values that were calculated from less than four different primary locations were considered too unreliable to replace Tier 1 values. Tier 2 values calculated from at least 4 primary sites and falling outside the 95% confidence interval of the Tier 1 EF were considered to be demonstrably robust enough to replace Tier 1 values. Following consultation with BEIS, Defra and the LULUCF Inventory Scientific Steering Committee, a decision was made to also use Tier 2 EFs (based on sufficient source data) that fell within the 95% confidence interval of Tier 1 values, on the basis that they should nevertheless provide a more realistic estimate of emissions from UK peatlands. This was particularly important for some CH_4 emissions categories, where the 95% confidence intervals on the Tier 1 EFs were extremely wide (e.g. 0 to 856 kg CH_4-C ha^{-1} yr^{-1} for rewetted temperate fen) such that it was effectively impossible to demonstrate significant differences between Tier 1 and Tier 2 values.

2.2 Emission Factors

We were able to derive new Tier 2 EFs for direct emissions of CO_2, CH_4 and (in most cases) N_2O for all of the UK-relevant drained land-use categories in Chapter 2 of the 2013 Wetlands Supplement (forest land, cropland, grassland, and peatlands used for peat extraction), incorporating new and/or region-specific field data. In two cases, grassland and extraction sites, the data could be further disaggregated. For undrained semi-natural peatlands, we also (in contrast to Chapter 3 of the Wetlands Supplement) derived separate EFs for undrained ('near-natural') and re-wetted systems. Categories for which EFs were derived are shown as coloured boxes in Figure 2.1, with one exception: based on the available flux data we were unable to derive separate EFs for heather-dominated and grass-dominated modified bogs (primarily due to a lack of measurements from grass-dominated sites). We therefore derived a single, 'modified bog' EF for each GHG, but retained both categories in our reporting hierarchy in recognition of the importance of (and likely difference in emissions from) these two condition categories of UK bogs, in the expectation that it will become possible to derive separate EFs in the future.

We were not able to identify sufficient new data to refine the existing Tier 1 EFs for the emission of CO_2 associated with fluvial export of DOC, for CH_4 emissions from drainage ditches, or for indirect emissions for N_2O from downstream waterbodies, therefore existing default Tier 1 values for these categories were retained. No Tier 1 EFs were given in the Wetlands Supplement for CO_2 emissions arising from POC losses. However, Tier 2 emissions factors from Evans *et al* (2017) were used in conjunction with the guidance outlined in Appendix 2a.1 of the Wetlands Supplement, which estimates POC loss as a function of the bare peat area associated with each condition category.

Calculated Tier 2 EFs for direct ('on-site') CO_2, CH_4 and N_2O emissions are summarised (relative to the corresponding Tier 1 EFs) in Tables 2.1 to 2.3, and in Figure 2.3. Results are summarised by land-use category in the following sections. The reporting convention is that a positive EF indicates net emissions to the atmosphere, and a negative EF indicates net removal/uptake from the atmosphere. As in the Wetland Supplement, EFs for CO_2 incorporate emissions from both peat and biomass litter (the two are hard to differentiate in most peatland types, and both are captured by measurements). Unlike Tier 3 models, the Tier 2 EFs exclude CO_2 uptake into tree biomass on the grounds that all forest biomass is harvested (and thus its stored carbon is eventually released back into the atmosphere), although this is a simplification. In practice, stumps and brash will be left on site post-harvest, and carbon will be transferred from trees to soil as leaf letter, fine root litter and exudates during the lifetime of the trees. Peat removed from peat extraction sites (which is assumed to be emitted as CO_2) is not considered in this project, but is accounted for elsewhere in the LULUCF GHG inventory.

***Table 2.1**. Tier 1 and Tier 2 emission factors for direct CO_2 emissions (t CO_2-C ha^{-1} yr^{-1}); 95% CI = 95% confidence intervals (CI), n = total number of observations used to derive each Tier 2 EF. Note that a positive EF indicates net emission, and a negative EF indicates net uptake.*

IPCC Tier 1 category	Tier 1	95% CI		UK Tier 2 category	Tier 2	95% CI		*n*
		Low	High			Low	High	
Forest land, drained	**2.6**	2.0	3.3	Woodland	**2.0**	1.7	2.3	*18*
Cropland, drained	**7.9**	6.5	9.4	Cropland	**7.2**	4.0	10.5	*20*
Grassland, drained, nutrient-poor	**5.3**	3.7	6.9	Modified eroded bog	**0.2**	-0.1	0.6	*
				Modified bog	**0.0**	-0.4	0.3	*83*
				Extensive grassland	**3.6**	2.1	5.2	*40*
Grassland, deep-drained, nutrient-rich	**6.1**	5.0	7.3	Intensive grassland	**6.4**	3.7	9.1	*27*
Peatland managed for extraction	**2.8**	1.1	4.2	Extracted domestic	**1.3**	-0.4	3.0	*5*
				Extracted industrial	**1.8**	1.3	2.2	*10*
Rewetted organic soils, nutrient poor	**-0.2**	-0.6	0.2	Rewetted bog	**-0.6**	-1.1	-0.1	*48*
				Near natural bog	**-1.0**	-1.4	-0.5	*16*
Rewetted organic soils, nutrient rich	**0.5**	-0.7	1.7	Rewetted fen	**0.2**	-2.2	2.6	*37*
				Near natural fen	**-1.5**	-3.3	0.4	*9*

**Modified eroded bog EF calculated from modified bog data, with adjustment for bare peat area.*

***Table 2.2**. Tier 1 and Tier 2 emission factors for direct CH_4 emissions (kg CH_4 ha^{-1} yr^{-1}); 95% CI = 95% confidence intervals (CI), n = total number of observations used to derive each Tier 2 EF.*

IPCC Tier 1 category	Tier 1	95% CI		UK Tier 2 category	Tier 2	95% CI		*n*
		Low	High			Low	High	
Forest land, drained	3	-1	6	Woodland	5	2	8	*21*
Cropland, drained	0	-3	3	Cropland	1	0	2	*29*
Grassland, drained, nutrient-poor	2	1	3	Modified eroded bog	48	29	66	*
				Modified bog	55	34	75	*45*
				Extensive grassland	73	18	127	*53*
Grassland, deep-drained, nutrient-rich	16	2	29	Intensive grassland	15	-14	44	*32*
Peatland managed for extraction	6	2	11	Extracted (all)	8	-8	24	*6*
Rewetted organic soils, nutrient poor	123	0	1143	Rewetted bog	81	20	142	*21*
				Near natural bog	113	46	180	*24*
Rewetted organic soils, nutrient rich	289	0	594	Rewetted fen	169	110	229	*34*
				Near natural fen	155	88	223	*11*

***Table 2.3**. Tier 1 and Tier 2 emission factors for direct N_2O emissions (kg N_2O-N ha^{-1} yr^{-1}) ; 95% CI = 95% confidence intervals (CI), n = total number of observations used to derive each Tier 2 EF.*

IPCC Tier 1 category	Tier 1	95% CI		UK Tier 2 category	Tier 2	95% CI		*n*
		Low	High			Low	High	
Forest land, drained	2.5	-0.6	6.1	Woodland	1.4	0.3	2.4	*23*
Cropland, drained	13	8.2	18	Cropland	19.1	6.8	31.5	*25*
Grassland, drained, nutrient-poor	4.3	1.9	6.8	Modified eroded bog	0.1	0.0	0.3	*
				Modified bog	0.1	0.0	0.2	*20*
				Extensive grassland	3.2	0.2	6.2	*16*
Grassland, deep-drained, nutrient-rich	8.2	4.9	11	Intensive grassland	6.0	2.8	9.1	*32*
Peatland managed for extraction	0.3	-0.03	0.64	Extracted (all)	*Insufficient data*			
Rewetted organic soils, nutrient poor	0.0	0.0	0.0	Rewetted bog	0.1	0.0	0.2	*33*
				Near natural bog	0.1	-0.2	0.3	*5*
Rewetted organic soils, nutrient rich	0.0	0.0	0.0	Rewetted fen	*Insufficient data*			
				Near natural fen	0.5	-1.2	2.3	*5*

2.2.1 Forest Land

The UK currently applies a model-based Tier 3 approach to emissions from forest land, based on the CARBINE process model which uses a carbon stock change approach, tracking carbon flows through the forest carbon pools.

Tier 2 data are presented here for completeness, and as a basis for comparison with modelled outputs. These Tier 2 data have been generated using flux data from either chamber or micro-meteorological measurements. Conceptually the balance of carbon fluxes into and out of the peat should be identical to the change in peat carbon stock, however both flux and stock change methods have associated methodological limitations and uncertainties, particularly for managed forests that may be accumulating new carbon into above ground biomass, roots and litter, whilst simultaneously losing old carbon from the peat. GHG flux measurements based on the eddy covariance method tend to aggregate multiple fluxes, including uptake into biomass, making it difficult to determine the true change in peat carbon stock and the associated CO_2 emissions or removals. Flux measurement methods based on chambers generally measure total (heterotrophic plus autotrophic) ecosystem respiration, or soil (heterotrophic) respiration only, by excluding roots. The chamber approach generally needs to be adjusted for above- and below-ground litter inputs in order to obtain an overall peat CO_2 balance, giving large uncertainties and potential biases in some of the source data used.

Overall, the field flux data used to derive both Tier 1 and Tier 2 EFs for forest land are sparse, and additional measurements are needed to reduce uncertainties in both empirically-based (Tier 2) and model-based (Tier 3) EFs for UK woodlands. Flux tower net ecosystem exchange (NEE) data are now being collected at Dyke Forest in Northern Scotland, and Cloosh Forest in Ireland, which should support an update of the Tier 2 EF for CO_2 once published.

> **CO_2**: The IPCC Tier 1 EF for temperate forest is based on rather few data points (a total of eight sites, obtained from four references). We were unable to identify additional UK-relevant data, but excluded sites from outside the oceanic temperate climate region, and applied a slightly different analytical approach by treating different measurement locations in the same geographic area as nested, rather than independent, sites. We also took account of the fact that all source studies used static chamber methods to measure total below-ground respiration, which comprises both heterotrophic (peat-derived) and autotrophic (root-derived) respiration, by assuming that the heterotrophic respiration comprised 50% of the total measured flux (e.g. Ojanen *et al*., 2010). The resulting CO_2 EF (Table 2.1, for 'woodland' according to the agreed hierarchy shown in Figure 2.1) was slightly lower than the Tier 1 value, although still indicative of significant CO_2 emission. The incomplete treatment of litter cycling (as was also the case for the IPCC Tier 1 values) may have led to a positive bias in the Tier 2 EF. On the other hand, the only study of long-term changes in peat carbon stock under forest (Simola et al., 2012), which was based on multiple sites in Finland, arrived at a mean CO_2 emission of 1.74 t CO_2-C ha^{-1} yr^{-1}, close to our Tier 2 estimate. Some of the sites in this study were in afforested areas which not forested at the start of the study (similar to most UK forest on peat which was planted on treeless areas during the last century), and some sites were in existing semi-natural peatland forest which was drained to improve tree growth (an infrequent occurrence in the UK).

> **CH_4**: Application of the same approach generated a slightly higher Tier 2 EF for CH_4 compared to the Tier 1 value, but with closely overlapping confidence intervals. Fluxes were comparatively low in both cases, reflecting the drained status of afforested peatlands.

> **N_2O**: The Tier 2 EF was slightly lower than the corresponding Tier 1 value, and the 95% confidence interval was narrower, suggesting that this represents a more robust estimate of emissions.

2.2.2 Cropland

All cropland EFs were recalculated through the exclusion of non-oceanic sites and the addition of a significant number of additional studies published since 2013.

> **CO_2**: The Tier 2 EF was very close to (albeit slightly lower than) the Tier 1 value (Table 2.1, Figure 2.3) and can be considered robust given the number of observations. It is not currently possible to differentiate cropland EFs with respect to peat type, arable versus horticultural use or drainage depth, but work on the Defra Lowland Peat Project (which contributed to this assessment) does suggest that agricultural land with a higher mean water table is likely to have lower CO_2 emissions (Evans et al., 2017) as has also been suggested by previous analyses (e.g. Couwenberg et al., 2011).

> **CH_4**: The Tier 2 EF for cropland is close to zero, consistent with the Tier 1 EF. The Tier 2 value has a reduced uncertainty range, and can be considered reasonably robust given the number of data points used. It should be noted that all but one of the data points for cropland were from fen-type peatlands. The oligotrophic nature of the UK's upland bogs generally makes their use as cropland unprofitable, but large areas of lowland raised bog in England have been converted to cropland. The one site for which an EF could be calculated (an arable site in the Manchester

Mosses) had similar CH_4 emissions to sites on drained fen peat. For Scotland, cropland on blanket bog or raised bog comprises a very small area. Hence, although our Tier 2 value is largely reliant on data from fen peats, it is considered also applicable for the smaller area of cropland on bog peat.

N_2O: The Tier 2 EF for cropland was the highest recorded for any of the land-use categories considered, consistent with high levels of fertiliser application to arable land. The Tier 2 value also exceeded the Tier 1 default by around 50%, although the uncertainty ranges are wide in both cases, and overlap. It is likely that variations in N_2O emissions among cropland sites reflect fertiliser regimes, crop types and water table depth (e.g. Couwenberg et al., 2011), suggesting that a Tier 3 approach may be more appropriate in future.

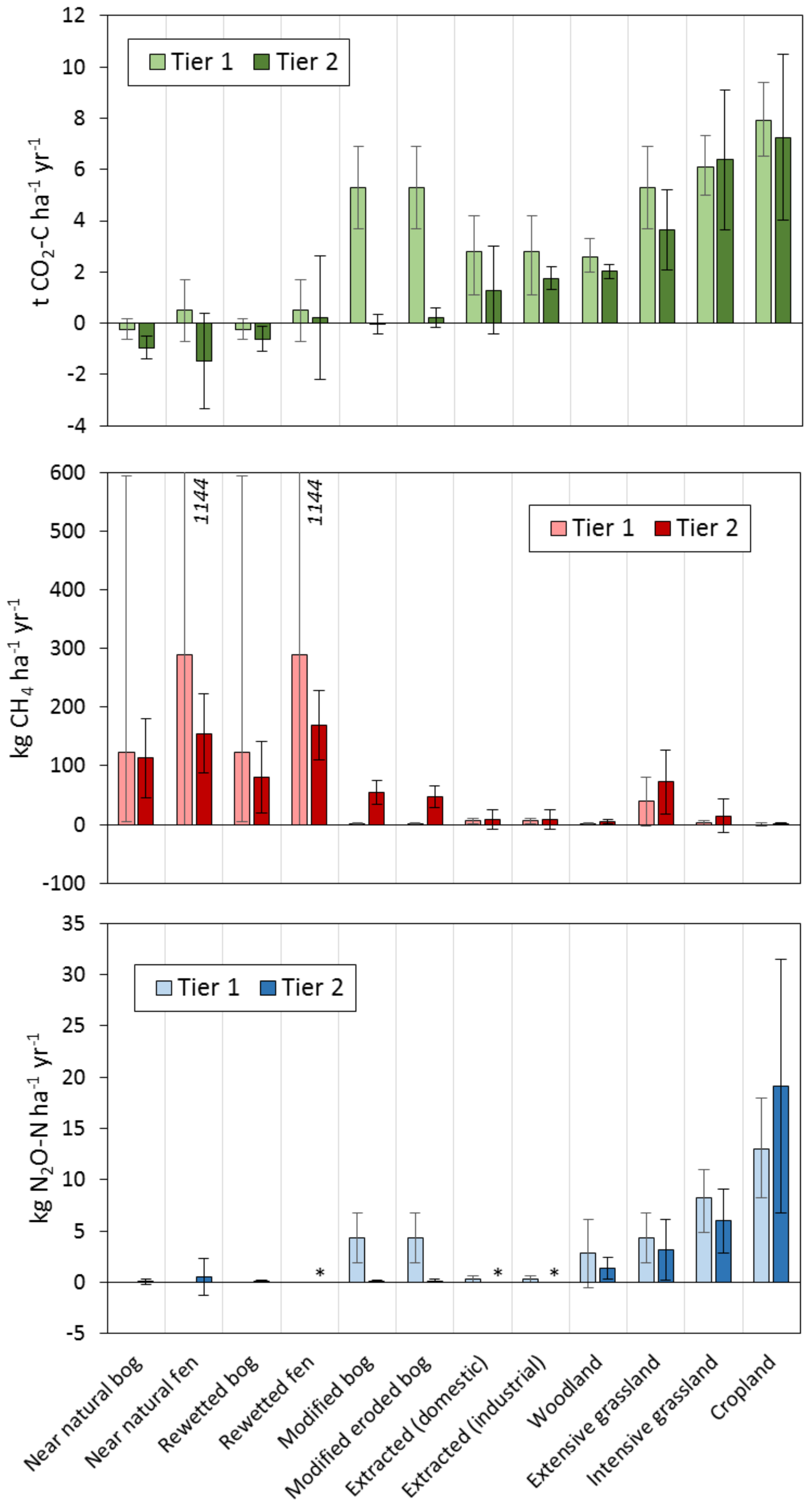

Figure 2.3. *Tier 1 and Tier 2 Emission Factors for direct emissions of CO_2-C, CH_4 and N_2O-N. Error bars show 95% confidence ranges. Asterisks indicate that there were insufficient data to derive a Tier 2 EF. Note that a positive EF indicates net emission, and a negative EF indicates net uptake.*

2.2.3 Grassland

The IPCC 'grassland' category currently encompasses a very wide range of UK habitats on peat, from near-natural peatlands to high-intensity fertilised grasslands. However the Tier 1 EF data presented under the drained grassland categories of the Wetlands Supplement essentially only represent drained agricultural grasslands, whilst undrained bog and fen habitats are only represented by the 're-wetted' Tier 1 EFs. Semi-natural peatland habitats that have been affected by drainage or other human activities such as burning for vegetation management were not captured by the Tier 1 EFs, but are clearly important in a UK context. In this section we summarise the Tier 2 EFs derived for 'agricultural' grasslands, i.e. those grassland categories that are represented in the Wetlands Supplement. Near-natural, modified and re-wetted semi-natural peatlands are considered in subsequent sections.

The deep-drained and shallow-drained grassland categories used in the Wetlands Supplement broadly correspond to intensive grassland (fertilised, ploughed and re-seeded, high-density grazed or hay-cropped) and extensive grassland (unfertilised permanent grassland, lower-density grazed or hay-cropped). Since drainage depth cannot be mapped directly from available data, we defined agricultural grasslands as either 'intensive' or 'extensive' on the basis that these grassland types can be differentiated in most UK land cover surveys, thereby providing a better connection between the EFs and the associated activity data (see Section 3). Both grassland categories can theoretically occur on both fen ('nutrient-rich') and bog ('nutrient poor') peat types, but intensive grassland is more common on fen peat, and extensive grassland more common on bog peat. Since it was rarely possible to map grassland on bog and fen peat separately based on available spatial data (see Section 3) we aggregated all emissions data to produce a single Tier 1 EF for all extensive grassland, and one for all intensive grassland.

CO_2: The Tier 2 EF for extensive grassland was around one third lower than the Tier 1 EF for the closest analogous category in the Wetlands Supplement (grassland, drained, nutrient-poor) although the confidence intervals overlap. Since the Tier 1 value did not differentiate sites by grassland type or drainage depth, and includes sites from a broader range of climatic conditions, the Tier 2 EF is considered more representative for UK extensive grasslands on peat. For intensive grasslands, the Tier 2 EF was almost identical to the Tier 1 EF for deep-drained, nutrient-rich grassland. Although the difference is small, the Tier 2 EF has been adopted because it is considered to be more representative of UK conditions.

CH_4: The Tier 2 EF for extensive grassland was much higher than the Tier 1 value for drained nutrient-poor grassland. Although the uncertainty range was very wide for the Tier 2 value, it did not overlap with the Tier 1 range. The Tier 2 EF was similar to that obtained for modified bog, and may reflect the inclusion of relatively poorly-drained, extensive grassland sites from the oceanic climate zone in the Tier 2 dataset, whereas the Tier 1 values (which as noted above were not defined in the same way, being based on peat type rather than land-use intensity) incorporated more efficiently drained agricultural grasslands from areas with a continental climate. Again, it is likely that this EF will vary within the extensive grassland category as a function of mean water table and other factors. For intensive grassland, the EF obtained was again very similar to the Tier 1 EF for deep-drained, nutrient-rich peat, suggesting that these categories are broadly analogous.

N_2O: The Tier 2 EF for extensive grassland was 25% lower than the Tier 1 EF for drained nutrient-poor grassland, with both estimates having wide (overlapping) uncertainty ranges. The Tier 2 EF for intensive grassland was also 25% lower than the Tier 1 EF for deep-drained, nutrient-rich grassland. This could suggest that typically wetter UK climate conditions result in slightly lower N_2O emissions than those typically observed in continental grasslands, although uncertainty ranges are wide in all cases and (as for cropland) probably reflect local variations in agricultural management.

2.2.4 Modified semi-natural peatlands

Perhaps surprisingly, we were unable to derive EFs specific to drained peatlands under semi-natural vegetation, in part because hardly any flux estimates have been published for these systems, and in part because drainage generally coincides with a change in vegetation composition, making these factors difficult to disentangle. We therefore classified modified peatlands into three categories based on their land-cover characteristics: heather-dominated, grass-dominated and eroded. Heather-dominated bogs typically occur as a result of some degree of drying, and/or burn-management. 'Grass-dominated' bogs have a high cover of graminoid species, such as *Molinia caerulea* and *Deschampsia flexuosa*, or sedges such as *Eriophorum,* and a low cover of peat-forming mosses. They are often associated with a higher intensity of grazing, may be burn-managed (currently or historically), and may or may not be drained. Modified bogs were categorised as 'eroded' where they contain significant areas of bare, gullied or hagged peat.

Whilst there are strong mechanistic reasons to expect differences in CO_2 and CH_4 emissions between these different categories, in practice we were unable to derive different Tier 2 EFs directly from measured flux data for each category, again due to an insufficient number of published studies. Specifically, although a large number of data exist for heather-dominated modified bog, far fewer data are available for graminoid-dominated areas, and we were therefore obliged to assign a single set of EFs for these two categories. They have nevertheless (as noted above) been treated separately in terms of activity data assessments and inventory implementation, to facilitate separate reporting of these two important categories in future, should new data allow separate Tier 2 EFs to be derived. We were also unable to unequivocally assign any literature values to the modified eroded bog category, and therefore derived Tier 2 EF estimates by assuming that eroded peatlands comprised 85% heather-modified bog (as above) and 15% bare peat surfaces. The bare peat component of the EF was obtained from the peat extraction site category (see below).

CO_2: For modified bog as a combined category, a substantial number of measurements were available from a range of primary sites, most of which were again from heather-dominated areas. The resulting Tier 2 EF was therefore considered fairly robust for these areas, but its applicability to grass-dominated areas remains uncertain. The Tier 2 EF was approximately zero, implying that modified bogs retaining a semi-natural vegetation cover are (on average) in approximate balance with regard to direct CO_2 exchange with the atmosphere (although they are net carbon sources once fluvial C loss and CH_4 emission are included). This result is in stark contrast to the large positive EF for the closest analogous Tier 1 category, drained nutrient-poor grassland. The much lower Tier 2 EF is consistent with the continued presence of native peatland species, and relatively shallow water table, in most modified UK peatlands, particularly upland blanket bogs. In contrast, the Tier 1 EF was based exclusively on lowland peat sites, primarily in Germany and the Netherlands, where bog species have been largely replaced by 'true' grassland species, and sites are subject to active agricultural management. Our results confirm that this Tier 1 EF is not applicable to the large areas of UK modified bog, and support the application of a Tier 2 approach. Including emissions from bare peat areas (assuming 15% bare peat cover in areas mapped as 'eroded') was sufficient to give a small positive Tier 2 EF for eroded modified bog.

CH_4: The Tier 2 EF for modified bog was based on a large number of studies that were not part of the Tier 1 calculations, and was considered reasonably robust. The Tier 2 EF was much higher than the equivalent Tier 1 value, reflecting the marked differences between sites used to calculate the two values. The Tier 2 EF is considered ecologically plausible because many modified bogs retain a near-surface water table, and considerable sedge cover, which can lead to high CH_4 emissions (e.g. Cooper et al., 2014). It is lower than the Tier 2 EFs for near-natural and re-wetted bog (see below), which is consistent with some degree of drainage impact. Although CH_4 emissions might be expected to be greater for sites with a higher graminoid (particularly sedge) cover, we were unable to detect clear differences between grass-dominated and heather-dominated sites from available data. For eroded sites, the inclusion of low CH_4 emissions estimates for bare peat areas resulted in a slightly lower overall Tier 2 EF.

N_2O: As for CH_4, a considerable amount of new data was used to develop the Tier 2 EF for N_2O emissions from modified bogs. The resulting EF was very low, with a confidence range that spanned zero, and far lower than the Tier 1 EF for drained grassland on bog peat. Again, this highlights the dissimilarity of UK modified bogs compared to the agricultural grasslands used to derive the Tier 1 EF for the category into which they fall. The Tier 2 EF for eroded modified bog was largely unchanged from the value for uneroded modified bog.

2.2.5 Near-natural and re-wetted peatlands

In the IPCC Wetlands Supplement, data from natural (undrained) and re-wetted sites were combined to produce a single set of Tier 1 EFs for re-wetted bogs and fens, based on an analysis suggesting that GHG fluxes for the two groups of sites were not significantly different (see Annex 3A.1 of IPCC, 2014). The IPCC's 'managed land proxy' approach requires that emissions from natural lands should not be reported, and thus Tier 1 EFs for undrained peatlands were not included in the Wetlands Supplement. However, because the UK inventory treats the entire land area as managed, it is necessary to account for fluxes from 'near-natural' areas, and we therefore differentiated these from re-wetted sites in our Tier 2 calculations. We were also able to add a substantial number of new (mostly UK) studies to the dataset used.

CO_2: For re-wetted bogs, our Tier 2 EF was slightly more negative than the Tier 1 value, with only slight overlap between confidence intervals. Whilst both EFs suggest that re-wetted bogs act as net CO_2 sinks (at least in terms of direct gaseous exchange), the more negative Tier 2 value, based on a large number of data points, suggests that re-wetted UK bogs can act as reasonably effective CO_2 sinks. It is important to note that our analysis excluded sites that had been re-wetted to the extent of causing surface inundation, and that it therefore assumes that re-wetting has been 'successful'. For re-wetted fens, on the other hand, the Tier 2 EF was marginally positive, albeit lower than the Tier 1 value, and had a wide confidence interval. Thus both the Tier 1 and Tier 2 EFs suggest highly variable outcomes from fen re-wetting, from successful reinstatement of significant CO_2 uptake, through to large ongoing CO_2 emission. Given the intrinsic complexity of fen peatlands, as well as the often severe level of past modification, this variability of outcome is not surprising, and emphasises the importance of effective restoration measures. It is also possible that the general bias of flux measurement studies towards recently re-wetted sites may be providing a somewhat pessimistic prediction of the long-term CO_2 balance of re-wetted peatlands. However an analysis of measured CO_2 fluxes versus time since re-wetting (up to 50 years for bogs, and 16 years for fens) showed no evidence of any relationship, suggesting that factors other than time since re-wetting alone are important in determining restoration outcomes.

For both near-natural bogs and near-natural fens, the Tier 2 EFs were strongly negative, consistent with the expectation that – in their relatively undisturbed state – both peat types should be active carbon sinks. The uncertainty range for near-natural bogs does not cross zero, implying that this sink function is consistent, whereas the broader uncertainty range for near-natural fens does include small positive fluxes, which could suggest that some 'near-natural' areas have been detrimentally impacted by land-use, either directly or via human impacts on the surrounding land, for example a reduction in water flow into the fen, or pollution of inflowing water by agricultural nutrients. Nevertheless, the strong net CO_2 sink indicated by the average Tier 2 EF for near-natural fens is in strong contrast to the positive Tier 1 EF for re-wetted fens. This resulted from the inclusion of new eddy-covariance based CO_2 flux estimates from a number of near-natural UK peatlands (Evans et al., 2017), as well as a careful screening of the other literature data based on vegetation descriptions (notably the large number of sites described in the German-language report by Drösler et al., 2013), to ensure that substantially modified sites were excluded. Clearly, it is mechanistically more reasonable to expect near-natural fens to be net carbon sinks.

CH_4: The Tier 2 analysis for CH_4 also utilised a significant number of additional data sources, and again data were split into near-natural and re-wetted categories. Our Tier 2 EFs for both re-wetted and near-natural bogs are lower than half the corresponding Tier 1 value, and have a greatly reduced uncertainty range. One factor that contributed to the lower and less variable Tier 2 values was the exclusion of studies that were affected by seasonal or continuous inundation, many of which had extremely high observed CH_4 emissions (e.g. Vanselow-Algan et al., 2015). The Tier 2 EFs are therefore not applicable to sites affected by inundation, which is generally considered an undesirable long-term outcome from a restoration perspective, although it may help to facilitate initial *Sphagnum* establishment. The Tier 2 EF for re-wetted bog was slightly lower than that for near-natural bog, which is somewhat surprising in light of the expectation that emissions may peak during the immediate period after re-wetting (e.g. Cooper et al., 2014), however this expectation was not borne out in our dataset. The high degree of overlap between the two Tier 2 EFs suggest that, in reality, re-wetted and near-natural bogs may have similar CH_4 emissions.

For fens, the Tier 2 EFs for re-wetted and near-natural areas were very similar, consistent with the assessment in the IPCC Wetlands Supplement, but both Tier 2 EFs were lower than the equivalent Tier 1 value. Again, uncertainty ranges were considerably reduced, in part due to the exclusion of sites affected by inundation.

N_2O: The Tier 2 EFs derived for both re-wetted and near-natural bog were extremely low, and the uncertainty ranges intersected zero in both cases, consistent with the zero flux assumed at Tier 1. A Tier 2 EF could only be derived for near-natural fen (not re-wetted fen) which gave a small positive emission, but this was based on very few data points, and had a wide uncertainty range spanning zero. Some N_2O emission is nevertheless plausible, given the impact of agricultural nutrient pollution on many surviving semi-natural fens in the UK.

2.2.6 Peatlands managed for extraction

A relatively high proportion of the IPCC Wetlands Supplement emissions dataset for peat extraction sites was derived from studies carried out in boreal and continental temperate regions (such as Finland and Canada) which were not applicable to the UK's oceanic temperate conditions. However a number of new data sources were available from the UK and Ireland (described in Wilson et al., 2015), and we also augmented the dataset with flux measurements made on bare peat in eroding areas, on the basis that these areas may be considered functionally similar to extracted bare peat areas. For CO_2 emissions, it was possible to split observations for extraction sites into those from industrially cutover sites and those from domestic (manual) extraction. Both categories included data from sites at which active extraction had ceased, but where no active restoration had taken place. Sites where re-wetting had taken place were excluded, even if the peat surface remained bare at the time of measurement.

CO_2: Reasonably robust EFs could be calculated for both domestic and industrial extraction sites. The Tier 2 EF for domestic extraction sites was lower than that for industrial extraction sites, consistent with the differing level of associated disturbance. Both Tier 2 EFs were considerably lower than the combined Tier 1 value, and whilst the 95% confidence intervals overlapped, the upper 95% confidence limits were similar to (domestic) or lower than (industrial) the Tier 1 mean. The data suggest that CO_2 emissions from UK extraction sites are lower than those from the more continental extraction sites used to derive the Tier 1 value. This is consistent with the findings of Wilson et al. (2015), based on largely the same primary data.

CH_4: After excluding continental temperate and boreal extraction sites, the CH_4 dataset for UK-relevant extraction sites was relatively small, and it was not possible to separate domestic and industrial extraction sites. The Tier 2 EF was similar to the Tier 1 value, with a wider uncertainty range, and the two values were not significantly different.

N_2O: A Tier 2 EF for extraction sites could not be calculated due to insufficient data following application of our exclusion criteria (all Tier 1 values were from non-oceanic sites and no new data could be identified). Thus, continued use of Tier 1 values is suggested.

2.3 Discussion

The analysis of emissions measurements from UK-relevant climatic regions and peat condition categories, together with the addition of data published since the 2013 IPCC Wetlands Supplement, has allowed a set of Tier 2 EFs to be developed for UK peatlands. In some cases these are significantly different to the Tier 1 values, and with few exceptions the Tier 2 EFs for CO_2 and N_2O were lower than the Tier 1 values, as were the Tier 2 EFs for CH_4 from re-wetted bogs and fens. The reasons for this are not known; they could reflect the more restrictive (cooler and wetter) climatic range from which the UK-relevant Tier 2 data were drawn, or potentially differences in analytical approach and the treatment of outliers.

The most striking differences compared to Tier 1 values arose for modified bogs under semi-natural vegetation, which are extensive in the UK but not represented in the Tier 1 analysis. The modified bog Tier 2 EFs for CO_2 and N_2O are far lower than the closest comparable Tier 1 category (drained nutrient-poor grassland) whereas Tier 2 EFs for CH_4 are higher. We were also able to define separate Tier 2 EFs for near-natural peatlands (indicating net CO_2 uptake in both bogs and fens, unlike the Tier 1 EFs which were based on a combination of natural and re-wetted sites) and to disaggregate CO_2 EFs for domestic and industrial extraction sites. The inclusion of these additional subcategories provides consistency with the classification framework developed in collaboration with the country agencies (Figure 2.1) and with other assessment approaches, notably the UK Peatland Code (Smyth et al., 2015).

More generally, we recognise that data availability limits the statistical robustness of some of the numbers obtained, and in many cases (particularly for CH_4, where uncertainty ranges for some Tier 1 EFs are very wide) it would be difficult, if not impossible, to demonstrate statistical difference between Tier 1 and Tier 2 estimates. Nevertheless, we consider that in most cases it is justifiable to move to a Tier 2 reporting approach for on-site CO_2, CH_4 and N_2O emissions, since in all cases the data are based on the most representative data currently available for the climatic conditions and management activities affecting UK peatlands. For off-site CO_2 emissions resulting from waterborne DOC and POC export, the existing Tier 1 guidance presented in the main text and appendices of the Wetlands Supplement (which incorporated a large body of UK data) remains largely applicable, although recent data from lowland fen sites (Evans et al., 2017) suggest that DOC export from drained fens may be lower than the Tier 1 values, which were derived largely from studies in bogs. Conversely, POC exports from rapidly eroding upland blanket bogs may be higher than the current estimates for eroded bogs as a whole, but more data are required to determine this. We were unable to identify sufficient new data to move beyond the current Tier 1 approach to estimate CH_4 emissions from ditches, but again new measurements from UK lowland peatlands suggest somewhat lower – but highly variable – ditch CH_4 emissions versus the Tier 1 defaults. Conversely, new data from ditches in rewetted sites (Evans *et al*, 2016) suggest that emissions continue to be higher than adjacent land areas even after drains have been blocked. This represents a significant gap in knowledge, because Tier 1 methodology currently assumes emissions from ditches are identical to those from the land surface after rewetting activities.

The analysis undertaken highlighted a number of key data gaps and uncertainties. All EFs for woodland are based on a relatively small number of measurements, as are those for some individual EFs in other categories. We were unable to differentiate emissions from heather-dominated and grass-dominated modified bogs, largely due to a lack of studies focusing on the latter. Furthermore, an insufficient number of studies specifically recorded the impact of drainage or managed burning on blanket bog, such that it was only possible to categorise sites based on vegetation characteristics which (although they reflect management) are not exclusively associated with a particular management activity. The relatively coarse categorisation of upland blanket bogs will limit the extent to which the effects of some upland management and restoration activities can be captured in the current UK emissions inventory, but is a fair reflection of the dearth of empirical data on GHG fluxes from blanket bog across the full range of vegetation and condition types.

Some similar constraints arose for other peatland types. In particular, insufficient data were available to develop EFs for modified fen peatlands remaining under semi-natural vegetation, and in any case the available spatial data rarely allowed fen and bog peat to be separately mapped (see Section 3). Similarly, emissions data and activity data limitations meant that we could only derive a single Tier 2 EF for extensive grasslands (regardless of underlying peat type). The same situation arose for intensive grasslands.

An assessment of the main sources of uncertainty in the overall inventory is provided in Section 4.

3 ACTIVITY DATA

The following section summarises methods and datasets used to derive activity data layers for use in the peatland inventory, which were described more fully in the detailed reports on baseline peat and land cover mapping and on quantifying activity changes since 1990.

3.1 Peat base map

Compiling a consistent base map of UK peatlands presented a significant challenge. Although several national soils maps exist, all have limitations with regard to their resolution, classification system or spatial extent. For inventory reporting, the use of mixed soil polygons ('associations') in lower resolution national maps is problematic, because it is necessary to know the actual location of the peat in order to overlay land cover or other spatial data relating to peat condition. We therefore aimed to produce a harmonised map of peat extent for each UK country, and for the CDs and OTs with the greatest peat extent (the Isle of Man and Falkland Islands respectively), using the best available spatially explicit data on peat extent in each case. We adhered to national peat depth definitions (40 cm in England and Wales, 50 cm in Scotland and Northern Ireland) although in practice the accuracy of peat mapping data makes this distinction somewhat immaterial. The definition of peat used included all areas that currently meet these criteria, as well as areas of former deep peat that have been partly lost through agricultural activity (so-called 'wasted' peats) where these areas have been separately mapped.

Soils with a peaty organic horizon over mineral soil (often confusingly referred to as 'shallow peats' or 'peaty soils') were not included. These organo-mineral soils are very extensive in the UK, covering a large part of the uplands, but do not meet national definitions of peat as they are either shallower than true peat or have a lower carbon density and in most cases are not thought to have ever been peat (i.e. they are not wasted former deep peat). They differ from true peat in important respects with regard to their hydrology and carbon cycle, and are subject to different land-use pressures. Organo-mineral soils with a gleyed mineral horizon meet the IPCC Wetlands Supplement's definition of Inland Wet Mineral Soils, but have not been the focus of the current project. A separate report from this project on non-peat wetland types (Burden et al., 2016) gives a preliminary analysis of emissions from management of non-peat wetlands in the UK. The approaches used to derive a harmonised peat map for each country are described in the following sections. Total estimated peat areas are recorded in Table 3.1

An overview of the methodology used for peat mapping is given in Appendix 3.

3.1.1 Scotland

Mapping peat in Scotland is hindered by a lack of high resolution data. The 1:250,000 Soils of Scotland (James Hutton Institute, JHI) dataset provides complete coverage, but smaller areas of peat soils amongst other organic soil types are mapped as mixed polygons, for which the proportion of peat is estimated as a separate attribute (it is this proportion of peat that has been used in the calculation of the area of peat soils in Scotland; Chapman et al., 2009). The exact location of the peat within each polygon cannot be extracted from the 1:250,000 dataset. The other national scale mapping dataset available is the British Geological Survey (BGS) 1:50,000 scale Geological Map of Great Britain, also known as DiGMapGB-50 (British Geological Survey, 2011; Lawley, 2011). We combined these two datasets as a first attempt to produce a harmonised peat map for Scotland, which showed good congruence in the locations and extent of larger peat deposits, as well as some smaller lowland peatlands, but showed less agreement in more mountainous areas, where the JHI map records large numbers of mixed polygons containing peat that are not mapped by the BGS dataset. For mixed polygons, we used a digital terrain model to estimate local slope, and assumed that the peat present in each polygon would occupy those areas with the lowest slopes. Following consultation with soils experts and project partners, as well as interrogation of the National Soils Inventory data on the ranges of slopes on which peat occurred, we assigned a maximum slope cut-off of 15%. A comparison of the combined, slope-limited JHI/BGS peat map with the peat point locations in the National Soils Inventory of Scotland (NSIS, Phase I) suggested that the approach was around 68% accurate at predicting the actual locations of peat and 84% accurate at predicting areas without peat. This represents a considerable improvement on the accuracy provided by either of the individual source maps (82 and 40% accurate at predicting peat locations, and 74 and 96% accurate at predicting non-peat locations, respectively, for the 1:250,000 JHI map and the 1:50,000 BGS map), and is the first 'unified' map of peat presence/absence (as opposed to probability of occurrence) ever produced for Scotland. The total mapped peatland area for Scotland was 1,947,750 ha.

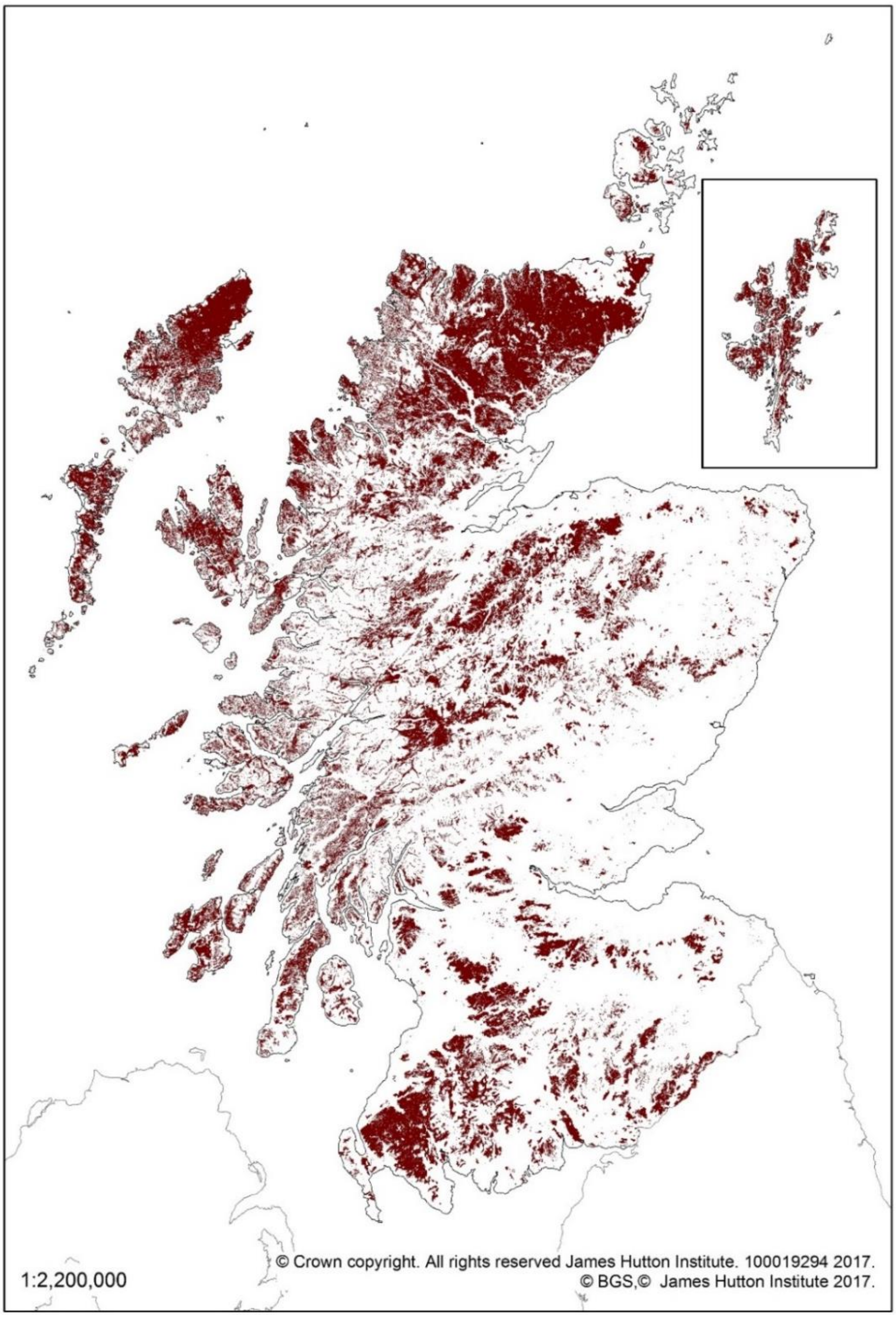

Figure 3.1*. Scotland peat base map*

3.1.2 England

A unified base map from the BGS and NSRI was already available for this project, based on previous work by Natural England, and was used as received. As described above, deep and 'wasted' peats were included in the inventory, but organo-mineral soils were not. The total area of mapped peat in England was 682,230 ha, of which 495,858 ha was deep peat, and 186,372 ha wasted peat (Figure 3.2)

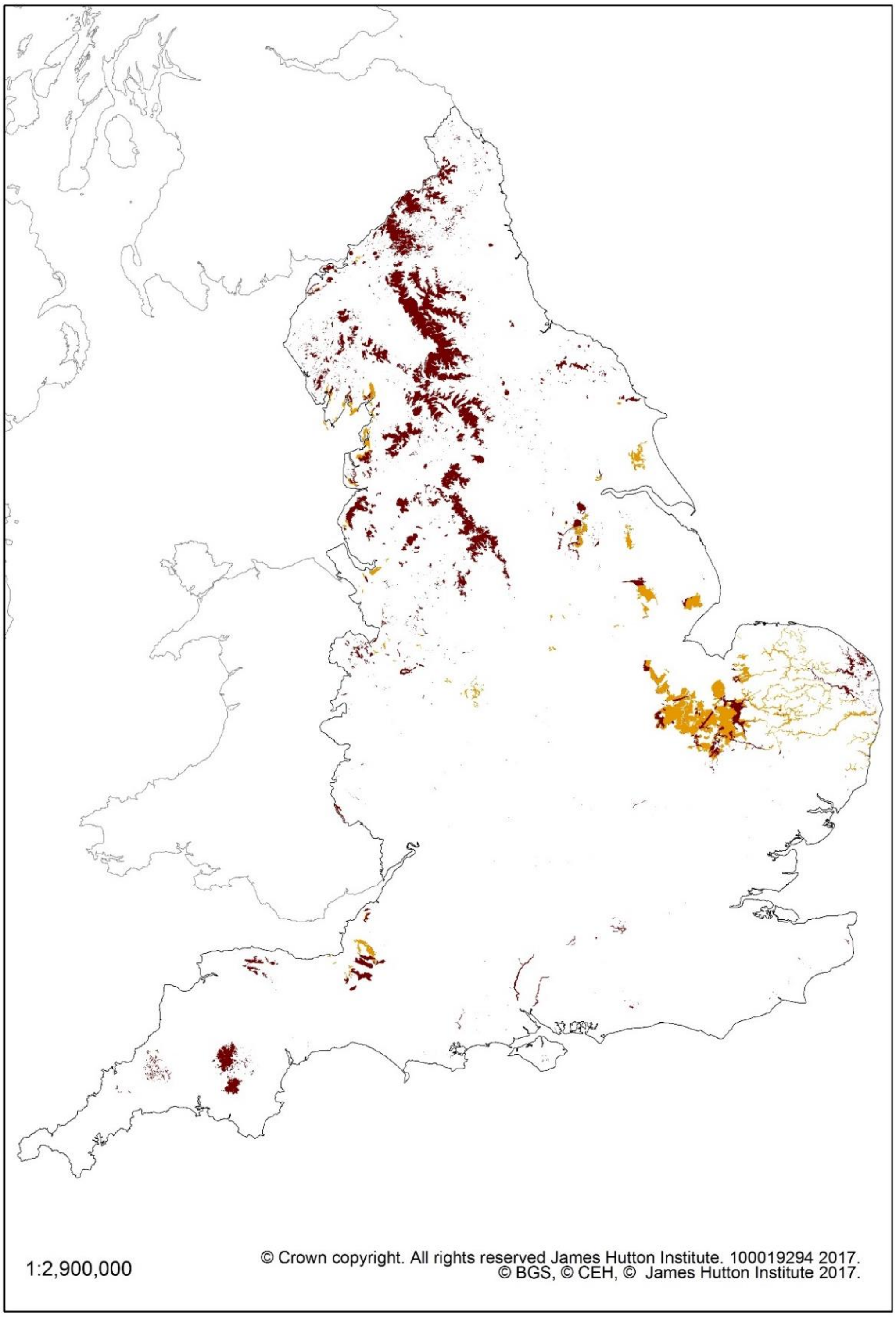

***Figure 3.2**. England peat base map (deep peats shown in brown, wasted peats in orange)*

3.1.3 Wales

A unified peat base map for Wales was developed in a previous project for the Welsh Government (Evans et al., 2014, Figure 3.3). This map is based on combination of peat areas recorded 1:50,000 BGS superficial geology dataset, and a range of survey data held by Natural Resources Wales (NRW), comprising the Lowland Peat Survey, peat-associated habitat categories recorded in the Phase I survey, and soil surveys undertaken by the former Forestry Commission Wales. The map gives a total peat area of 90,050 ha, and appears more effective at capturing smaller peat units, particularly in lowland areas, than previous assessments (e.g. JNCC, 2011).

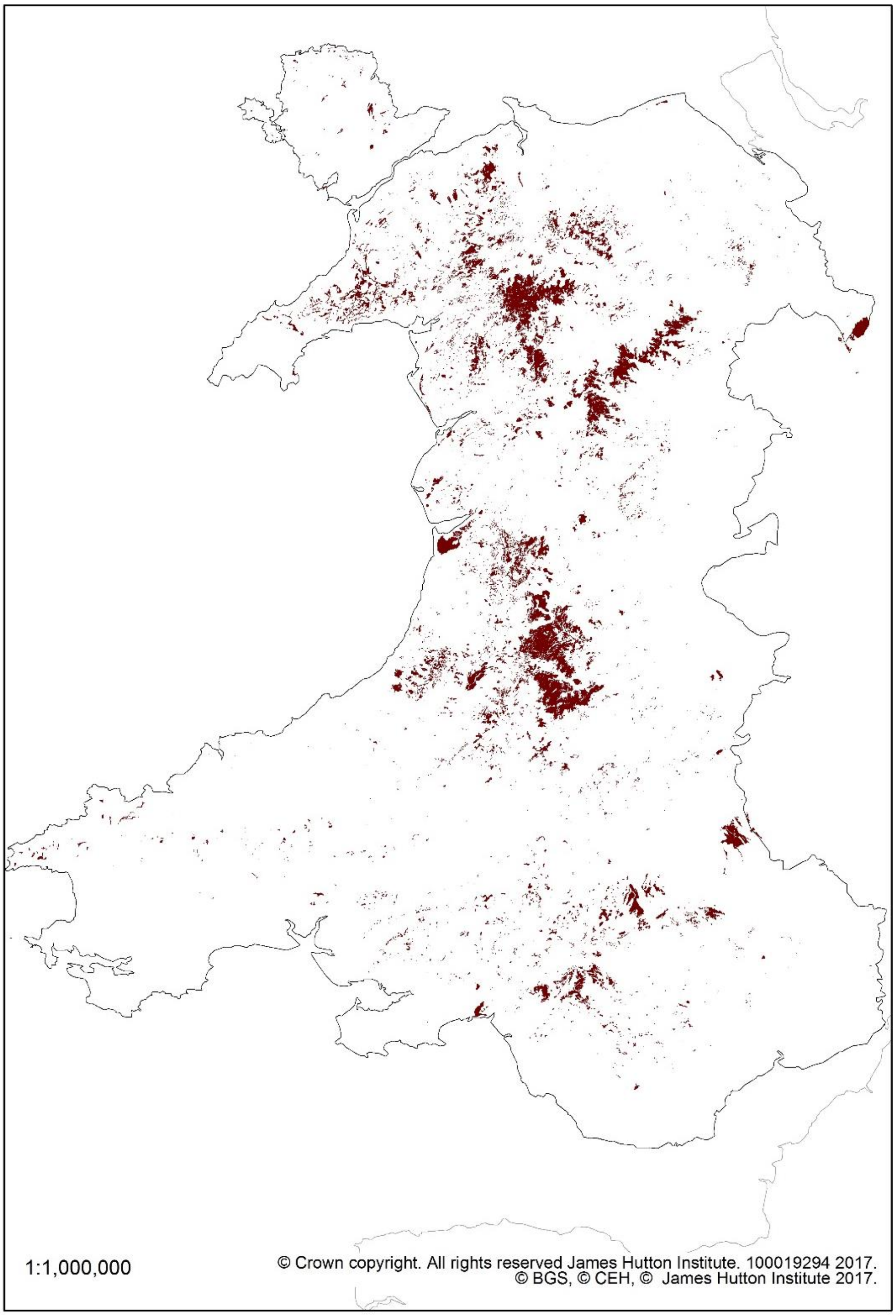

***Figure 3.3**. Wales peat base map.*

3.1.4 Northern Ireland

A new peat basemap for Northern Ireland was produced for this project by BGS (Figure 3.4). The map was based on the BGS 1:10,000 superficial geology dataset, but this does not provide complete spatial coverage, so gaps in coverage were 'infilled' with mapped histosol polygons from the Agri-Food and Biosciences Institute (AFBI) soil survey 1:25 000 scale. The areas for which AFBI data were used were the western tip of Strabane, the southern areas of Armagh, Banbridge, Downpatrick, and the whole area of Newry and Mourne (note that the two layers were not merged, and that the BGS data were used in preference where available). In addition, we obtained data from the 1988 Northern Ireland Peat Survey (Cruikshank and Tomlinson, 1990) which – although it showed reasonable overlap with the BGS/AFBI layer – also recorded substantial additional areas of peat in some regions. These additional areas typically surrounded BGS/AFBI mapped units, which we interpret as likely representing peat of intermediate thickness (i.e. greater than the 50 cm minimum threshold but less than the 1 m depth cut-off employed by BGS) on the periphery of larger blanket bogs. Inspection of aerial photographs and site visits supported the interpretation that these areas had been correctly recorded as peat in the 1988 survey, and these areas were therefore added to the BGS/AFBI layer. The resulting unified map for Northern Ireland gives a total peat extent of 242,622 ha.

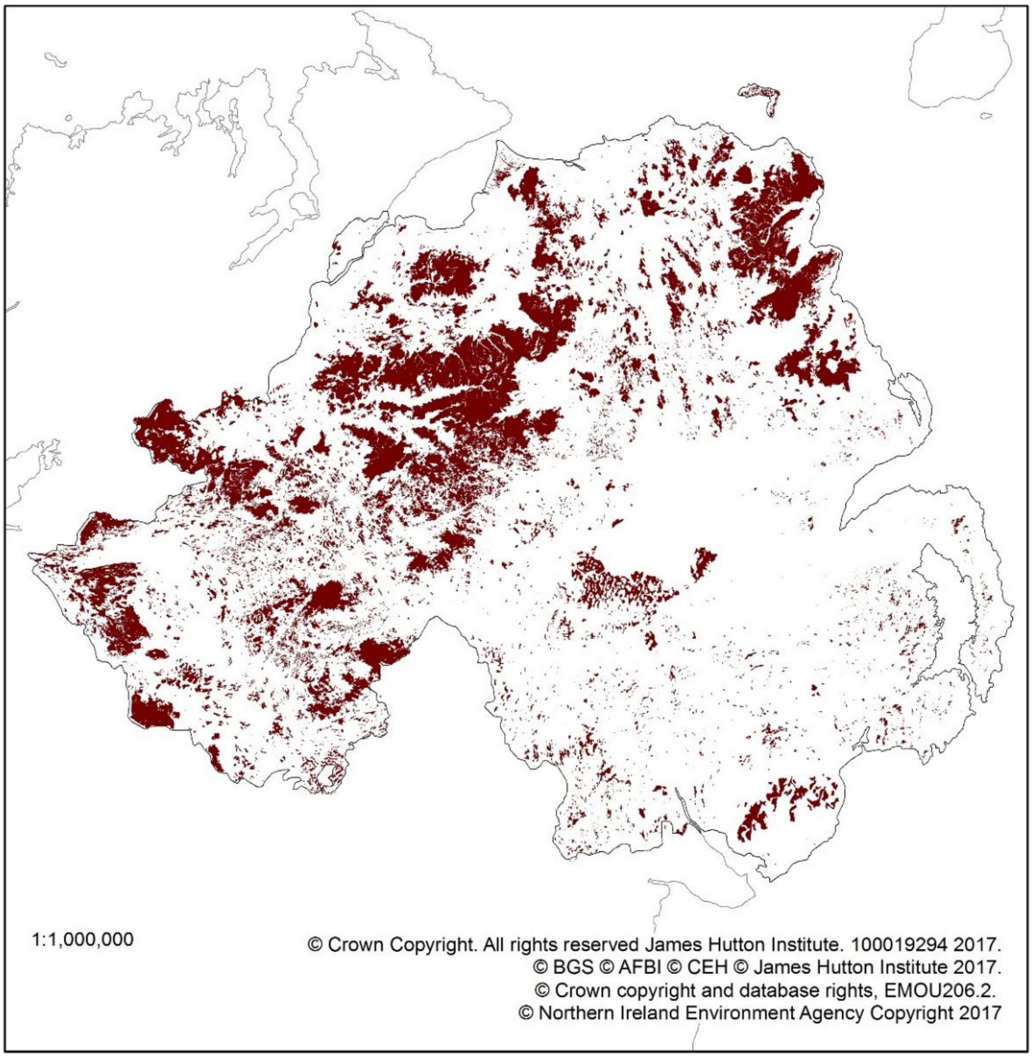

Figure 3.4*. Northern Ireland peat base map.*

3.1.5 Isle of Man

The only peat map we were able to obtain for the Isle of Man was the BGS 1:50,000 superficial geology map, which records a small area (476 ha, 0.83% of the total land area) as peat, all in lowland areas. A previous report by Sayle et al. (1995), together with an assessment of aerial imagery, suggests that a similar area may be occupied by blanket peat in the uplands, but this area likely did not meet the 1 m depth threshold used in the BGS map. Weissert and Disney (2013) estimated a much larger (> 5000 ha) peat area, but were unclear with regard to the depth thresholds, and did not clearly differentiate between blanket bog and heathland, suggesting that this may represent an over-estimate. Unfortunately, neither study provided spatially explicit data, therefore for the inventory we were only able to include the 476 ha of deep peat mapped by BGS. This is a likely underestimate of the true area.

3.1.6 Falkland Islands

The Falkland Islands have by far the largest peat extent of any of the UK's Overseas Territories, and were previously assumed to be entirely peat-covered in the UK emissions inventory. Although this is not the case, the islands nevertheless contain a significant fraction of the UK's total peat area. The Falklands peat base map was derived from a BGS superficial geology map produced as part of a geological survey of the islands by Aldiss and Edwards (1999). Although the original map only records relatively small areas of upland and coastal deep peat, extensive areas of deep (> 40 cm) peat occur in both upland and lowland settings. An exploratory field peat depth assessment carried out for this project (comprising depth probing at 286 locations in different parts of East Falkland) suggested that peat rarely occurs on steeper slopes in upland areas, but is widespread (and difficult to predict from topographic data alone) on gentler slopes. For these areas a 15% slope cut off was applied, using 30 m horizontal resolution DTM data from the Shuttle Radar Topography Mission, and (based on the depth probe data) the remaining area was estimated to contain 33% deep peat. In lowland areas, 'valley bottom deposits' in lowland areas were found to overwhelmingly contain deep peat, and were therefore all mapped as peat, whereas peat was found to be largely absent elsewhere. Based on these assumptions, a preliminary estimated peat area of 282,100 ha was obtained for the Falklands (Figure 3.5). It is worth noting that a soils map of the Falklands was also recently developed (also from the BGS superficial geology map) by Burton (2015). This map differs from our assessment in that i) valley bottom deposits were classified as peaty gleys, and ii) upland peat extent was not specifically estimated. A new initiative to develop a soils map of the Falklands based on new ground survey data is currently ongoing, and may produce improved peat area estimates in future.

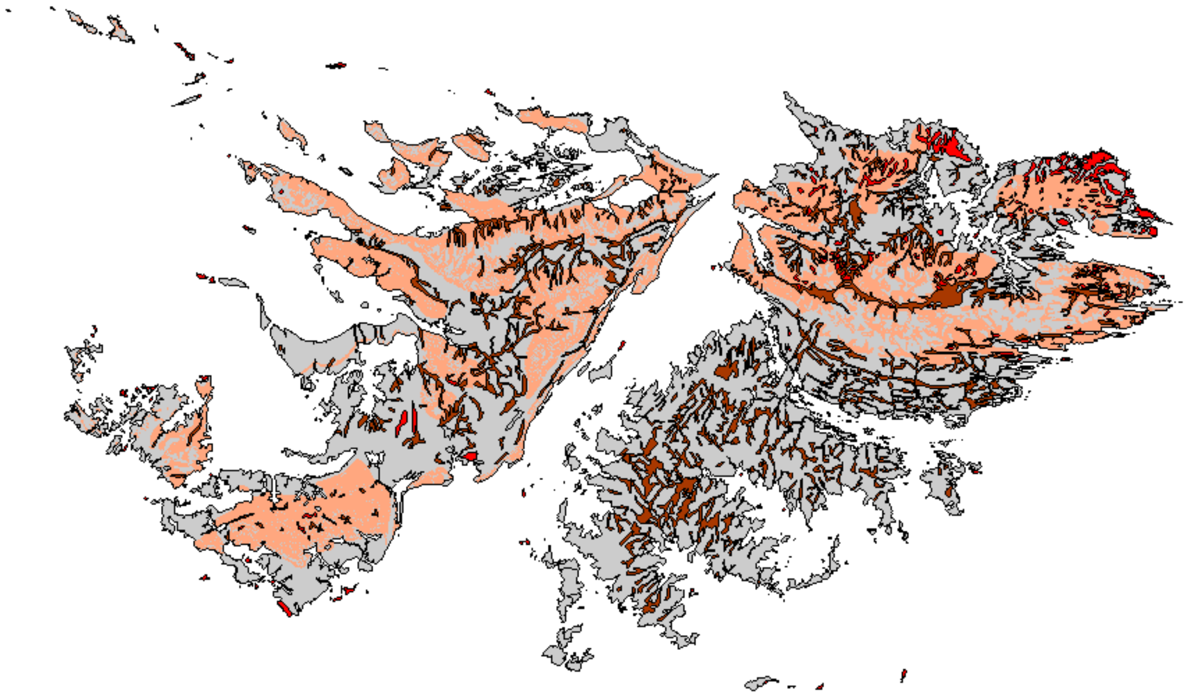

***Figure 3.5**. Falkland Islands peat map. Red represents upland deep peat, brown valley peat, orange mixed upland organo-mineral and deep peat soils, and grey areas with little or no peat cover (thin organo-mineral soils, mineral soils and bare rock)*

***Table 3.1**. Total estimated peat areas for each UK administration, the Isle of Man and the Falkland Islands (peat areas in other Crown Dependencies and Overseas Territories are considered to be minor) excluding Settlement on peat.*

Country/ administration	Peat area (ha)	Source data	Reference
Scotland	1,947,750	James Hutton Institute, British Geological Survey	This study
England	Deep: 495,828 Wasted: 86,372	National Soil Research Institute, British Geological Survey	Natural England (2010)
Wales	90,050	British Geological Survey, Natural Resources Wales	Evans et al. (2014)
Northern Ireland	242,622	Deep peat from British Geological Survey, Agri-Food and Biosciences Institute, Peat Survey of Northern Ireland	Cruikshank & Tomlinson (1990); this study
Isle of Man	475	British Geological Survey	This study
Falkland Islands	282,100	British Geological Survey, CEH unpublished data	Aldiss & Edwards (1999); this study
Total	***3,227,197***		

3.2 Baseline peat condition mapping

Under ideal circumstances, maps of peat condition would be produced for a consistent reference year (preferably the 1990 inventory baseline year) and changes in emissions over time derived from comparable maps in subsequent years. Unfortunately, no such complete or comparable datasets exist, and it was therefore necessary to develop alternative approaches. The definition of a reference year itself was problematic, because no single UK-wide land-cover survey provides sufficient spatial resolution or classificatory detail to assign emission factors to all peat areas, and the best available dataset(s) were collected in different years in different countries. We therefore adopted a flexible approach to the definition of map reference years, to ensure that the most robust data could be used in each case. The approach, summarised conceptually in Figure 3.6, was to define a 'map reference year', reflecting the best available data available for each country, and then to estimate changes over time relative to that reference year. The approach is described in detail for each country below. The estimation of changes in peat condition between 1990 and the present day is described in Section 3.3.

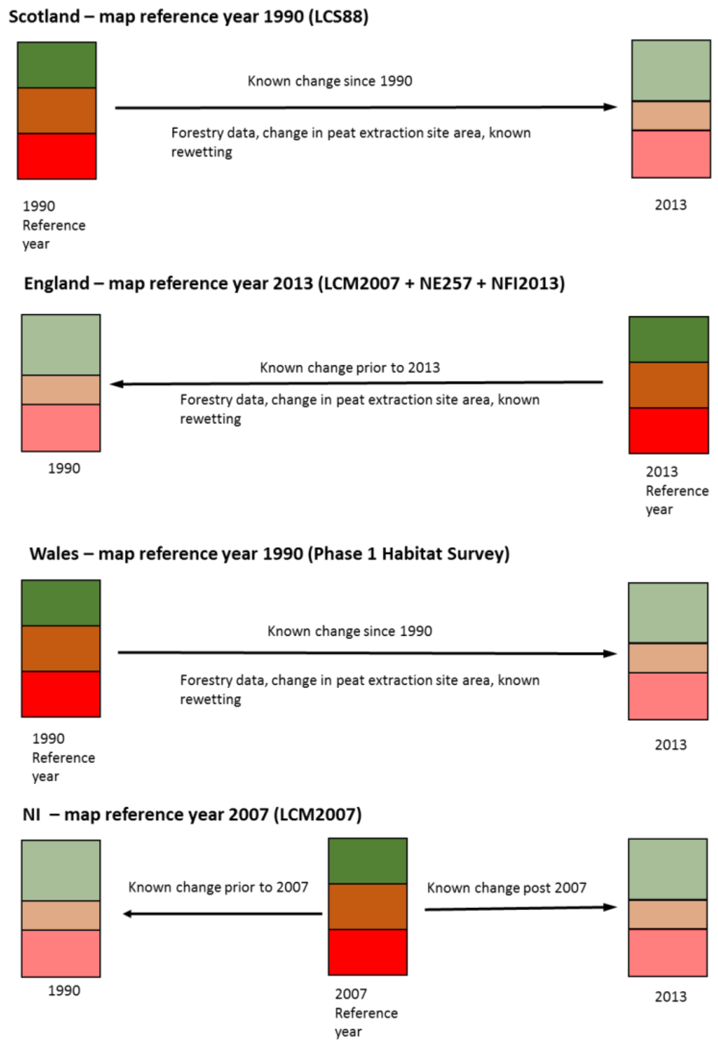

***Figure 3.6**. Schematic illustration of the approach used to derive activity data for emissions accounting in each UK country. The map reference year (for which full mapped condition data were derived) is shown in bold colours, different colours at each time point represent different peat condition categories. For illustrative purposes only three categories are shown rather than the 16 for considered in this project. Changes relative to the reference year (since the 1990 inventory baseline year and/or up to the present) were estimated from information on peat restoration projects and other land-cover changes (see Section 3.3).*

3.2.1 Scotland

For Scotland, a relatively high accuracy land cover dataset for the 1990 inventory baseline year is available in the Land Cover Map for Scotland 1988 (LCS88). This dataset classified land cover from aerial photographs into single and mosaic features at the 1:25,000 scale. Mosaic features, where several individual land cover components were found in a 25 m cell, were coded using a hierarchy structure and dominant and subdominant land cover classes digitally recorded. For the purpose of this report, only the categories within the dominant land cover class in the LCS88 were used. This approach will have missed out areas where the proportion of cover is lower than 33%, however at a national scale any associated errors in reporting as a result of this assumption should approximately cancel out.

LCS88 land cover categories were mapped onto the peat condition classification scheme shown in Figure 2.1. In some cases this was fairly straightforward, e.g. all areas of conifer and broadleaf woodland, as well as scrub, were assigned to the 'forest' category. Areas of cropland, intensive and extensive grassland, domestic and industrial peat extraction and settlement were all recorded directly in the LCS88 dataset. In Scotland and in all other countries, we were unable to differentiate grassland on fen peat from grassland on bog peat, so a single category was assigned in each case. Semi-natural peatlands were classified by LCS88 to a fairly high level of detail, conforming to the 'near-natural', 'modified heather-dominated' and 'modified grass-dominated' emission factor categories. However near-natural bogs and fens were not recorded separately, and all near-natural peatland was classified to bog as a default. Semi-natural peatland polygons were classified as 'eroded' in LCS88 if they contained visible erosional features such as gullies, bare peat or haggs, however only a proportion of these polygons was considered to be actively eroding (i.e. exposed bare peat). Based on visual assessment of a range of polygons we applied a default estimate of 12.5% for the extent of active erosion within these polygons. With regard to drainage within semi-natural regions, we applied the estimates of Aitkenhead et al. (2015) and an analysis of air photos for randomly selected locations across Scotland which was carried out of the current project. These sources suggest that 27.5% of all modified bog areas are drained. This was assumed to be distributed equally between the eroded, heather-dominated and grass-dominated categories. Small areas of peatland that could not be assigned to any category ('mapping offsets', i.e. where polygon boundaries in the peat map overlapped with implausible land cover categories such as open water in the LCS88) were assigned to the near-natural class. Finally, it was assumed that no peatland rewetting had taken place at the time of the survey.

Total land areas assigned to each Tier 2 emission factor class are shown in Table 3.2. A full list of underpinning assumptions is given in Table 3.3.

3.2.2 England

Suitable spatial data from around the 1990 baseline year could not be identified. The Land Cover Map 1990 is only available as a raster layer, which is not sufficiently detailed for the purpose of this report, and further suffers from a number of known misclassifications for semi-natural land cover. The subsequent Land Cover Maps (2000, 2007) used differing classification methods, and lack detail regarding semi-natural peatland condition, however LCM2007 provided the most reliable basis for classifying lowland peat areas. For the uplands, we used data from Natural England report NE257 (Natural England, 2010), together with the 2013 National Forest Inventory (NFI) and the CEH Google Map-based inventory of peat extraction sites. The LCM2007 is the only dataset with full national coverage, but the NE257 dataset provides additional attribute data, namely the presence of drainage, burning and erosion. In some cases, however, the NE257 data (which comprised nearly 600,000 polygons, most < 1 km^2) contained multiple incompatible attributes within the same location (e.g. afforested AND improved grassland). In order to combine the datasets and to address the internal issues with the NE257 data, we therefore applied a hierarchical approach, whereby areas were assigned to the highest-emitting category in cases where multiple condition attributes were recorded. This followed the order:

Pristine < rewetted < burned < drained < bare (eroded) < extracted < extensive grassland < improved grassland < cropland

For forests, the NE257 afforested attributes were found to be slightly out of date, as manual checks of overlays suggested that some changes had occurred between the NE257 assessment and the 2014 NFI. Therefore, the classification above was overwritten with information from the NFI 2014, as well as data on area of extraction sites which CEH has compiled using Google Earth data for sites listed in the Directory of Mines and Quarries. Although the exact time points at which the various spatial datasets were compiled varied, we assigned a reference year of 2013 to the merged dataset, on the basis that most of the 'dynamic' land cover categories in the merged dataset (e.g. the various semi-natural categories and forests) were captured by the more recent surveys, whereas the older LCM2007 dataset largely provided information on the distribution of comparatively 'fixed' categories (cropland and grassland).

As with Scotland, it was necessary to apply a number of assumptions in order to derive final areas for some semi-natural bog categories. Eroded areas were assumed to contain 12.5% bare peat (as above) whilst areas subject to burning were assumed to be heather-dominated modified bog. Unfortunately the data available did not support differentiation of grass-dominated modified bog, with this area initially being assigned to 'extensive grassland' based on the datasets used. The Tier 2 EFs for modified bog and extensive grassland are very different, notably for CO_2, with the former having near-zero emissions and the latter (based on data from lowland extensive grasslands) having large emissions (see Table 3.1). The implications for national inventory reporting are significant, with the potential to generate erroneously large emissions estimates as the result of a classification error. To address this problem, we used Defra's Moorland Line[1], a boundary derived from vegetation and land-use data as the basis for determining farm eligibility for certain agri-environment payments, which is defined as "predominantly semi-natural upland vegetation… used primarily for rough grazing". Areas mapped as extensive grassland above the line were reclassified as grass-dominated modified bog, whilst those below the line were retained in the extensive grassland category. The implications of this assumption are discussed later. On the other hand, from the NE257 data it was possible to explicitly map areas of upland bog affected by drainage. As for Scotland, it was not possible to separately map areas of near-natural fen and bog, and all such areas were assumed to be bog. Area data are reported separately for deep and wasted peats in Tables 3.1 and 3.2.

3.2.3 Wales

For Wales, detailed and complete land cover data were available from the NRW Phase 1 habitat survey, which was undertaken in the late 1980s. This dataset provides peat land cover and condition categories that broadly correspond to those for which Tier 2 emission factors were derived, and includes separate data on near-natural bog and fen, as well as differentiation between unmodified and modified bog (primarily associated with *Molinia* cover, so assigned to the grass-dominated modified bog category) and heathland (assigned to heather-dominated modified bog). Eroded areas were also mapped in the Phase 1 survey. In addition to the Phase 1 dataset, recent work by BGS mapped individual drainage ditches from aerial photographs for around two thirds of the entire Welsh peatland area (Evans et al,. 2015). Following consultation with NRW, ditches in lowland raised bog and fen were assumed to cause drainage of a 50 m buffer either side of the ditch, whilst ditches in blanket bog were assumed to drain a 10 m buffer. Drainage-affected areas were assigned to drained grass-dominated bog if they occurred in areas of Phase 1 'modified' bog (which are largely associated with *Molinia* cover in Wales), and to the heather-dominated modified bog category if they occurred in Phase 1 'unmodified' bog or heathland. Since the BGS ditch mapping did not cover 100% of the Welsh peatland area, those areas of semi-natural peatland in which ditches had not been mapped were separated into upland and lowland categories based on NRW's upland boundary, and assumed to have the same proportion of drainage as the upland and lowland areas which had been mapped. Data for the one (inactive) industrial peat extraction site in Wales was taken from the CEH's peat extraction site area dataset, as above.

[1] http://www.natureonthemap.naturalengland.org.uk/Datasets/Dataset_Download_MoorlandLine.htm

3.2.4 Northern Ireland

For Northern Ireland, we were unable to obtain comprehensive data for either the 1990 baseline year (although data from the 1988 Northern Ireland Peat Survey were available, this was focused mainly on semi-natural areas and thus did not provide full coverage) or the present day, due to a lack of any recent peat assessments. We therefore used the LCM2007 dataset as our main source of land cover data, and took 2007 as our map reference year. However, as in England, the LCM2007 data provide limited information on the condition of semi-natural peatland areas, therefore the Northern Ireland Peat Survey data were used to 'infill' LCM2007, providing data on heather-dominated modified, drained and eroded bog. Since the coverage of this survey was incomplete, area estimates for these categories are potentially low. Again, no data on the extent of grass-dominated modified bog or near-natural fen areas were available. As in England, we re-classified 'extensive grassland' in upland areas as grass-dominated bog to avoid the risk of reporting inaccurately high emissions from these areas. The Northern Ireland Peat Survey also provided data on the (very large) area of bog affected by current or historic domestic peat extraction.

3.2.5 Isle of Man

We were only able to obtain one digitised land cover dataset obtained for the Isle of Man, the Land Cover Map 2000. This was therefore used to define baseline land cover, giving a reference year of 2000. For the limited (and likely underestimated, see above) peat area captured by the base map, almost all of the peat was recorded as having been converted to grassland, forest or cropland, with remaining bog area classed as undrained heather-dominated modified bog. No data were obtained on drainage extent, but since most of the land cover classes on peat are inherently associated with drainage, this has little bearing on the results.

Table 3.2. *Assignment of peat areas to condition categories for each UK administration for the reference year used. Note that English data are subdivided into deep and wasted peat areas, whereas data for other countries cover all mapped peat areas due to an absence of more detailed information.*

Country	**England**		**Scotland**	**Wales**	**NI**	**Isle of Man**
Peat category	**Deep peat**	**Wasted peat**	**All**	**All**	**All**	**All**
Data sources	LCM2007 NE257 NFI2013	LCM2007 NE257 NFI2013	LCS88	Phase 1 Habitat Survey	LCM2007 NI Peat Survey	LCM2000
Reference map year	2013	2013	1990	1990	2007	2000
Forest	51,764	13,728	332,746	9,520	31,534	118
Cropland	50,594	132,107	8,181	102	3,141	41
Drained Eroded Modified Bog	5,653	0	75,147	19	2,170	0
Undrained Eroded Modified Bog	43,560	8	198,116	206	3,470	0
Drained Heather Dominated Modified Bog	19,208	0	155,196	1,588	6,667	4
Undrained Heather Dominated Modified Bog	87,166	55	409,154	6,237	10,702	9
Drained Grass Dominated Modified Bog	24,053	0	33,130	1,588	6,667	0
Undrained Grass Dominated Modified Bog	32,992	1,833	87,344	29,000	15,747	0
Extensive grassland	1,377	518	31,794	8,993	1,932	99
Intensive grassland	38,416	35,265	78,641	6,577	31,248	204
Near Natural Bog	83,930	2,348	490,497	23,548	35,915	0
Near Natural Fen	0	0	0	2,674	0	0
Extracted Domestic (fuel peat)	4,254	137	44,923	0	87,539	1
Extracted Industrial (horticultural)	4,627	1	2,881	0	525	0
Rewetted Bog	23,784	286	0	0	5,032	0
Rewetted Fen	24,451	86	0	0	334	0
Total	**495,829**	**186,372**	**1,947,750**	**90,050**	**242,623**	**475**

Table 3.3. *Key assumptions used in the assignment of peat areas to condition categories.*

No.	Assumption	Applicable to	Justification / basis
1	All near-natural peatlands are bogs rather than fens with regard to emissions.	Scotland England N Ireland	No or incomplete data on fen versus bog distribution available for these countries; areas were assumed to be bogs as these comprise by far the largest areas of extant near-natural peatland in all cases.
2	12.5% of areas classed as containing erosional features are bare peat	Scotland England N Ireland	Aerial photograph assessment
3	27.5% of all Scottish modified bog classes are affected by drainage	Scotland	Independent aerial photograph assessments of randomised selections of peatland sites by Aitkenhead et al. (2016) and Smyth et al. (2016)
4	No re-wetting took place prior to the 1990 baseline year	All	The vast majority of re-wetting activity has occurred since this date.
5	Any semi-natural land converted to forest or peat extraction during the reporting period is assumed to be modified bog and extensive grassland, split according to the proportion of peat in each category in each country	All	Good condition ‘near-natural’ peatlands are unlikely to have been converted to other land-uses since 1990
6	All deforestation on peat is assumed to convert land to re-wetted bog	All	The majority of forest area on peat occurs on bog rather than fen peat.
7	Areas recorded as bracken were included in the extensive grassland category	All	Minor category, considered to be most analogous to extensive grassland in terms of emissions
8	Drainage impacts extend 10 m either side of ditches in blanket bog, and 50 m either side of ditches in lowland raised bog or fen	Wales	Expert judgement based on consultation with NRW and hydrological modelling work by Baird and Low (2013), consistent with previous assessment by Evans et al., (2014).
9	All cropland, grassland, woodland and peat extraction on peat is drained	All	IPCC Tier 1 assumption
10	Former peat extraction areas (domestic and industrial) which have been abandoned but not restored remain in the peat extraction category	All	Available evidence suggests that extraction sites do not convert back to functioning peatlands in the absence of restoration intervention,
11	Shallow (‘wasted’) peatlands continue to emit at the same rate as deep peats, for all land use categories	England (shallow peat not separately mapped elsewhere)	Limited available data indicate that shallow peats under agriculture continue to emit CO_2 at a high rate (Evans et al., 2017; Leiber-Sauheitl et al., 2014; Tiemeyer et al., 2016)
12	Total area of peat remains constant over time	All	No mapping data to enable change in peat extent over time to be reported (although some decrease in extent is likely in areas of highest carbon loss)
13	All areas mapped as ‘extensive grassland’ in defined upland areas are considered to be grass-dominated modified bog	England N Ireland	Landcover classifications in these countries do not adequately differentiate grass-dominated bog from ‘true’ agricultural grassland, but available information suggests that most ‘extensive grassland’ on upland blanket bog falls within the grass-dominated modified bog category.

3.2.6 Falkland Islands

As described above, the Falklands contain very extensive peat areas (estimated to be greater than in either Northern Ireland or Wales). During the project we were unable to obtain any digital land cover data for the Islands, however a vegetation map has subsequently been made available online by the South Atlantic Environment Research Institute[2]; this could support a peat condition assessment in future. A qualitative assessment of peat condition, based on field observations and previous studies, was reported in a project interim report (Smyth et al., 2016). Briefly, the Falkland peats are distributed across upland and lowland areas, with the majority of this area affected by sheep grazing. In some areas managed burning, drainage (by dredging stream channels) and ploughing of topsoil are practiced in order to increase cover of palatable grasses, in place of shrubs and other bog species. An assessment for the Falkland Islands Government (Otley et al., 2008) estimated that 80% of the original 22,000 ha of tussac grass, which is the natural vegetation of coastal peat areas, have been lost to grazing. The figure for the two main islands is even higher, with an estimated 98% loss in 1988, although some restoration has taken place since that time. The very low rainfall and high wind speeds make the islands susceptible to wind erosion, particularly in upland areas, where eroding 'peat banks' are widespread, and also to wildfire. Domestic peat cutting occurs close to settlements, but is limited in extent given the low population. Other land-use impacts appear minor. Overall, it appears that much of the Falkland peat area could be classed as either grass-dominated modified bog, shrub-dominated modified bog (analogous to heather-dominated areas in the UK) or eroded modified bog. However in the absence of more quantitative information, as well as uncertainties regarding both the location of peat in upland areas, and the applicability of UK Tier 2 emission factors to the much drier (albeit visually similar) peats of the Falklands, we did not undertake an inventory assessment at this stage.

3.3 Condition changes since 1990

Changes in peat condition were estimated from available data from each UK administration for the period 1990 to 2013. As has already been noted, no consistent and comparable land cover maps from different time points exist for any part of the UK. Comparisons of land cover maps from different time points revealed large and clearly spurious changes in the extent of many land classes, as a result of inconsistencies in classification methods and definitions, and could not therefore be used. Therefore, we were unable to comprehensively map activity changes at a UK scale, and instead had to collate data from a range of different datasets that reliably described individual land cover changes (e.g. associated with forestry) or interventions such as peatland re-wetting.

3.3.1 Peat restoration

A database of peatland restoration projects was developed during the project, using the 'Peatland Compendium' (Holden et al., 2008) as its starting point. This web-based resource, now linked to the IUCN Peatland Programme, contains a list of individual restoration projects, their locations and spatial extents, a description of the sites and restoration measures undertaken, and contact details. Restoration data in the compendium were uploaded by the individual project managers (from a broad range of NGOs, government agencies and others) and have not been systematically updated in recent years, so it was necessary both to review the existing data holdings to ensure accuracy and completeness, and to collate information on new or previously omitted restoration projects. Note that since the assessment covered the period prior to 2013, it does not capture a significant amount of restoration activity that has happened during the last few years in many areas. Restoration between 2013 and 2016 has been assumed to continue at the same rate as prior to 2013, but (given the recent expansion of peat restoration activity across the UK) this may underestimate the true area restored.

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[2] http://148.251.22.181/saeri_webgis/lizmap/www/index.php/view/map/?repository=v02&project=renewable_energy

The final database contains information from 409 peatland restoration and management projects. Information for each project was often derived from a number of sources: direct from project managers, through written reports and accounts of the project, or from publically available datasets. Aerial images were often used to verify reported ‘before and after’ condition and land use classifications. Areas which were deforested as part of the restoration process are included in the area of restored peatland. Pre and post rewetting/peatland management condition for each project was firstly categorised following the condition category criteria developed for the Peatland Code (Smyth et al., 2015), as this was simple and relatively easy to apply by interpreting information provided by restoration and management projects. These categories were then mapped onto the Tier 2 condition hierarchy shown in Figure 2.1. In some cases, the assignment of projects to Tier 2 categories was difficult given the level of information available, notably when trying to distinguish between ‘modified bog’ and ‘grassland’. As a rule, we assumed that a project fell into the ‘modified bog’ category if it specifically targeted or was known to have peatland-type vegetation.

The total area of peatland subject to restoration interventions was estimated as 109,679 ha. Each project area was classified as ‘re-wetting’ only if ditch-blocking or hydrological management were specified in the project description. Without consistent, detailed reporting and a consensus on a methodology for estimating the area of rewetting, we assumed that the entire area reported by each individual project had been re-wetted. In cases where the length of ditches blocked were reported, an area figure was derived by assuming a 10 m buffer around each drain (following the methodology described in Section 3.2.3.). In Wales, a digitised map of blocked ditches on peatland was used to estimate re-wetted areas around each ditch, according to the same procedure (equivalent data were not available for other UK administrations).

Projects which only mentioned vegetation management (e.g. scrub removal, grazing management) were classified as ‘peatland management’, rather than re-wetting. In many cases these interventions did not cause sites to transition from one Tier 2 condition category to another, and therefore did not influence emissions estimates. Similarly, although a much larger area peatland (around 1,000,000 ha) has been subject to management activities linked to agri-environment schemes during the reporting period, a lack of information on their location and outcome (as well as their typically limited duration and often modest level of intervention, e.g. reduced grazing intensity) meant that these activities could not be assumed to lead to a change in peat condition category, and were not included in the inventory calculations. The overall extent of peatland management activities derived from project-level information is summarised in Table 3.3. The associated changes in peat condition category were incorporated in the final inventory implementation (see Section 4).

Table 3.4. *Area (ha) of rewetting and peatland management activity by country between 1990 and 2013, derived from information recorded in individual restoration projects. A further 1,071,997 ha of peatland included in agri-environment schemes during this time is omitted, as impact on condition could not be determined*.

Activity	England	N. Ireland	Scotland	Wales	Total
Peatland Management	11,509	7,803	8,869	8,303	36,484
Rewetting	45,444	862	21,326	5,563	73,195
Total	***56,953***	***8,665***	***30,195***	***13,866***	***109,679***

3.3.2 Changes in forest cover

Areas of afforestation on peat were assessed using the data on afforestation supplied by Forest Research for use in the LULUCF inventory. This gives consistency with the forest areas used elsewhere in the inventory. These areas are derived from Forestry Commission data on grant assisted planting. We assumed that the proportion of total afforestation occurring on peats was constant within each UK administration. The data therefore do not reflect changes in forestry policy which have tended to discourage afforestation and encourage tree removal on peat in recent years. However they do reflect the general decrease in afforestation across the UK between 1990 and 2016, and therefore show the rate of afforestation on peat decreasing from 1,086 ha for the whole of the UK in 1990 to 83 ha in 2015.

The Forest Research data on deforestation used in the LULUCF inventory prior to 2000 are derived from unconditional felling licence data for authorisations for felling with no subsequent replanting. Post-2000 these data are assembled from a number of sources including the NFI, and takes account of habitat restoration, wind farm development and other permanent woodland loss. The deforested area is not currently split between organic and mineral soils, so could not be used specifically to assess the area of deforestation on peat. Instead, the area of deforestation on peat was derived from the area of restored peatland that was formerly forest, using the peatland restoration areas described in Section 3.3.1. As annual data on the area of deforested and restored peatlands are not available, constant annual restoration rates were assumed based the average value for 2000 – 2013.

Table 3.5. *Area (ha) of afforestation and deforestation on peat by country between 1990 and 2013. Afforestation data are derived from Forestry Commission data on grant assisted planting assuming a constant proportion of planting is on peat. Deforestation areas are taken from the area of restored peat which was formerly forest (see Section 3.3.1)*

Activity	**England**	**Scotland**	**Wales**	**N. Ireland**	**Total**
Afforestation	411	24,348	76	3,930	28,766
Deforestation	1,503	2,857	331	0	4,692
Net change	**-1092**	**+21,491**	**-255**	**+3,930**	**+24,074**

3.3.3 Changes in peat extraction areas

Changes in peat extraction site area over time were generated from data on peat extraction sites used in the LULUCF inventory. These changes were applied to the baseline peat extraction areas to give a time series of peat extraction area. Fuel peat was assumed to be extracted for domestic use. In contrast to the IPCC Tier 1 assumptions, fuel peat extraction was assumed to occur on bog peat, and horticultural peat extraction on fen peat, reflecting UK practice, where most (domestic) peat cutting occurs on blanket bog. Although industrial extraction generally occurs on raised bogs, the material left after extraction ends typically consists of underlying fen peat, such that re-wetted extraction sites develop a fen-type vegetation (e.g. Wilson et al., 2017).

Change in the area of sites registered in the Directory of Mines and Quarries (BGS, 2014) from 2002 onwards was assessed from Google Earth Imagery. Prior to 2002 the area of commercial peat extraction sites in Great Britain was assessed from planning consent data for 1991 (Cruickshank and Tomlinson, 1997) and the area of commercial peat extraction sites in NI in 1991 was taken from Tomlinson *et al* (2010). Linear extrapolation was used to infill extraction site area between these dates.

Table 3.6*. Area (ha) of industrial and domestic peat extraction sites by country in 1990 and 2013.*

Activity	**Year**	**England**	**Scotland**	**Wales**	**N. Ireland**	**Total**
Industrial extraction	1990	7,082	2,881	0	761	10,724
	2013	4,628	2,840	0	503	7,971
Domestic extraction	1990	4,402	44,923	0	92,202	141,527
	2013	4,391	44,649	0	87,539	136,579
Total	**1990**	**11,484**	**47,804**	**0**	**92,963**	**152,251**
	2013	**9,019**	**47,489**	**0**	**88,042**	**144,550**

3.3.4 Other activity changes

Although most large-scale peatland drainage pre-dated the 1990 baseline year for inventory reporting, some new drainage is known to have occurred since that time, for example as part of wind farm developments or on blanket bog, or other building or infrastructure developments. To date, it has not been possible to obtain appropriate data that would allow the effects of these activities to be included in the inventory. Similarly, the absence of consistent land-cover mapping from different time periods means that land-use transitions other than those listed in the preceding sections (for example between improved grassland and cropland) cannot be reliably quantified. As a result, with the exception of known restoration projects affecting these land classes (such as reversion of drained cropland to fen vegetation in parts of East Anglia) changes in these land categories were assumed to have been zero during the reporting period.

In the absence of data to support an alternative approach, we assumed that there had been no changes in agricultural land management since 1990, such as rotation between cropland and grassland, or change between intensive and extensive grassland. It is likely that in practice some of these types of change have occurred reflecting changes in agricultural policy, agri-environment schemes and market demands, but spatially explicit data on agricultural land use have not been available to this project. It might be possible to use data sources such as the Integrated Administration and Control System (IACS) dataset, which contains spatially explicit data on the use of land in receipt of payments under the Common Agricultural Policy (CAP). However this dataset does not cover the whole time period required, is not necessarily specific to peat areas, and its long term continuation in its current form is not guaranteed.

3.3.5 Overall estimates of peat condition change between 1990 and 2013

Final estimates of changes in the area of each Tier 2 peat condition category that could be estimated from available data are shown, by UK administration, in Table 3.6. The largest activity changes recorded are reductions in all modified bog categories, and commensurate increases in re-wetted area, largely associated with upland blanket bog restoration projects. Modest reductions in the area of forest and extensive grassland on peat have occurred in England, Scotland and Wales. Reductions in cropland and intensive grassland have occurred predominantly in England (exclusively on areas of deep peat), with accompanying increases in the area of re-wetted fen. The area under industrial extraction has declined by nearly 8000 ha, mainly in Northern Ireland and England, whereas the change in the area affected by domestic extraction has been small. Overall, 69,000 ha of peat is estimated to have been re-wetted during the assessment period, including significant areas in all four UK countries.

Table 3.7. *Estimated changes in area (ha) of each peat condition category due to rewetting between 1990 and 2013*

Tier 2 peat condition category	England Deep peat	England Wasted peat	Scotland	Wales	Northern Ireland	Isle of Man
Forest	-1,110	-286	-2,653	-308	0	0
Cropland	-3,378	0	0	0	0	0
Eroded Modified Bog	-5,278	0	-4,818	-17	-85	0
Heather Dominated Modified Bog	-11,414	0	-9,951	-609	-247	0
Grass Dominated Modified Bog	-6,316	0	-2,124	-2380	-323	0
Extensive grassland (bog + fen)	-1,756	0	-1731	-2,243	-29	0
Intensive grassland	-2,904	0	0	-1	-150	0
Near Natural Bog	-	-	-	-	-	-
Near Natural Fen	-	-	-	-	-	-
Extracted Domestic	-11	0	-308	0	-258	0
Extracted Industrial	-2,914	-86	-262	0	-4,663	0
Change in drained area	-35,083	-372	-21,848	-5,558	-5755	0
Rewetted Bog	24,304	286	20,415	4,014	5,347	0
Rewetted Fen	10,779	86	1,433	1,544	408	0
Change in rewetted area	35,083	372	21,848	5,558	5,755	0

4 INVENTORY IMPLEMENTATION

This section describes the implementation of LULUCF reporting for UK peatlands, based on the emission factors (EFs) and activity data described in the preceding sections.

4.1 Methods

As described in Section 2, we were able to develop Tier 2 EFs for a range of UK-relevant peat condition categories. In a number of cases it was possible to further divide the existing IPCC Tier 1 EFs, and to effectively introduce new reporting categories for modified semi-natural bog habitats, and near-natural bogs and fens. In the case of agricultural grasslands, the availability of data (either UK-relevant field data measurements or landcover data) was insufficient to support the Tier 1 classification approach based on peat type and drainage depth, therefore the simpler (but arguably more UK-relevant) categories of intensive and extensive grassland were applied. In the majority of cases (grassland, forestry, cropland, peat extraction sites), the assumption could be made that all sites were drained, but this was not necessarily the case for modified semi-natural bogs, where modification can also occur as a result of burn-management and grazing.

In order to implement the inventory for the UK, it was necessary to apply a number of simplifying assumptions to take account of data limitations. Those used to generate activity data in the baseline year for each administration (Table 3.2) are listed in Table 3.3. To implement inventory reporting over the assessment period, it was also necessary to make some additional assumptions. In particular, the dates at which all individual restoration projects were undertaken were not known, and it was necessary to assume the proportion of activities that took place within each simulation year. Since very little peat restoration activity took place during the 1990s, we made the simplifying assumption, for all countries, that no re-wetting or restoration (other than peat extraction sites, for which more detailed data were available) took place before 2000. Thereafter, we assumed that activities took place at a constant rate from 2000 to 2013, in order to give the total changes in peat condition recorded in Table 3.2.

For areas of drained modified bog (Table 3.2), the same EFs for on-site CO_2 and N_2O emissions were applied as for undrained areas in the same condition category. For CH_4, direct emissions from the peat surface were also assumed to be the same for drained and undrained areas of modified bog (because the EF dataset was not sufficient to differentiate emissions from drained versus undrained sites) but additional emissions of CH_4 from drainage ditches and CO_2 from exported DOC were included for all drained areas, following the Tier 1 methodology described in the IPCC Wetlands Supplement. Off-site CO_2 emissions from POC were estimated from the area of exposed peat associated with each land-use category, based on the method outlined in Appendix 2.a.2 of the IPCC Wetlands Supplement. Finally, indirect N_2O emissions associated with nitrate leaching from soils were accounted for according to the Tier 1 methods set out in the 2006 IPCC Guidelines.

As already noted, it was not possible to account for emissions from the Falkland Islands (as the main Overseas Territory containing peatlands) due to the lack of sufficient activity data. However the approach described here could be applied to the Islands in future, given improved spatial data on peat condition. It would also be desirable to collect new flux measurements that would enable specific Tier 2 EFs to be developed that reflect the characteristic vegetation, climate and management of the Islands. However, UK Tier 2 EFs (particularly those for blanket bog) may be sufficiently representative to enable a first-pass inventory assessment, preferably supported by some field verification.

4.2 Final Emission Factors

The final emission factors used to implement the 1990-2013 inventory, expressed in t CO_2e ha^{-1} yr^{-1}, are shown in Table 4.1. The collated data suggest that almost all of the 'Tier 2' peat condition categories included in this assessment are net sources of GHG emissions. The only exception is near-natural fen, where the high rate of CO_2 sequestration from the atmosphere outweighs CH_4 and N_2O emissions, and indirect CO_2 losses via DOC leaching. In near-natural bogs, fluxes effectively balance out, making these areas 'climate neutral' on the 100 year time horizon used to define Global Warming Potentials (GWPs) in the UK inventory. Over longer time horizons, the shorter atmospheric lifetime of CH_4 compared to CO_2 means that these areas have a strong net cooling impact (Frolking et al., 2006). Re-wetted bogs are estimated to be net sinks for carbon, but this is (marginally) outweighed by CH_4 emissions, whilst re-wetted fens on average remain sources of both CO_2 and CH_4. Modified (but not eroded) bogs take up a small amount of CO_2 from the atmosphere, but this is more than balanced by DOC loss, and once CH_4 emissions are accounted for they are considered to be net GHG emission sources, whether they are drained or not. This emission is exacerbated by drainage and erosion, although (as noted earlier) the magnitude of CO_2 emissions associated with POC loss is uncertain, and may be under-estimated here.

***Table 4.1** Emissions factors for peat condition types. All fluxes are shown in tCO_2e ha^{-1} yr^{-1}. Note that a positive EF indicates net GHG emission, and a negative EF indicates net GHG removal.*

Peat condition category	Drainage status	Direct CO_2	CO_2 from DOC	CO_2 from POC	Direct CH_4	CH_4 from ditches	Direct N_2O	Indirect N_2O	TOTAL
Data source		*Section 2 (this report)*	*IPCC (2014)*	Evans *et al.* (2016)	*Section 2 (this report)*	*IPCC (2014)*	*Section 2 (this report)*	*IPCC (2006)*	
Tier		*Tier 2*	*Tier 1*	*Tier 2*	*Tier 2*	*Tier 1*	*Tier 2*	*Tier 1*	
Forest	Drained	7.39	1.14	0.30	0.12	0.14	0.65	0.17	**9.91**
Cropland	Drained	26.57	1.14	0.30	0.02	1.46	8.97	0.54	**38.98**
Eroded Modified Bog	Drained	0.85	1.14	0.89	1.19	0.66	0.06	0.06	**4.85**
	Undrained		0.69	0.71		0.00		0.05	**3.55**
Heather Dominated Modified bog	Drained	-0.14	1.14	0.30	1.36	0.66	0.05	0.03	**3.40**
	Undrained		0.69	0.10		0.00		0.02	**2.08**
Grass Dominated Modified bog	Drained	-0.14	1.14	0.30	1.36	0.66	0.05	0.03	**3.40**
	Undrained		0.69	0.10		0.00		0.02	**2.08**
Extensive Grassland	Drained	13.33	1.14	0.30	1.82	0.66	1.50	0.29	**19.02**
Intensive Grassland	Drained	23.37	1.14	0.30	0.37	1.46	2.80	0.48	**29.89**
Rewetted Bog	Rewetted	-2.23	0.88	0.10	2.02	0.00	0.04	0.00	**0.81**
Rewetted Fen	Rewetted	0.86	0.69	0.10	4.24	0.00	0.24	0.04	**6.37**
Near Natural Bog	Undrained	-3.54	0.69	0.00	2.83	0.00	0.03	0.00	**0.01**
Near Natural Fen	Undrained	-5.44	0.69	0.00	3.88	0.00	0.24	0.00	**-0.61**
Extracted Domestic	Drained	4.73	1.14	0.89	0.20	0.68	0.14	0.13	**7.91**
Extracted Industrial	Drained	6.44	1.14	5.00	0.20	0.68	0.14	0.24	**13.84**

Of the other (drained) peat condition categories, total GHG emissions range from around 8 t CO_2e ha^{-1} yr^{-1} from domestic extraction sites to 39 t CO_2e ha^{-1} yr^{-1} from cropland. There is a clear relationship between intensity of land-use and emissions, which is likely related to the relationship between CO_2 emissions and depth to mean water table that has been demonstrated empirically for UK peatlands (Evans et al., 2017), with cropland and intensive grassland requiring the deepest drainage. This effect greatly outweighs the reduction in (natural) CH_4 emissions that occur following peatland drainage, in part due to continued CH_4 emissions from drainage ditches, which act as emissions 'hotspots' within agricultural landscapes. Emissions of N_2O make a significant contribution to total GHG emissions from fertilised agricultural systems, most notably from cropland.

4.3 Country emissions estimates

4.3.1 1990 baseline emissions

Estimated emissions for the 1990 inventory baseline year are shown by UK administration and greenhouse gas in Table 4.2. Total UK emissions from peatlands at this time are estimated to have been 23,700 kt CO_2e yr^{-1}. Of this total, approximately two thirds was caused by CO_2 emissions, the overwhelming majority of which was associated with drainage-based land-use (i.e. arable and grassland agriculture, forestry and peat extraction). Emissions of CH_4 contributed around 20% of the total, primarily from undrained areas and drainage ditches in agricultural areas. To a large extent, CH_4 emissions from undrained peatlands may be considered a natural emission. Because the UK regards all of its land area as managed, this emission is included in the inventory, and some CH_4 emission would therefore be recorded even if all peatlands were in a natural condition. However, as noted above, the Tier 2 EFs obtained suggest that this emission is effectively balanced by natural CO_2 uptake in peat-forming systems, as a consequence of which near-natural peatlands can be considered approximately 'climate neutral' based on 100 year GWPs. A simple calculation assuming that UK peatlands comprise 85% bog and 15% fen peat suggests that they would have acted as marginal net GHG sinks of around 250 kt CO_2e yr^{-1} in their undisturbed state. As already noted, their net cooling impact would have been much greater when considering the millennial timescales over which they formed. Emissions of N_2O, which are overwhelmingly derived from drained and fertilised agricultural land, contributed 13% to 1990 total GHG emissions.

Table 4.2 *1990 Emissions by UK administration including emissions from forest estimated using Tier 2 EFs generated in this project. All fluxes are shown in ktCO$_2$e yr^{-1}.*

Administration	CO_2	CH_4	N_2O	Total emission
England (total)	7,936	1,102	2,110	11,149
Deep peat	*3,233*	*828*	*726*	*4,787*
Wasted peat	*4,703*	*274*	*1,384*	*6,361*
Scotland	5,759	3,180	766	9,706
Wales	331	169	50	549
Northern Ireland	1,734	335	190	2,260
Isle of Man	9	1	1	11
UK (excluding Isle of Man)	15,760	4,786	3,117	23,664
UK + OTs/CDs (including Isle of Man)	15,769	4,787	3,117	23,675

Note there may be discrepancies of +/- 1 ha in the totals in this table due to rounding issues.

Of the four UK administrations, close to half of all 1990 GHG emissions were derived from peat in England. Of the total emission for England, an estimated 56% (26% of the UK total) came from areas of wasted peat under arable and grassland cultivation. This emission is considered relatively uncertain, as discussed below. The remaining 44% of emissions from England incorporates both the emissions from remaining lowland deep peat under agriculture, and all other emissions from land-use activities in both upland and lowland areas.

Emissions from Scottish peats, which make up 67% of the UK's total peat area, generated an estimated 41% of 1990 UK emissions. The lower intensity of emission per unit peat area reflects the smaller extent of intensive agricultural use in Scotland, as well as the slightly higher proportion of remaining near-natural bog compared to England and Northern Ireland (Table 3.2). Conversely, plantation forestry occupies a higher proportion of Scottish peatlands and (based on the Tier 2 EFs derived for this study) contributes significantly to total GHG emissions. Wales accounts for 2.3% of UK peat GHG emissions, which is also lower than its percentage of peat area (3%), again reflecting the relatively high proportion of relatively good condition upland bog within the country. In contrast, Northern Ireland is a more intensive source of emissions (10% of the UK total from 8% of the UK peat area). Baseline 1990 emissions from the Isle of Man are low, reflecting the small mapped peat area. As noted earlier, areas of upland blanket bog with a depth between 40 cm and 1 m were not captured in the BGS Isle of Man map, so true emissions may be slightly higher.

4.3.2 2013 emissions

Total emissions for 2013 are summarised by country in Table 4.3, and by peat condition category in Figure 4.1. Overall reductions in emissions captured by the inventory from 1990 to 2013, based on the activity changes recorded in Table 3.6) were modest, in the region of 423 kt CO_2e yr^{-1} (2.3% of 1990 emissions). As discussed in Section 3, quantifying changes in activity on peatlands is challenging given incomplete information on peat restoration schemes, and the absence of repeated land cover mapping with the required consistency or resolution, therefore it is possible that some significant activities contributing to emissions reductions could have been omitted. However, changes in the extent of some major sources of emissions (e.g. cropland, intensive grassland and forestry) are known to have been limited; emissions from wasted peat areas hardly changed during the reporting period. Conversely, many of the larger restoration schemes have occurred on upland blanket bog, for which the differences in emissions between modified and re-wetted bog are comparatively small (1-4 t CO_2e ha^{-1} yr^{-1} depending on whether areas were drained or eroded pre-restoration; Table 4.1). Although the benefits of these activities become significant for the overall UK budget when scaled up over large areas, we only identified around 43,500 ha of such areas during the reporting period. In total, around three quarters of all estimated present-day UK emissions derive from cropland, intensive grassland and forest (Figure 4.1), the areas of which each declined by < 5000 ha since 1990 (Table 3.3). In this context, continued high overall emissions from UK peatlands are not surprising. One notable observation, however, is that increases in CH_4 emission due to re-wetting are estimated to have offset < 10% of the associated reduction in CO_2 and N_2O emissions; therefore concerns about increased CH_4 emission due to peat restoration should not negate the climate mitigation benefits of peatland re-wetting when viewed at a national level.

Table 4.3 *2013 Emissions by UK administration including emissions from Forest estimated using Tier 2 EFs generated in this project. All fluxes are shown in kt CO_2e yr^{-1}.*

Administration	CO_2	CH_4	N_2O	Total emission
England (total)	7,654	1,145	2,064	10,863
Deep peat	*2,956*	*870*	*681*	*4,507*
Wasted peat	*4,698*	*275*	*1,383*	*6,356*
Scotland	5,718	3,165	754	9,637
Wales	290	173	46	510
Northern Ireland	1,705	336	190	2,232
Isle of Man	9	1	1	11
UK (excluding Isle of Man)	15, 367	4,820	3,053	23,241
UK + OTs/CDs (including Isle of Man)	15,375	4,820	3,055	23,251

Note there may be discrepancies of +/- 1 ha in the totals in this table due to rounding issues.

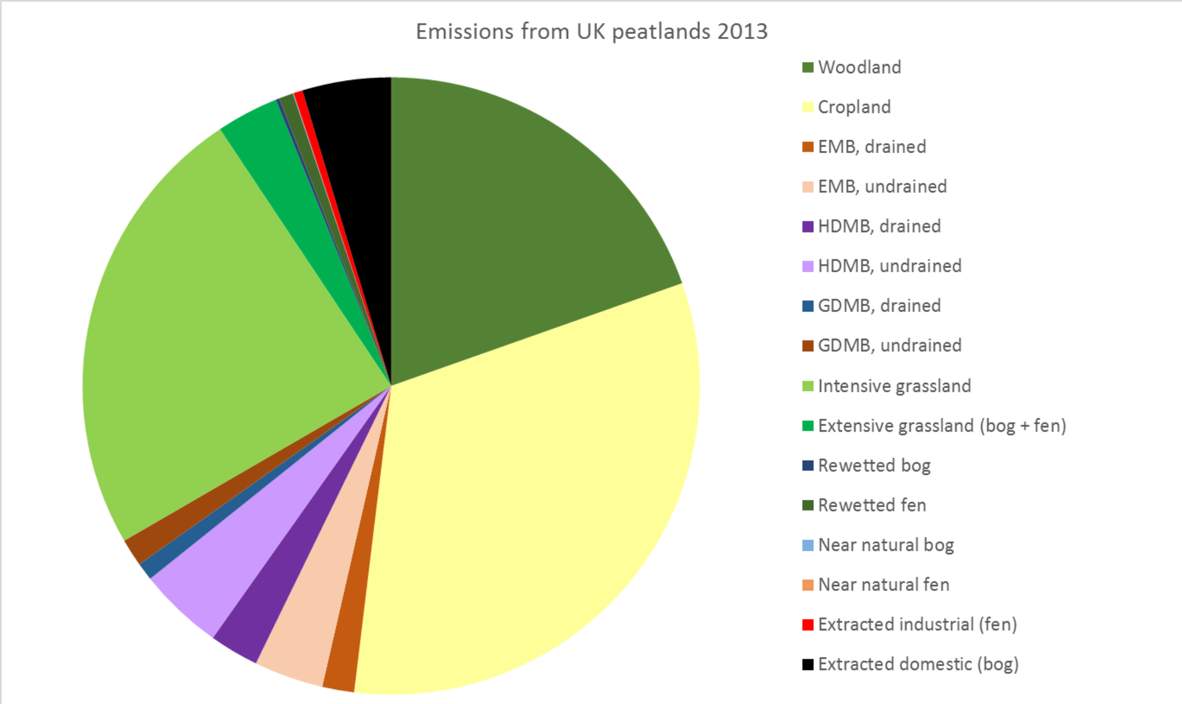

Figure 4.1. *Contribution of individual 'Tier 2' peat condition categories to total UK emissions in 2013. EMB = Eroded modified bog, HDMB = Heather-dominated modified bog, GDMB = Grass-dominated modified bog.*

Total annual estimated emissions per country are shown in Figure 4.2. Figure 4.3 shows annual emissions per country (and peat type in England) aggregated by UNFCCC reporting category. Figure 4.4 shows the same data for the whole UK. As noted in Section 3, all activities (other than changes in forest and extraction area) were assumed to commence in 2000, and to occur at a steady rate thereafter; this assumption obviously has a strong influence on the trajectory of emissions changes. In general, the annual data emphasise the limited degree of temporal change in emissions. The largest proportional reductions in emissions have occurred on deep peat in England, and in Wales.

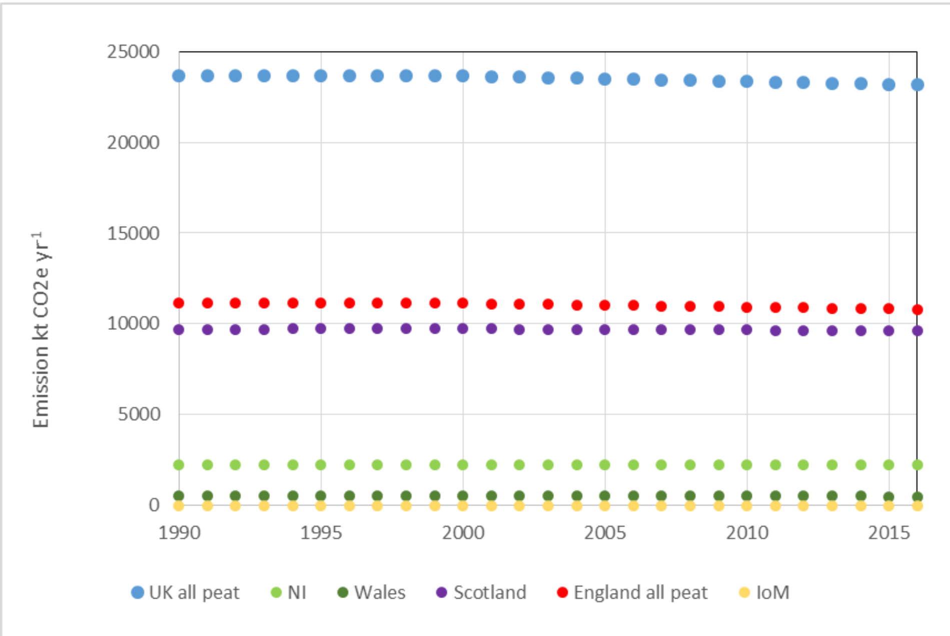

Figure 4.2. *Annual total GHG emissions, for the whole UK and by country, from 1990 to 2016.*

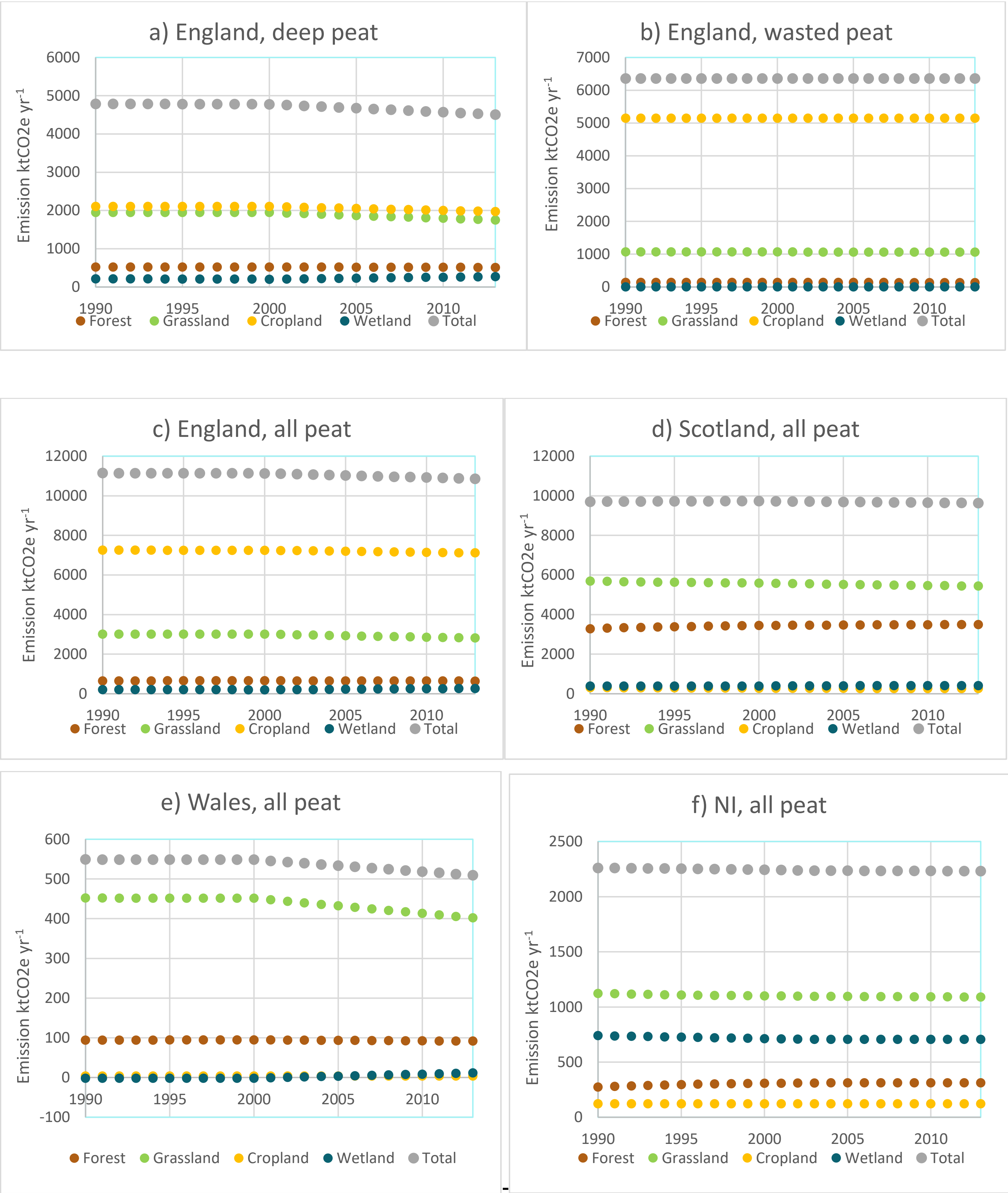

Figure 4.3. *Annual emissions by country/peat type, summarised by UNFCCC reporting category*

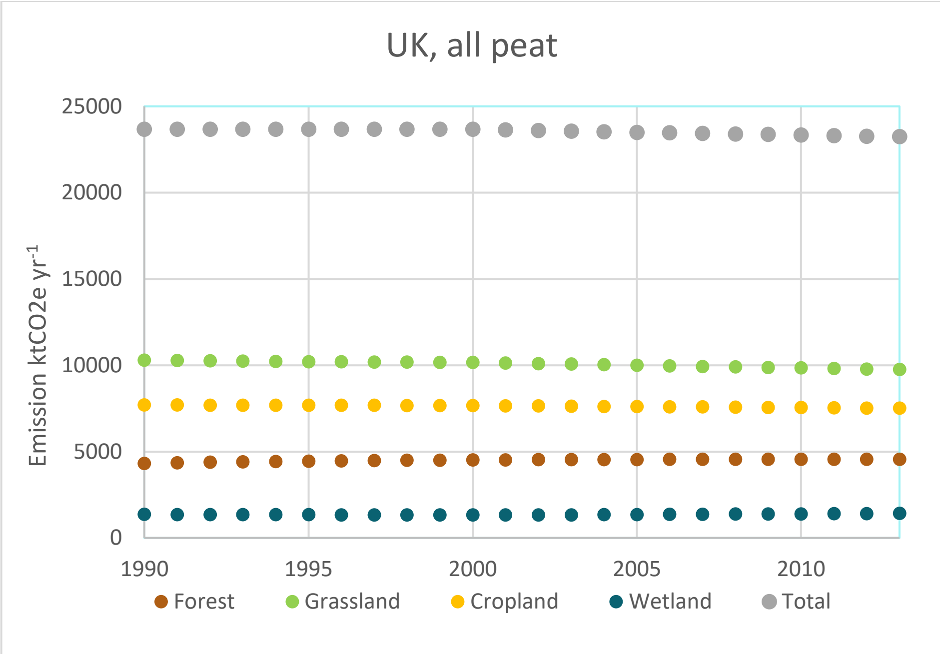

Figure 4.4. *Annual emissions for the whole UK, summarised by UNFCCC reporting category.*

4.3.3 Comparison to peatland emissions reported in the current UK inventory

The current UK inventory captures GHG emissions and removals associated with forestry, cropland, intensive grassland and industrial extraction on peat (Tables 4.4 and 4.5). The current methodology gives a total emission of around 2,600 kt CO2e yr^{-1} in 1990 and 1,600 kt CO_2e yr^{-1} in 2013, just 7% of the emissions estimate we obtained from this assessment (compare totals in Tables 4.2 and 4.3 with those in Table 4.4 and 4.5). These dramatic changes reflects multiple improvements in methodology and completeness of emissions reporting, including: differences in mapping of peat extent; differences in the approach used to map land-use categories; differences in emission factor estimates for individual peat condition categories (notably we obtained higher EFs for cropland and improved grassland, consistent with the Tier 1 values from the IPCC Wetlands Supplement); different assumptions about emissions from wasted peatlands; and the inclusion of additional condition categories in the current assessment (i.e. the various categories of modified bog, extensive grassland, domestic extraction and re-wetted bog and fen).

Table 4.4 *1990 total GHG emissions from peatlands by administration included in the 1990 – 2015 UK emissions inventory. All fluxes are shown in ktCO2e yr^{-1}.*

Administration	Forest remaining forest	Land converted to forest	Cropland	Improved grassland	Industrial peat extraction	Total emission
England	-16	21	1,436	53	4	1,498
Scotland	-30	692	157	51	4	874
Wales	-6	16	16	5	0	31
N. Ireland	-5	77	92	68	18	250
UK	-56	807	1,702	177	26	2,656

Table 4.5 *2013 total GHG emissions from peatlands by administration included in the 1990 – 2015 UK emissions inventory. All fluxes are shown in ktCO2e yr-1.*

Administration	Forest remaining forest	Land converted to forest	Cropland	Improved grassland	Industrial peat extraction	Total emission
England	-69	3	1,436	53	3	1,426
Scotland	-377	137	157	51	2	-30
Wales	-23	1	16	5	0	-1
N. Ireland	-4	19	92	68	0	175
UK	-472	160	1,702	177	6	1,573

The most pronounced difference between the two inventory estimates is associated with the treatment of forest on peatland. In the current inventory, based on the Tier 3 CARBINE-SCA model, peat in areas that have been recently converted to forest act as a small emission source, but peat under mature forest ('forest remaining forest') is predicted to act as a net GHG sink because as the forest matures, litter inputs to soil increase and the model suggests that these eventually outweigh lost from soil due to oxidation. In 1990 this results in forest acting as a net source of 751 ktCO$_2$e for the total area of peat under forest, but as UK forests have matured, this has become a net GHG sink of -312 kt CO$_2$e yr^{-1} by 2013. The net GHG sink in peat under mature forests modelled by CARBINE-SCA is sufficient to make peatlands in Scotland overall net GHG sinks in 2013, and those in Wales approximately GHG-neutral. In stark contrast, our emissions estimates for UK forestry based on empirical Tier 2 data give an overall GHG emission of around 4600 kt CO$_2$e yr^{-1} throughout the time period. This mismatch clearly represents a crucial area of uncertainty in the UK emissions estimates, and is discussed further in the next section.

Although less dramatic than for forest land, the contrast in total emissions estimates for other land-use categories are nevertheless very large. For croplands, our total estimated emissions of 7512 kt CO$_2$e yr^{-1} in 2013 are about 4.5 times higher than the current inventory values, and for intensive grassland our estimate of 5579 kt CO$_2$e yr^{-1} is 32 times higher than the current value. Even the estimate for industrial peat extraction 110 kt CO$_2$e yr^{-1} is much larger than the existing inventory value.

4.4 Uncertainty assessment

Overall uncertainty in the recent (2013) emissions estimates for UK peatlands derives from a number of sources: uncertainties in the emissions factors used; uncertainties in the mapping of peat extent; uncertainties in the allocation of peat areas to condition classes; and uncertainties in the extent of peat condition change since the map reference year (for countries where this was not 2013). Whilst uncertainties in EFs are to some extent quantifiable (as reflected in the 95% confidence intervals recorded in Tables 2.1 – 2.3), those associated with the activity data cannot be objectively determined. Therefore we have assessed the uncertainty associated with each component of the total GHG emission as high, medium or low based on a combination of the EF confidence intervals and expert judgement as to the likely accuracy of the activity data. We also considered the (currently unquantifiable) uncertainty associated with the extrapolation of EFs from measurements made largely on deep peat to shallower 'wasted' peatlands. The resulting 'uncertainty matrix' is shown in Table 4.6, which also takes account of the relative contribution of different fluxes to the overall UK emissions total.

4.4.1 Carbon dioxide

For CO$_2$, several major fluxes are considered to have a low overall uncertainty. In particular, CO$_2$ emissions estimates for cropland and intensive grassland on deep peat, which comprise 8% and 16% of total UK peat net GHG emissions respectively, are considered to be based on robust Tier 2 EFs and reliable land-cover mapping data; the largest uncertainties for these categories are associated with the accurate mapping of the boundary between peat and non-peat soils in lowland areas. CO_2 emissions from industrial extraction sites are also considered fairly reliable, as they are based on good EF data and accurate mapping data. Estimated CO_2 sequestration by near-natural bogs is also considered to be based on robust EFs and reasonably reliable mapping information. This flux is significant for the overall inventory; total GHG emissions would be around 8% higher without the inclusion of CO_2 uptake by peat-forming systems. CO_2 emission factors for near-natural fens, and for re-wetted bogs and fens, are also considered fairly reliable, but the mapping of these areas carries a higher uncertainty due to the reliance on individual project descriptions to quantify re-wetted areas, and the lack of information on natural fen peat extent in all countries except Wales.

Table 4.6. *Total 2013 emissions (kt CO_2e yr^{-1}) per greenhouse gas, peat condition category and depth category (deep/wasted; note that wasted peat data derive from England only). Cells are shaded according to assessed uncertainty in the flux (a function of uncertainty in the emission factor and uncertainty in the area estimate – red = high, amber = intermediate, green = low). Intensity of shading indicate importance of flux to overall emissions estimate (Dark > 1000 kt CO_2e yr^{-1}, Mid 100-1000 kt CO_2e yr^{-1}, Pale 10 -100 kt CO_2e yr^{-1}). Fluxes contributing < 10 kt CO_2e yr^{-1} are unshaded.*

GHG	CO_2		CH_4		N_2O	
Peat category	**Deep**	**Wasted**	**Deep**	**Wasted**	**Deep**	**Wasted**
Forest	3941	121	113	3	365	11
Cropland	1698	3698	90	196	577	1255
Eroded Modified Bog	766	0	431	0	35	0
Heather-dominated Modified Bog	555	0	1036	0	45	0
Grass-dominated modified Bog	187	1	347	3	15	0
Extensive grassland	579	8	97	1	70	1
Intensive grassland	3753	874	276	64	496	116
Near Natural Bog	-1802	-5	1792	7	17	0
Near Natural Fen	-13	0	10	0	1	0
Extracted Domestic	922	1	120	0	37	0
Extracted Industrial	100	0	7	0	3	0
Rewetted Bog	-68	0	110	1	2	0
Rewetted Fen	50	0	115	0	8	0

CO_2 emissions from modified bogs carry moderate-to-high levels of uncertainty, as a result of a number of factors, including: i) limited knowledge regarding the flux and fate of POC lost from eroded bogs; ii) lack of data on the extent of actively eroding bog within areas mapped as containing erosional features; iii) insufficient data to map specific land-use activities such as ditch drainage and managed burning within each category; and iv) a corresponding lack of measured flux data from which to derive specific EFs for these sub-categories. The EF for heather-dominated modified bog was based on a large dataset, but data for grass-dominated modified bogs were sparse, and it was therefore necessary to apply a single EF for both categories. Defining grass-dominated modified bog also presented particular difficulties in defining the boundary between grass-dominated bog and extensive grassland from available spatial datasets, especially in England and Northern Ireland where we had to apply a simple upland/lowland split. The uncertainty in estimated emissions from grass-dominated bogs is significant given the extensive *Molinia* bogs of Southwest England, South Wales and Southwest Scotland, which might be expected to have different GHG balance to heather-dominated areas. In combination, the three modified bog categories are estimated to contribute 10% of total UK peat GHG emissions, with heather-dominated modified bog forming the largest contributor. CO_2 emissions from bogs affected by domestic peat extraction contribute a further 6% to UK GHG emissions, with Northern Ireland representing the largest source. Many of these areas are no longer actively worked, but remain strongly modified by historic cutting, and the extent to which such areas continue to lose CO_2 is not well quantified, leading to a high overall uncertainty.

The highest uncertainties in CO_2 emissions from deep peat were considered to be associated with forest (responsible for 27% of total UK peat GHG emissions based on this analysis). Although forest areas are reliably mapped, uncertainties in the peat base map (especially in Scotland, where most afforested peat is located) make the total forest area on peat uncertain, and (as noted in Section 2) the CO_2 EF for forest on peat is based on a very limited dataset. Emissions from all forest land in the UK inventory are currently reported using a Tier 3 (model-based) methodology, so it is unlikely that these emissions estimates will be used directly, however they do provide a potentially useful independent check on the Tier 3 predictions, and would become more valuable in this regard if based on a greater number of primary flux measurement data.

For wasted peatlands, land use is heavily dominated by cropland and improved grassland. CO_2 emissions from these areas are highly uncertain as a result of: i) uncertainties in the mapping of wasted peats (only available for England); ii) a lack of information on the surviving peat content of these soils; and iii) a near-complete lack of UK flux data from areas of wasted peat. As noted earlier, data from other countries suggest that shallow cultivated peats continue to emit CO_2 at a high rate, but clearly there are limits to the amount that can be emitted as remaining carbon stocks become depleted. Since the vast majority of wasted peat is under cropland or intensive grassland, total emissions from these categories are very large (20% of total GHG emissions) despite the comparatively small proportion (7%) of the total mapped UK peat area they occupy. Uncertainties in these emissions thus have a strong bearing on total estimated GHG emissions from UK peatlands.

4.4.2 Methane

Emissions of CH_4 are mainly associated with undrained areas, with the largest emissions coming from near-natural and modified bogs. Each of these categories contributes 8% to total UK GHG emissions from peatlands, but it is important to note that both fluxes can be considered predominantly natural, and that CH_4 emissions from near-natural bogs are cancelled out in CO_2-equivalent terms by CO_2 uptake. Emission factors for both categories were based on fairly large datasets, although (as for CO_2) it was not possible to differentiate emissions from the different modified bog categories, due primarily to a lack of flux data for grass-dominated bog, and also could not distinguish emissions from drained and undrained areas within each category. Taking these issues into account, as well as uncertainties in the mapping data, all CH_4 emissions from modified bogs, rewetted bogs and fens, and near-natural fens were all assigned a moderate level of uncertainty, whereas CH_4 emissions from near-natural bogs were assigned a low uncertainty. Given the issues identified above with regard to the mapping and function of domestic peat extraction areas, CH_4 emissions from this source were assigned a high uncertainty.

For drained land-uses on peat, including cropland, forestry and agricultural grassland, the majority of CH_4 emissions are derived from drainage ditches, and were estimated using the IPCC Tier 1 methodology. Limited field data suggest that CH_4 emissions from ditches have a high temporal and spatial variability (Peacock et al., 2017), so these emissions were also assigned a moderate uncertainty. This issue also affects drained areas of modified bog, albeit to a lesser extent (Table 4.1).

4.4.3 Nitrous oxide

All N_2O emissions estimates were considered to have a high uncertainty. In addition to the uncertainties in area mapping discussed above in relation to CO_2 and CH_4 emissions, most N_2O EF estimates are reliant on a small number of flux measurements, often with a high degree of within-category variability, leading to wide confidence intervals (Table 2.3). This is a particular issue for cropland and intensive grassland, likely due to local variations in fertiliser and drainage regimes, as well as the intrinsic spatial and temporal heterogeneity of N_2O emissions. Cropland N_2O emissions from peat account for 8% of UK GHG emissions from peatlands, and N_2O emissions from intensive grassland on peat contribute for a further 3%, therefore high uncertainties in these fluxes have a significant bearing on the national inventory.

Of the remaining peat categories, N_2O from forestry on peat contributes 2% to UK total GHG emissions from peatlands, but all other categories contribute < 0.5%. Therefore, although these estimates are uncertain, their impact on total emissions is minor.

4.4.4 Overall confidence levels

Whilst acknowledging that the uncertainty classes in Table 4.4 are subjective, used this classification has been used to provide a crude estimate of the robustness of the emissions fluxes in the current peatland inventory. Based on the green 'low uncertainty' cells, it is estimated that a total of 5,541 kt CO_2e yr^{-1} of emissions can be quantified with a fairly high degree of confidence. This number is lower than might be expected, because two large 'low uncertainty' fluxes, CO_2 uptake and CH_4 emissions from near-natural bog, effectively cancel out. The amber 'medium uncertainty' cells collectively contribute 3,413 kt CO_2e yr^{-1} to total emissions, and the red 'high uncertainty' cells contribute 14,283 kt CO_2e yr^{-1} to total emissions (the remaining white cells contribute just 0.1% of the total).

Based on this simple assessment, 24% of the current estimate of total emissions from the UK's peatlands can be estimated with fairly high confidence, and a further 15% with moderate confidence, but that the majority of the estimate (61%) can only be estimated with a low level of confidence. Clearly, this does not imply that these emissions should be discounted – in many cases emissions are as likely to be under-estimated as over-estimated. However, there is clearly a need for ongoing effort to further constrain both emission factors and activity (i.e. area) estimates for many land-use and condition categories on the UK's peatlands, in particular for those high-uncertainty categories that exert a strong leverage on the overall total. Priorities for future work are considered in Section 6.

Figure 4.5 shows estimated UK emissions from peatlands generated using the Tier 2 EFs developed in this project, and the upper and lower Confidence Intervals (CIs) associated with these EFs. The yellow line shows emissions from all land uses but using implied emission factors from CARBINE for forestry rather than the Tier 2 EFs.

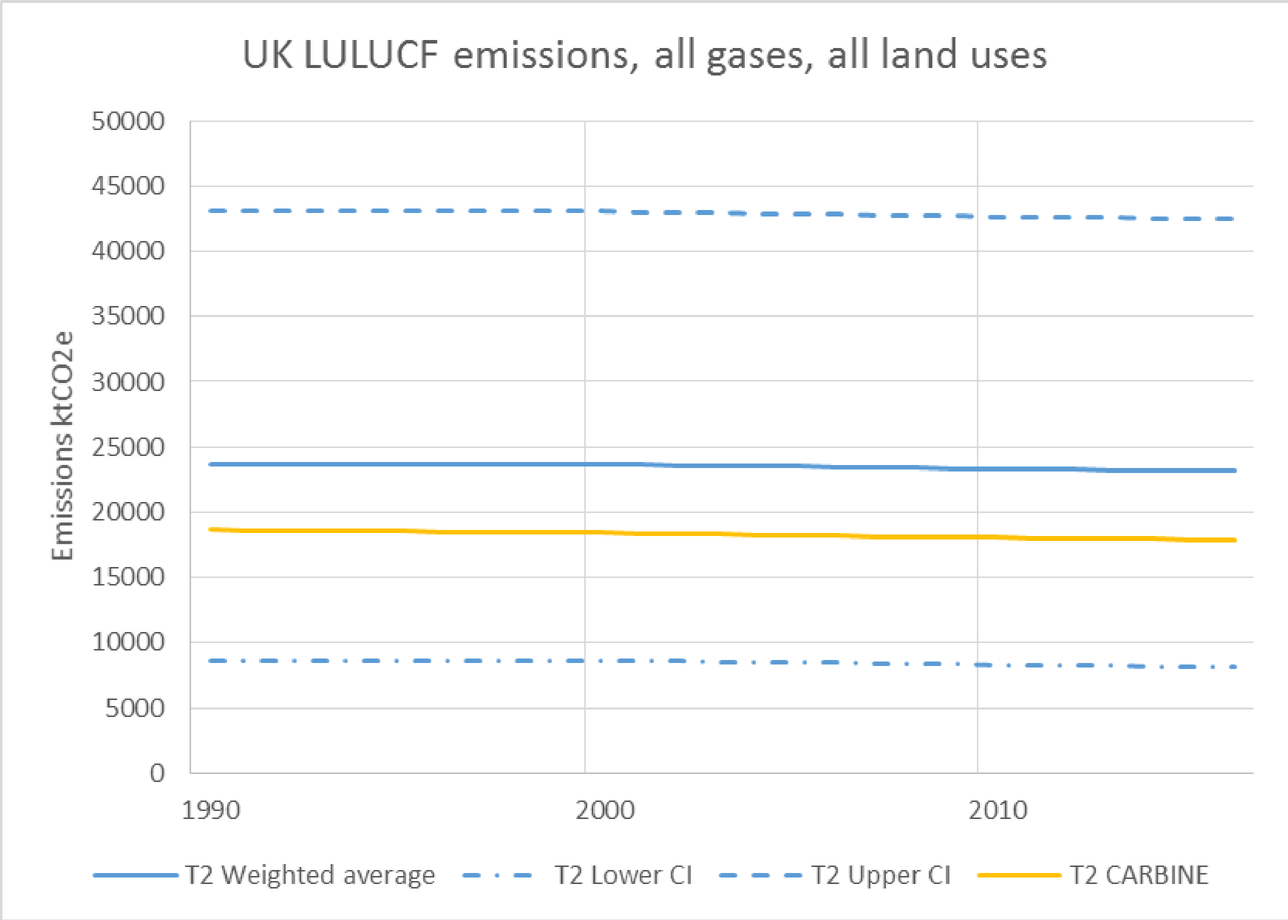

Figure 4.5. *Uncertainty analysis of UK emission estimates showing the upper and lower Confidence Intervals (CIs) of the Tier 2 two emissions factors, and emissions estimated using the Tier 2 EFs for all land uses except for Forest where implied EFS from CARBINE are used.*

5 MITIGATION SCENARIOS

5.1 Mitigation scenario development

Five scenarios for future peatland management to 2050 were developed in consultation with representatives of BEIS, Defra and the Devolved Administrations (DAs) of the UK. The **Baseline** scenario reflected policies for peatland restoration which were in place in 2009; the **Central** scenario included current policies; the **Low** emissions scenario included policy aspirations and the **Stretch** scenario was designed to include policies beyond current aspirations or funding. In addition, a **High** emissions scenario which projected further degradation of near-natural peatlands leading to increased emissions from peatlands was included to provide a 'counterfactual' assessment of potential emissions in the absence of any conservation or restoration measures. Details of the five scenarios are shown in Table 5.1. In this assessment, 'Lowland Peat' comprises Cropland and Improved Grassland on peat, while 'Upland Peat' comprises Modified Bog and Extensive Grassland. Where targets for change in management involve multiple peat conditions, the areas affected are split between peat conditions based on their ratio in 2016.

Note that the emissions scenarios modelled do not include off-site emissions from extracted peat. These would be expected to reduce as the area of peat extraction reduces. The reduction in off-site emissions from use of extracted peat will offer additional abatement to that estimated in the projections of on-site emissions from peat extraction sites.

Similarly, the scenarios do not take account of changes in tree biomass or Harvested Wood Products from forests on peat, or the subsequent fate of this material, as these carbon stock changes are accounted for separately in the UK GHG Inventory. In this case, reduced emissions from peat under forest would be partially offset by a decrease in timber entering the harvested wood products pool or being used for bioenergy production, both of which contribute to reducing emissions. Reductions in the forest area on peat could also impact on other non-peatland areas if additional afforestation is required to maintain timber supplies.

***Table 5.1**. Scenarios for peatland management to 2050*

Scenario	Description	England	Scotland	Wales	N. Ireland
Baseline	Climate change-related policies extant in July 2009	*Peat extraction*: ceases at planned expiry dates, with 100% restoration. *Restoration*: assume current areas for each peat condition remain unchanged to 2050 (except for restoration of extraction sites).	*Peat extraction*: remain at 2009 levels. *Restoration:* assume current areas for each peat condition remain unchanged to 2050 (except for restoration of extraction sites).	*Peat extraction*: remain at 2009 levels. *Restoration*: assume current areas for each peat condition remain unchanged to 2050 (except for restoration of extraction sites).	*Peat extraction*: remain at 2009 levels. *Restoration*: assume current areas for each peat condition remain unchanged to 2050 (except for restoration of extraction sites).
Central	The scenario with current policies and funding in place	*Peat extraction*: ceases at planned expiry dates, with a 50% assumption on restoration success to target habitats. *Restoration*: assume no restoration of lowland or upland peat (except for restoration of extraction sites).	*Peat extraction*: Remain at 2014 levels. *Restoration*: Restore 50 kha of peatland by 2020 and 250 kha (40% of currently degraded peatland) by 2030. 10,000 ha in 2017/18 and 20,000 ha in subsequent years (Scottish Government, 2017). Restored peatland is assumed to be upland peat and forest.	*Peat extraction*: N/A. *Restoration*: assume no restoration of lowland or upland peat.	*Peat extraction*: Remain at 2014 levels. *Restoration*: assume no restoration of lowland or upland peat (except for restoration of extraction sites).
Low	Policy aspirations in each of the DAs projected forward beyond 2021	*Peat extraction*: ceases at planned expiry dates, with a 100% assumption on restoration success to target habitats. *Restoration*: 25% area restoration of degraded lowland peat, restoration of 50% of area of degraded upland peat.	*Peat extraction*: cessation of peat extraction with 50% restoration by 2050. *Restoration*: Restoration: 25% area restoration of degraded lowland peat, restoration of 50% of area of degraded upland peat.	*Peat extraction*: N/A. *Restoration*: 25% area restoration of degraded lowland peat; restoration of 50% of area of degraded upland peat.	*Peat extraction*: cessation of peat extraction with 50% restoration by 2050. *Restoration*: 25% area restoration of degraded lowland peat; restoration of 50% of area of degraded upland peat
Stretch	Exceeding current policy aspirations or funding.	*Peat extraction*: Cessation of all peat extraction 100% restoration by 2030. *Restoration*: 50% area restoration of degraded lowland peat, 75% area restoration of degraded upland peat; restoration of 50% of forest area planted on peat since 1980	*Peat extraction*: Cessation of all peat extraction with 100% restoration by 2030. *Restoration:* 50% area restoration of degraded lowland peat, 75% area restoration of degraded upland peat; restoration of 50% of forest area planted on peat since 1980	*Peat extraction*: N/A. *Restoration*: 50% area restoration of degraded lowland peat, 75% area restoration of degraded upland peat, restoration of 50% of forest area planted on peat since 1980	*Peat extraction*: Cessation of all peat extraction with 100% restoration by 2030. *Restoration*: 50% area restoration of lowland peat, 75% area restoration of degraded upland peat; restoration of 50% of forest area planted on peat since 1980

High	Sensitivity analysis scenario of further degradation of existing peat	*Peat extraction:* as for Central scenario 25% of near natural bog becomes modified bog, forest and extensive grassland.	*Peat extraction:* as for Central scenario 25% of near natural bog becomes modified bog, forest and extensive grassland.	*Peat extraction*: as for Central scenario 25% of near natural bog becomes modified bog, forest and extensive grassland.	*Peat extraction*: as for Central scenario 25% of near natural bog becomes modified bog, forest and extensive grassland.

5.2 Projections

Projected emissions for the UK as a whole are shown in Figure 5.1. Projections for each of the constituent administrations are shown in Appendix 1, and the overall changes in emissions between 2016 (the most recent year for which actual data are available) and 2050 for each administration are shown in Table 5.2. Emissions by land use category for each UK administration under each scenario are shown in Appendices 2 -6. The uncertainty associated with the each projection is shown at a UK level in Appendix 7.

***Table 5.2**. Change in total GHG emissions (in kt CO2e yr^{-1}) from each UK administration, 2016-2050.*

	England	Scotland	Wales	NI	UK
High	+90	-456	+54	+54	-259
Baseline	-4	+1	0	0	-3
Central	-3	-1,084	0	0	-1,088
Low	-2,131	-1,742	-118	-339	-4,331
Stretch	-4,214	-3,186	-201	-685	-8,286

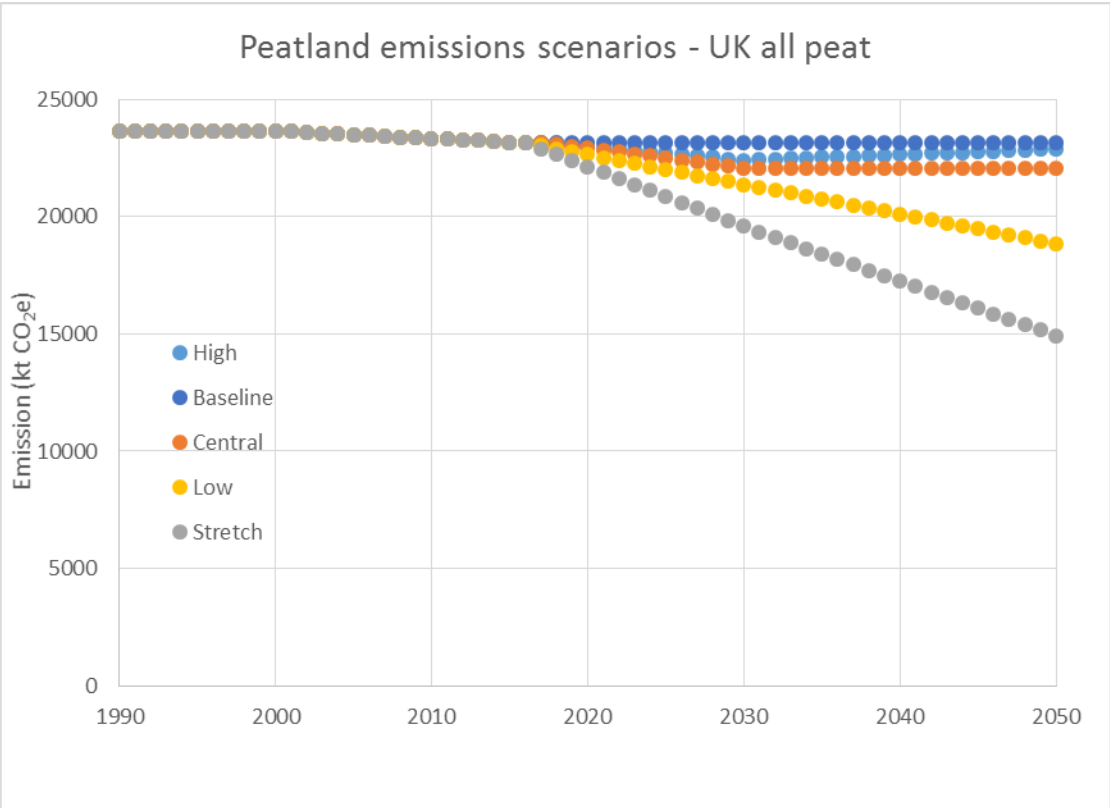

***Figure 5.1**. Peatland emissions scenarios, UK*

5.2.1 Baseline Scenarios

The Baseline emission scenarios (Appendix 2) show little difference from current emissions, as the only driver for change is change in peat extraction site area.

Data on expected closure dates of peat extraction sites based on planning consents were only available for England and these expected extraction site closures give a small reduction in emissions by 2050. For Scotland the Baseline scenario suggests a very small increase in emissions as the peat extraction site area post-2016 is set at 2009 levels which are slightly larger than the 2016 area.

For Wales and Northern Ireland the Baseline scenarios show no change from current emissions.

5.2.2 Central Scenarios

The Central emission scenarios (Appendix 3) again show little change in emissions for England, Wales and Northern Ireland, as there are no definite funded policy targets for peatland rewetting in these administrations.

For England a very small reduction in emissions by 2050 is projected due to expected closure of peat extraction sites. The Central scenario assumes that the success rate for restoration of these sites is only 50% and so this change is less than for the Baseline scenario, which assumes restoration of extraction sites is 100% successful.

Scotland has laid out targets for funded restoration of peatlands as part of the latest Draft Climate Change Plan (Scottish Government, 2017), so these targets have been included in the Central scenario. It has been assumed that the restored area comprises Forest, Modified Bog and Extensive Grassland, and the total restoration areas have been split between these peat conditions based on their relative proportions in 2016. This gives an emissions reduction for Scotland of 1084 ktCO_2e yr^{-1} by 2050, with 52% of this emissions reduction arising from rewetting of forest on peat, and 39% from rewetting modified bogs, and a smaller contribution from rewetting extensive grassland. However this estimate only considers the change in emissions from the peat itself, and does not include emissions due to change in biomass carbon stocks. Emissions produced by loss of tree biomass carbon as a result of removing forest on peat would reduce the abatement provided this scenario.

5.2.3 Low Scenarios

The Low emissions scenarios, which include aspirational targets for restoration of degraded upland and lowland peat (but not Forest) give emissions reductions for all administrations (Appendix 4), and a total emissions reduction of 4331 ktCO_2e yr^{-1} for the UK by 2050.

On a UK level, abatement was fairly evenly split between cropland on peat (32% of the total abatement), modified bogs (29% of the total) and intensive grassland (24% of the total). Rewetting of extensive grassland and peat extraction sites offered smaller abatements.

In England, the proportion of abatement offered from rewetting cropland on peat was higher than for the UK as a whole with 68% of the projected abatement coming from cropland rewetting. Rewetting intensive grassland gave 21 % of the abatement in England, and rewetting modified bogs 11%. For other administrations, cropland rewetting made a much smaller contribution (less than 10% of the total abatement in all cases).

In Scotland, the majority of the abatement (54%) came from rewetting modified bogs, with rewetting of intensive grassland also making a significant contribution (23% of the total abatement). Rewetting extensive grassland and peat extraction sites made smaller contributions.

For Wales, abatement was split fairly evenly between rewetting of extensive grassland, intensive grassland and modified bogs, with these peat conditions contributing 40%, 33% and 26% of the total abatement respectively.

50% of abatement in Northern Ireland came from rewetting peat extraction sites, because of the large area of these domestic extraction sites in the province. 34% of abatement came from rewetting intensive grassland, with 9% from rewetting modified bogs, and smaller contributions from rewetting cropland and extensive grassland.

5.2.4 Stretch Scenarios

The **Stretch** emissions scenarios (Appendix 5) are intended to exceed the current aspirations and policy. They incorporate ambitious restoration of upland and lowland peat, and removal of 50% of post-1980 afforestation on peat. They suggest an emission reduction of 8286 ktCO_2e for the UK overall, and reductions in excess of those from the Low emissions scenario for all administrations.

The abatement was split between peat condition categories in a similar pattern to the Low emissions scenarios. Again, for UK as a whole, abatement was split fairly evenly between cropland on peat (33 % of the total abatement), modified bogs (23 % of the total) and intensive grassland (25 % of the total), with smaller abatements from rewetting of forest, extensive grassland and peat extraction sites.

As in the Low scenario, in England, rewetting cropland on peat provided 68% of the projected abatement, while rewetting intensive grassland gave 21 %. In the Low scenario for England, modified bogs gave 8 % of the abatement.

In Scotland, the rewetting modified bogs again provided the largest abatement source, although in the Stretch scenario they contributed a smaller proportion of the total abatement (45 %) than in the Low scenario. The relative contribution of rewetting of intensive grassland was slightly higher in the Stretch scenario than in the Low scenario (26% of the total abatement). Rewetting of forest, extensive grassland and peat extraction sites each contributed just under 10% of total abatement.

For Wales, abatement was split fairly evenly between rewetting of intensive and extensive grassland, intensive grassland contributed 39 % and 35 % the total abatement respectively, while rewetting modified bogs contributed 23 % of the total.

As in the Low scenario, the large area of domestic peat extraction sites in Northern Ireland led to rewetting of extraction sites giving 50% of its projected abatement. 34% of abatement came from rewetting intensive grassland, with 7% from rewetting modified bogs, and smaller contributions from rewetting modified bogs, cropland, forest and extensive grassland.

The uncertainty analysis of this scenario suggests that it might result in a net GHG sink by 2046 if emission factors were used which were at the lower limit of the EF confidence interval. This requires very ambitious action coupled with EFs at the lowest end of the range and would only occur at the far end of the projected time series when uncertainty is highest.

5.2.5 High Scenarios

The **High** emissions scenarios (Appendix 6) assume that 25% of near-natural bog becomes degraded to Modified Bog or Extensive Grassland by 2050, and project increased emissions for England, Wales and Northern Ireland, although this effect is relatively small for England, because current peatland management means that near-natural bog makes up only 1.3% of the total peatland area, a smaller proportion than in Wales and Northern Ireland administrations. Conversely it is more significant for Wales where around 25% of peatlands are classified as near-natural bog.

For Scotland the effect of further peatland degradation is offset by the peatland restoration which forms part of the Central scenario on which the High emissions scenario for further degradation of near-natural peat is based. Therefore the High scenario for Scotland projects a slight decrease in emissions from peatland despite further deterioration in the condition of near-natural areas.

The effect of further peatland degradation modelled by the High scenarios underlines the importance of protecting near-natural peatlands from further degradation, as well as restoring peatlands which are already damaged. The High emissions scenario only considers degradation of near-natural bog, and not further deterioration in the condition of peatlands which are already degraded (e.g. conversion of Intensive Grassland to Cropland, afforestation of Modified Bog or conversion of Modified Bog to Extensive Grassland). Further deterioration in the condition of degraded peatlands would further increase the higher emissions projected by the High Scenario.

It is worth noting that while the Central, Low and Stretch scenarios offer worthwhile abatement of peatland emissions, no scenario using the Tier 2 EFs suggests that restoration can convert peatlands into net GHG sinks, because all scenarios still allow for some continuation of agriculture and forestry on peat, as well as the continued existence of some degraded upland blanket bogs. In a very extreme projection, using the lowest emission confidence limits for the Tier 2 EFs in the Stretch scenario, it is suggested that there is a possibility of UK peatlands becoming a net GHG sink from 2046, but this requires a very particular combination of emissions factors and action over a long period, so is a very uncertain outcome. Additionally, as shown in Section 2, re-wetted peatlands are not (based on their calculated Tier 2 EFs) expected to achieve the same CO_2 sink function as near-natural areas, and CO_2 sequestration will be at least partially offset by CH_4 emissions under higher water tables. Nevertheless, the extent of mitigation predicted under the higher-ambition scenarios represents a significant proportion of the current total emissions (Figure 5.1)

The potential importance of different land uses in mitigating emissions varies across the UK, reflecting patterns of land use on peat. In England, restoration of peat under cropland could provide substantial abatement under the Low and Stretch emission scenarios, while for other administrations it can only play a small role. However modifications to the management of cropland on peat would have to be balanced against other desired outcomes, particularly food production. Nearly two thirds of cropland on peat in England is on wasted rather than deep peat, and there is a risk that this proportion will increase if current management practices which reduce peat depth continue.

For Scotland, Wales and Northern Ireland, changes in the management of grassland on peat offer the greatest mitigation potential under most scenarios. The High emissions scenario highlights the importance of careful management of near-natural peats in these administrations, as deterioration in their condition would increase emissions.

The current scenarios suggest that removal of forest on peat could only have a modest role in reducing emissions. However this partly reflects the scenarios themselves, which in most cases only consider removal of a proportion of post-1980 forest. When removal of older forest is considered, as it is for Scotland in the Central Scenario, larger emissions reductions are achieved. However, the behaviour of peatlands under established forest remains uncertain, with significant divergence between the Tier 2 emission factors described above and estimated fluxes for mature forest currently estimated by the Tier 3 CARBINE-SCA model. It is therefore difficult to draw firm conclusions about the GHG consequences of removing forest on peat, although in many cases such deforestation could bring other benefits through improvements in biodiversity and landscape value.

6 Future research and data priorities

A separate report on gap-filling data and evidence needs for peatland inventory reporting was produced at an interim stage of the project (Taylor et al., 2016). This section briefly summarises and updates that report following the completion of the project, the initial inventory implementation, and other recent developments.

6.1 Emission factor estimation

The collation of emission factors described in Section 2 of this report highlighted some surprising data gaps for important UK peat condition categories. For the modified blanket bogs that occupy a large part of the UK uplands, it was not possible to robustly define separate EFs as a function of the dominant vegetation type (e.g. graminoid versus heather dominated); presence/absence of drainage; presence/absence of burn management; and presence/absence of erosion. Although new data are being gathered for some of these categories, a well-designed set of consistent flux measurements across representative examples of each sub-category would do much to improve our ability to accurately report on emissions associated with each category. CO_2 losses associated specifically with burning events (both prescribed fires and wildfires) are not well quantified, and better estimates of POC loss from eroding peatlands would also be beneficial. Given the large sums of money being invested in blanket bog restoration across the UK, often in part justified by anticipated reductions in GHG emissions, an improved evidence base in this area should be considered a high priority.

As described in Section 4.3, emissions from wasted peatlands, primarily in lowland England, make a large but highly uncertain contribution to the UK emissions total. Field measurements of CO_2 emissions from wasted peat under cropland and intensive grassland should be considered a high priority, as well as more data on N_2O emissions from these land-use categories in general, and on CH_4 emissions from drainage ditches. Given the overall importance of cultivated lowland peatlands to the UK peatland emissions budget, it may be appropriate to move towards a Tier 3 approach for these areas in future, for example taking into account local variations in water table as a dominant influence on CO_2 and N_2O emissions (Couwenberg et al., 2011; Evans et al., 2017) as well as the influence of agricultural management activities such as fertiliser use.

Our analysis also suggests that emissions from peat under conifer plantations make a major contribution to UK peat GHG emissions, but with a very high uncertainty and some potential for over-estimation of emissions based on the data sources used. We recognise that the UK already uses a Tier 3 approach to emissions accounting for forestry, and that work is ongoing to refine this modelling approach for organic soils. Both Tier 2 and Tier 3 methods would however benefit from a more extensive set of field flux measurements from afforested areas, incorporating a combination of flux towers, combined chamber and litter flux studies, and long-term stock change assessments if possible. We also note that *no* flux data are available for other woodland types on peat, such as wet woodland on fen peat or scrub woodland on raised bogs. A specific Tier 2 EF for forest sites that have been cleared and re-wetted would also be of value, since there are reasons to expect that these may function differently from re-wetted non-forested sites.

Finally, we note the scarcity of measured fluxes from abandoned domestic peat extraction sites, which are assumed to continue acting as significant CO_2 emission sources. Measurements over a chronosequence of active to long-term abandoned domestic extraction areas would provide a more reliable basis for reporting on emissions from these areas.

6.2 Peat area mapping

This project has made significant advances in mapping the presence/absence (rather than probability of occurrence) of peat across the four UK countries, based on best available data. Nevertheless, this analysis highlighted significant discrepancies between different maps for individual countries, and significant errors in defining the boundary between peat and other soil types are likely to exist in all current maps, with the potential to lead to significant errors in emissions estimates (notably where small semi-natural peat fragments occur within agricultural landscapes). Based on current data, we were also unable to differentiate bog and fen peat in most areas, despite the recognised importance of this classification for all aspects of peat function, biodiversity and GHG balance. An ongoing programme of improvement in peat mapping would therefore be beneficial, as would the development of standard mapping and reporting procedures across the four UK administrations, as well as Overseas Territories and Crown Dependencies with significant peat areas. Given the large area of peat in the Falkland Islands, further ground surveys and spatial data analysis to improve on the peat map created during this project should be considered a high priority. New satellite data may also provide opportunities for improved mapping of peat extent, for example based on InSAR analysis of Sentinel-1 radar data, which has the potential to detect the small-scale changes in surface elevation that are characteristic of most peatlands.

Finally, it is important to note that the peat mapping datasets used in the project came from multiple sources, and most are subject to licencing restrictions. This is likely to significantly limit wider use of the 'unified' peat layer created during the project. If the final peat map could be made accessible as 'open data' to other organisations and projects this would greatly enhance its future value for policy, land-management and research.

6.3 Activity mapping

In order to develop the UK peatland emissions inventory we were obliged to collate land cover data from a disparate range of sources, resulting in likely inconsistencies in classification between countries, as well as the need to assign different map reference years depending on when the best available data were collected. The absence of a single, consistently repeated UK land cover map represents a major evidence gap both for this work and for many other applications, including the wider LULUCF inventory. A similar map is also needed for the Falkland Islands.

For such a mapping approach to be of value for peat activity mapping, a sufficient level of classification detail will be needed to differentiate different condition categories, particularly the relatively subtle changes in semi-natural species composition that influence emissions from modified bogs and fens. Mapping of drainage extent presents particular difficulties, and previous attempts to automate ditch mapping from aerial photographs have proved challenging (Evans et al., 2015). However the use of vegetation-based proxies to infer peatland hydrological status and resulting GHG emissions (e.g. Couwenberg et al., 2011) may provide a more viable alternative to ditch mapping, utilising the unprecedentedly high-resolution spectral data now being generated by the Sentinel-2 satellite. The potential of this approach is being explored as part of an ongoing research project for Defra, and is discussed further below.

6.4 Monitoring activity change over time

For the current inventory, we were heavily reliant on descriptions of individual peat restoration projects, recorded by project participants in the Peatland Compendium, which has since been discontinued. Much of the information recorded in this database reflected actions undertaken (e.g. km of ditches blocked) rather than measured outcomes (e.g. re-establishment of a

Sphagnum-dominated bog community). Reporting is known to have been incomplete, and limited to restoration projects – for example no new drained activities (such as windfarm developments) were recorded. There is consequently a need to establish a long-term, regularly updated repository of peatland activities (both drainage and rewetting) as a basis for future reporting, and for this repository to record more quantitative information on activities undertaken (e.g. boundary GIS shapefiles to define the spatial extent of re-wetting, digitised ditch lines). Consistent outcome measures are also needed, which could be based on Peatland Code assessment methods. In the long-term, it may be necessary to establish a single organisation or programme to manage and update the repository, and to make this type of monitoring and reporting a requirement for projects receiving public funds.

In the current project, we were unable to account for possible changes in GHG emissions linked to agri-environment activities (other than those involving active restoration and re-wetting) due to a lack of sufficient information on the nature, extent, location and in particular the outcome of these activities on peatlands. More effective reporting of the location of agri-environment interventions, and more comprehensive recording of outcomes, are needed if the potential benefits of these activities are to be captured in the UK emissions inventory.

As described above, there is growing potential to use new remote sensing data to develop repeated, high-resolution condition maps for UK peatlands. Following the launch of the first Sentinel-2 satellite in 2015, capacity to accurately monitor change in peat condition (e.g. vegetation type, bare peat extent, burning) at the required resolution has greatly increased, and work is ongoing to develop and test peat classification methods using these data. A key constraint for these methods is access to ground-based observations of an appropriate scale to train classification algorithms, and the collection of such data (e.g. large-plot vegetation and peat condition assessments) as part of the restoration outcome monitoring described above would be highly valuable. Repeated aerial surveys of restoration sites, which are increasingly feasible using UAVs, would provide an additional 'intermediate' source of training and verification data for satellite-based classification methods, as would greater use of LiDAR to characterise fine-scale peat topography. Given the relatively recent launch of the Sentinel satellites, 'hindcasting' peat condition changes since the 1990 inventory baseline year remains problematic, and other (coarser resolution) satellite data would be needed to retrospectively estimate changes in peat condition over this period.

Finally, synthetic aperture radar (SAR) data from the Sentinel-1 satellites offer additional potential to measure key variables such as moisture and vegetation structure, whilst interferometric methods based on the same data (InSAR) have the potential to measure fine-scale changes in peat surface elevation. Over the longer term, these methods could be used to monitor peat growth or subsidence as a function of management, whilst short-term (sub-annual) variations in peat elevation may be indicative of changes in peat hydrological function (David Large, pers. comm.). Both long- and short-term data from InSAR monitoring thus has the potential to remotely monitor changes in peat status, for example as a measure of restoration success; the potential of this method is currently being explored via a NERC Soil Security project.

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Appendix 1. Projections for England, Scotland, Wales and Northern Ireland.

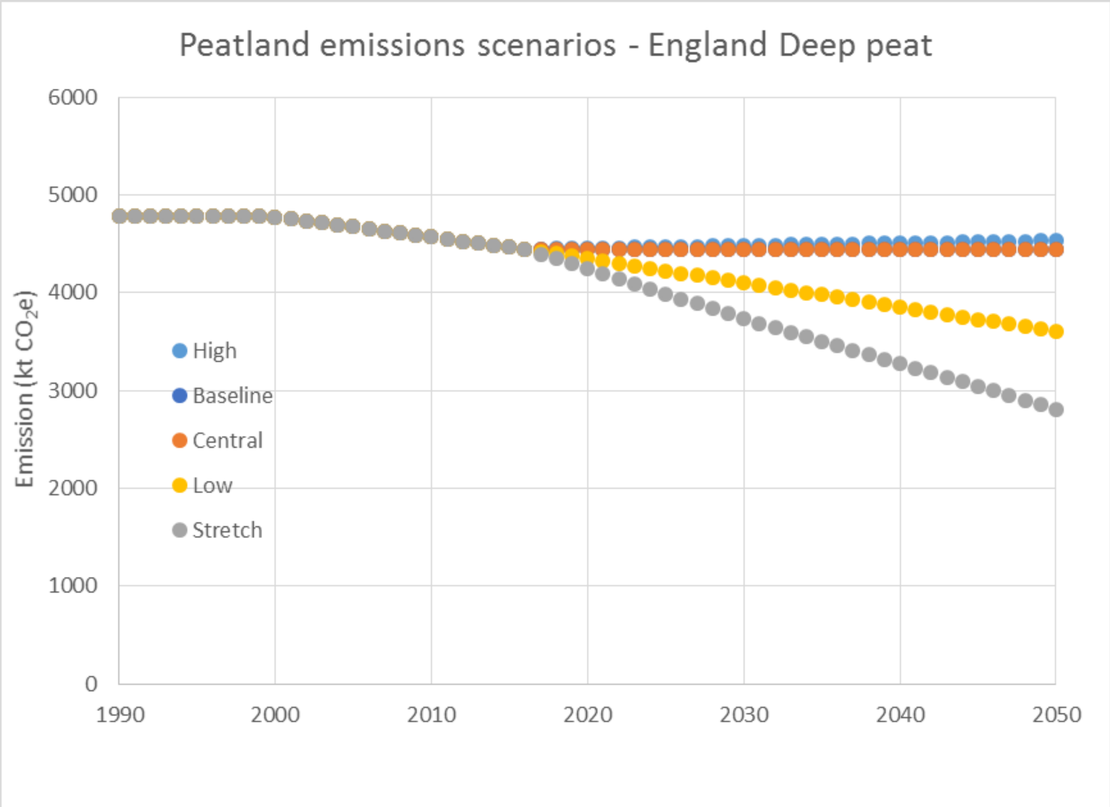
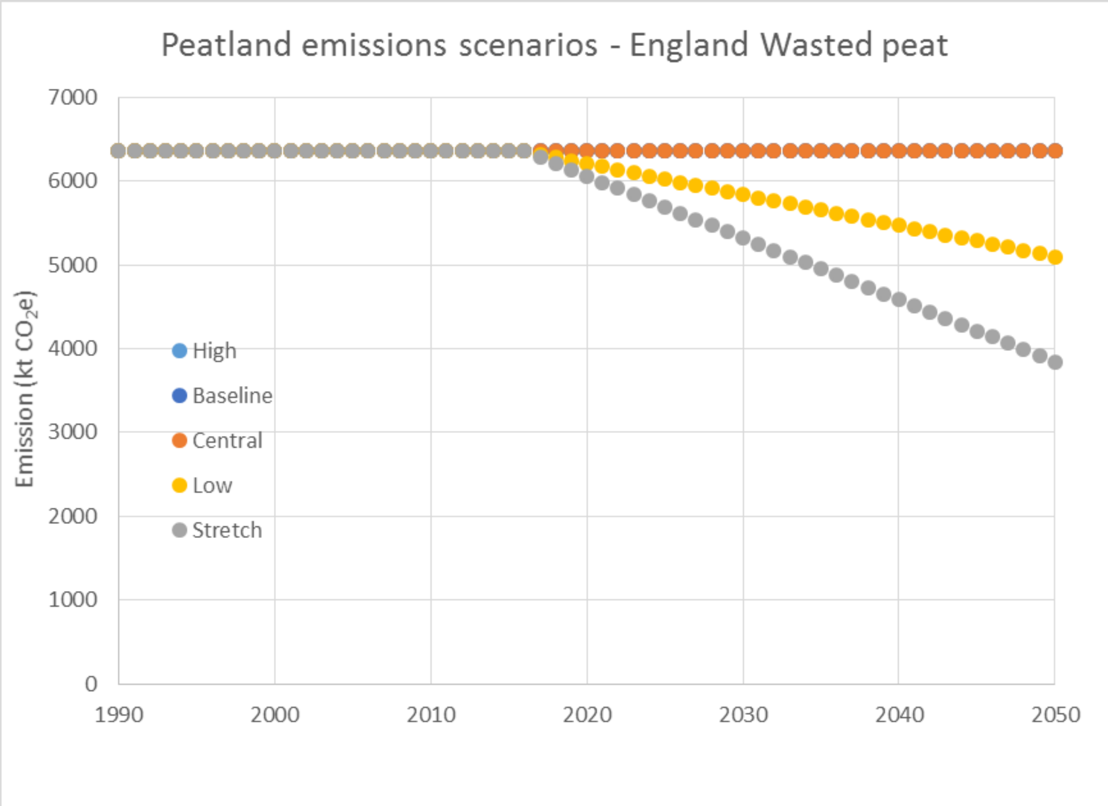


FIGURE A1.1 PEATLAND EMISSIONS SCENARIOS, ENGLAND, DEEP PEAT



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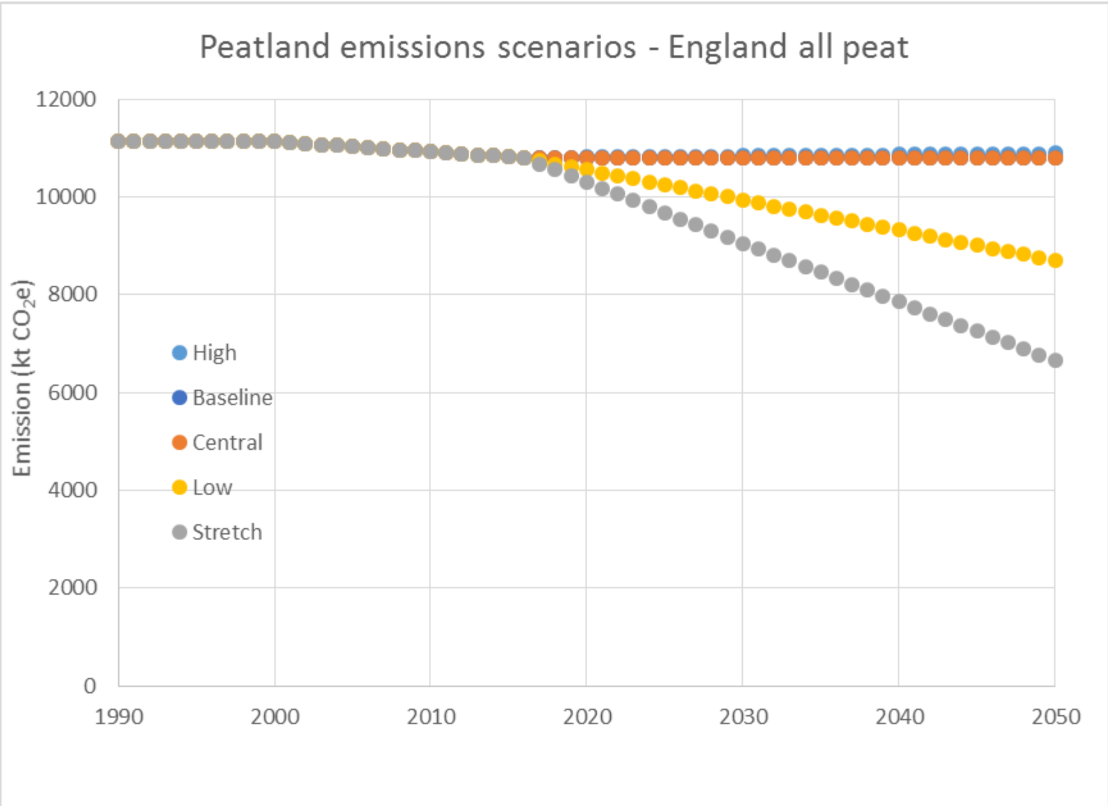

FIGURE A1.3 PEATLAND EMISSIONS SCENARIOS, ENGLAND ALL PEAT

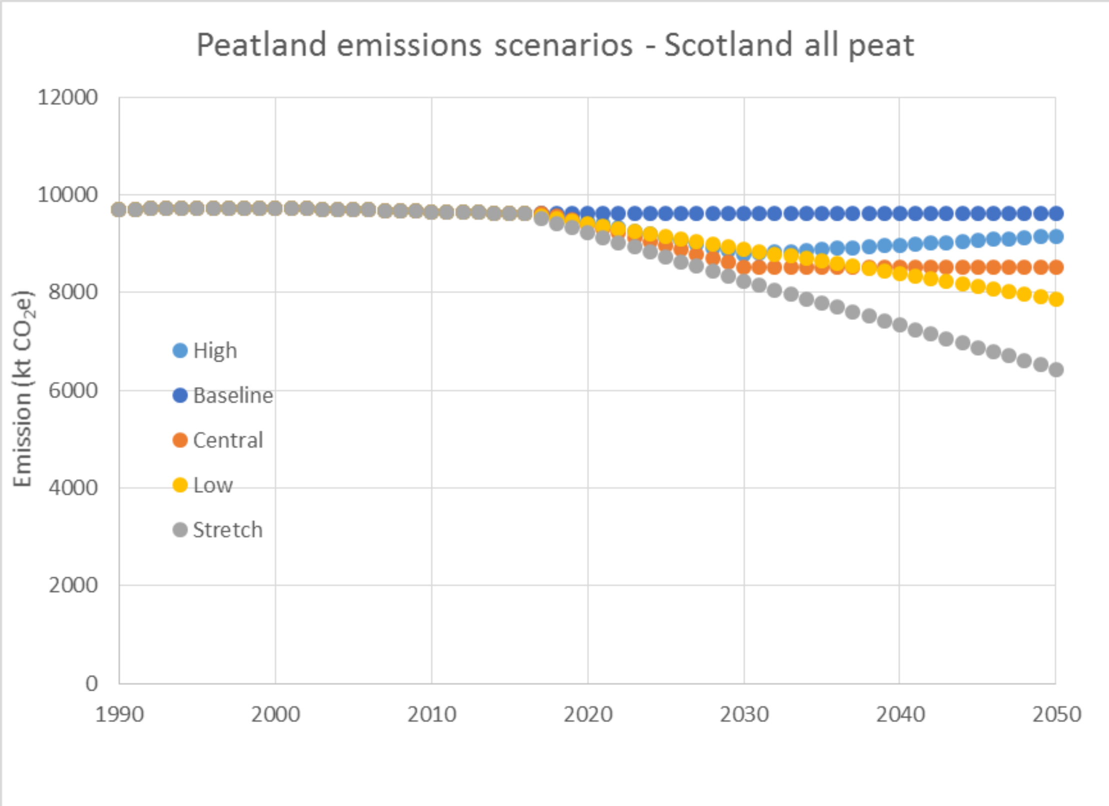

FIGURE A1.4 PEATLAND EMISSIONS SCENARIOS, SCOTLAND

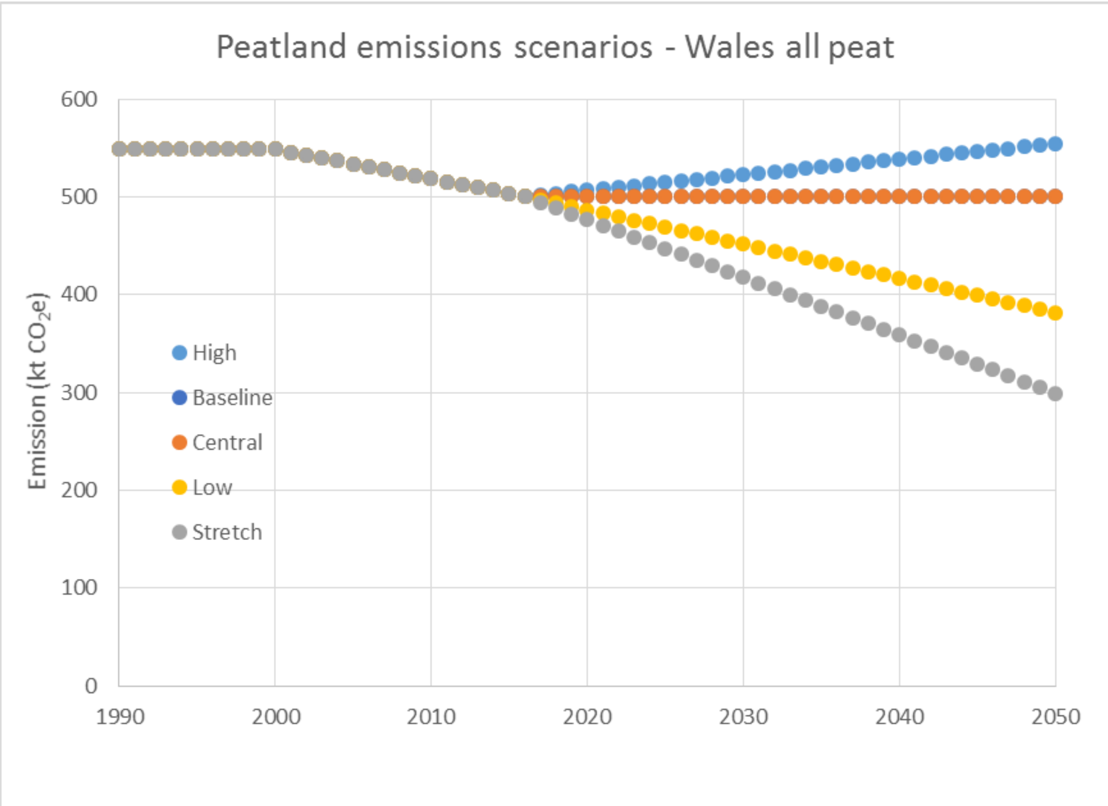

FIGURE A1.5 PEATLAND EMISSIONS SCENARIOS, WALES

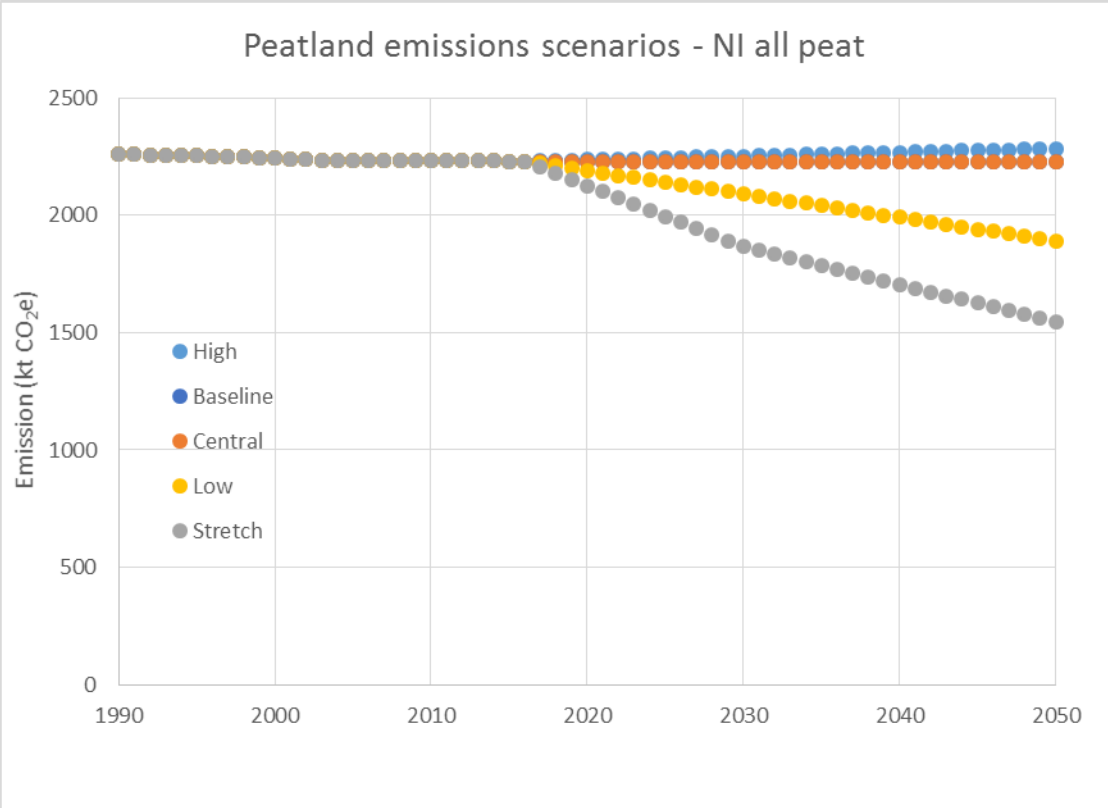

FIGURE A1.6 PEATLAND EMISSION SCENARIOS, NORTHERN IRELAND

Appendix 2. Baseline emissions scenario. Emissions by administration and land use.

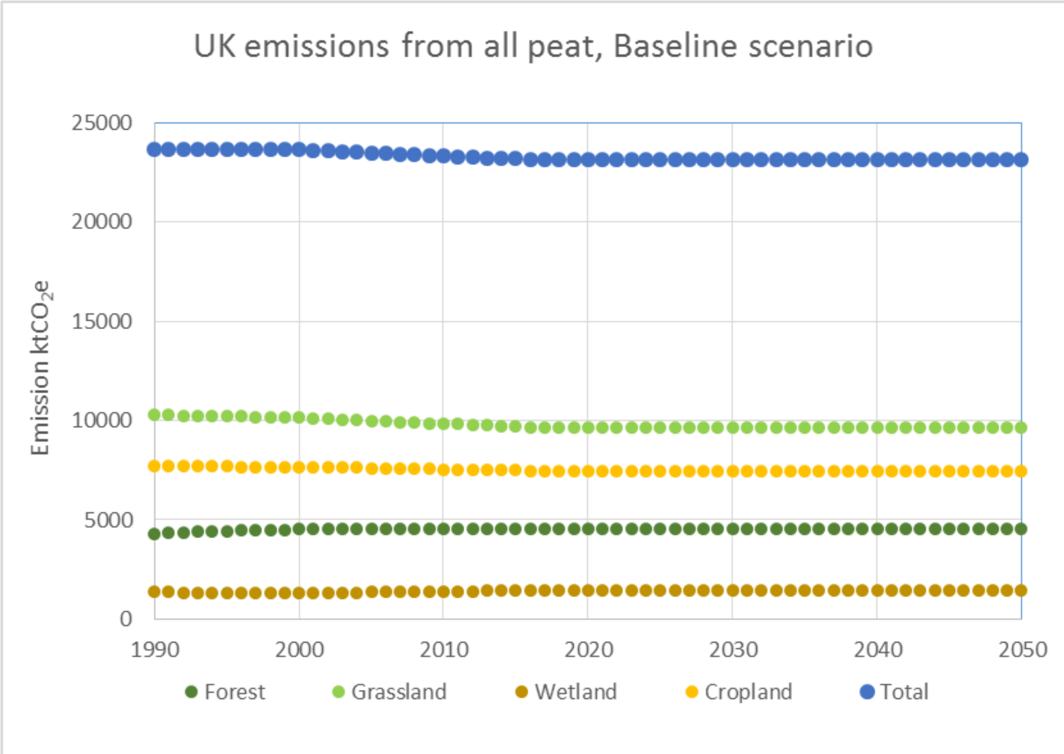

FIGURE A2.1 UK EMISSIONS BY LAND USE, BASELINE SCENARIO

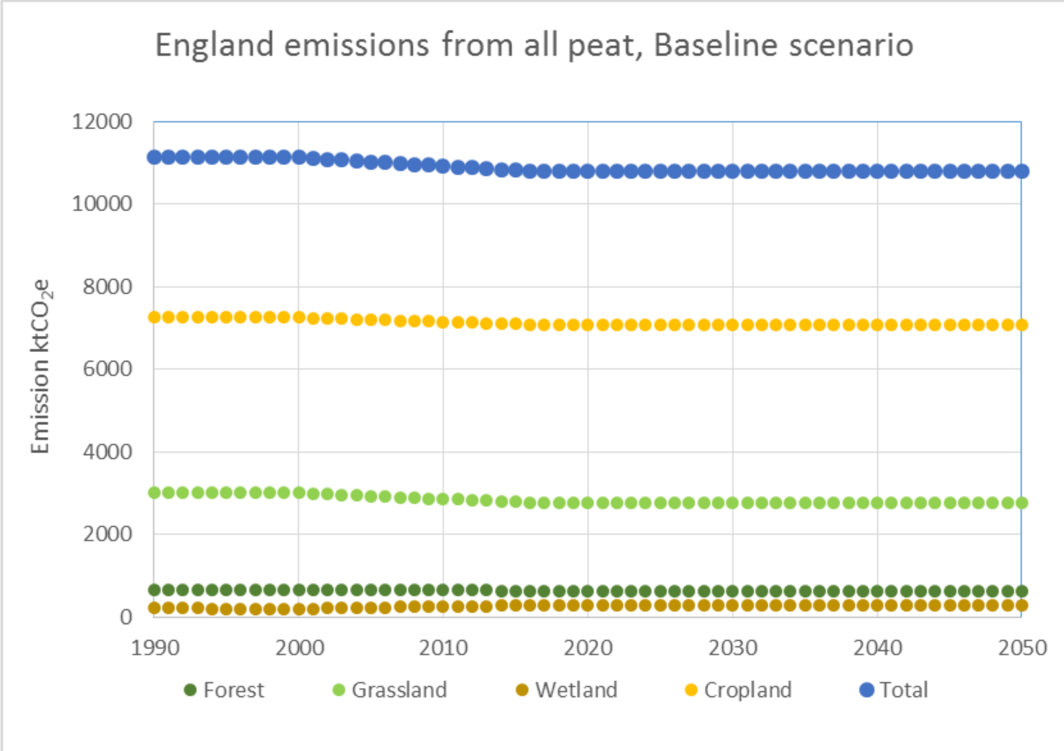

Figure A2.2 England Emissions by Land Use, Baseline Scenario

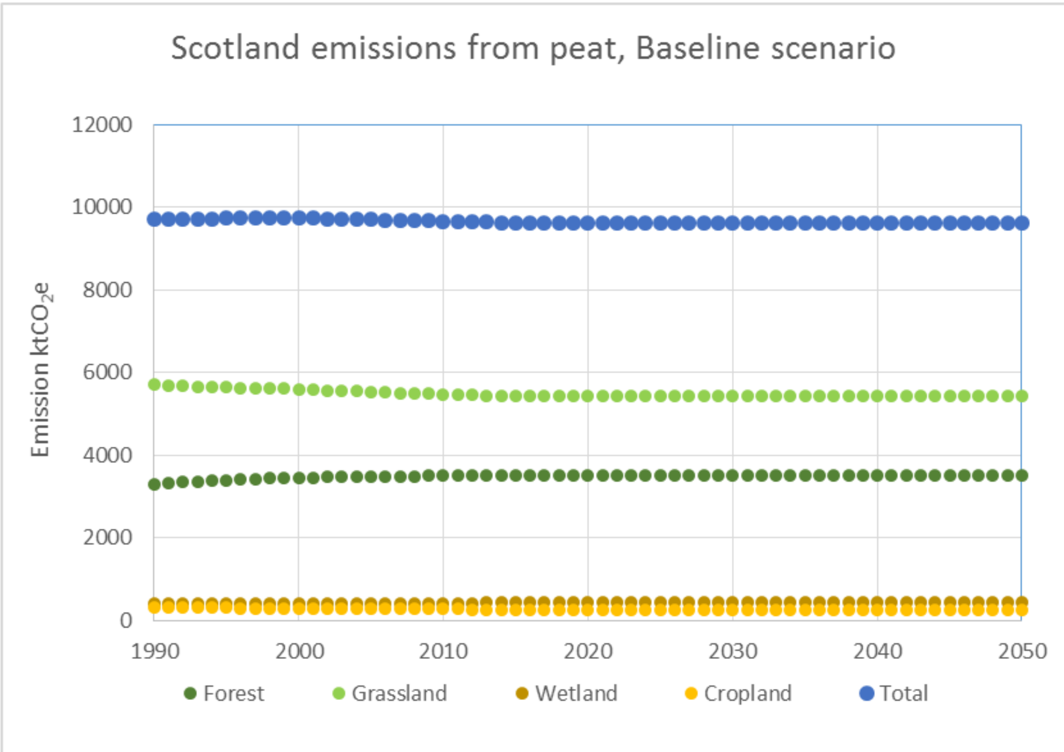

Figure A2.3 Scotland Emissions by Land Use, Baseline Scenario

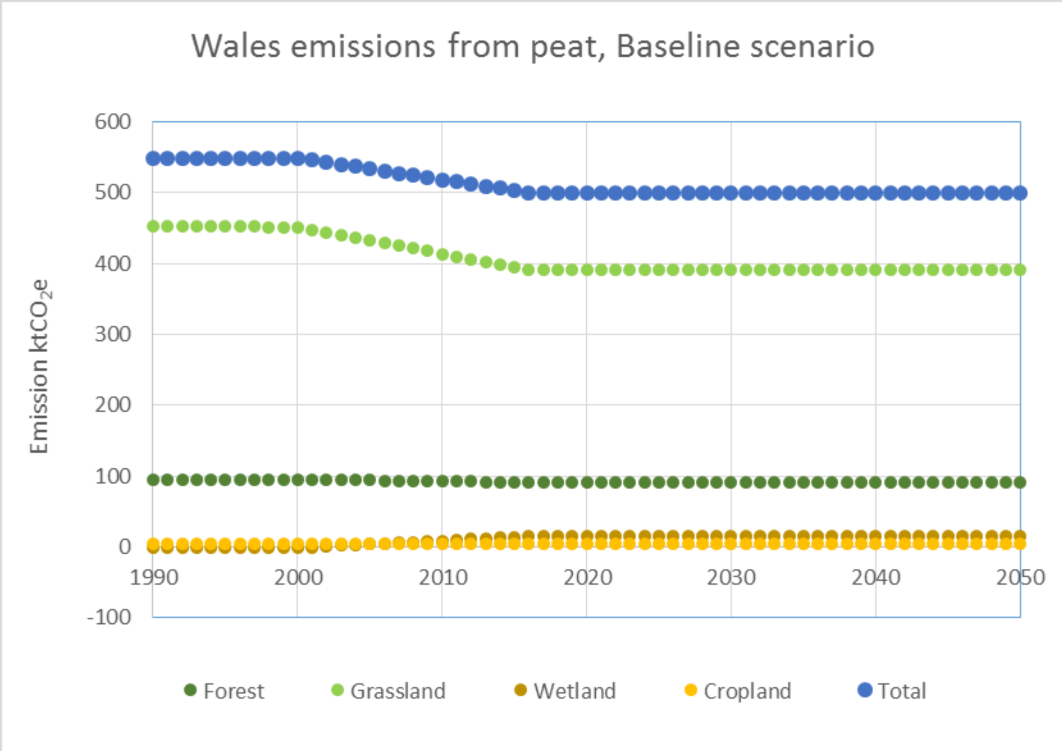

FIGURE A2.4 WALES EMISSIONS BY LAND USE, BASELINE SCENARIO

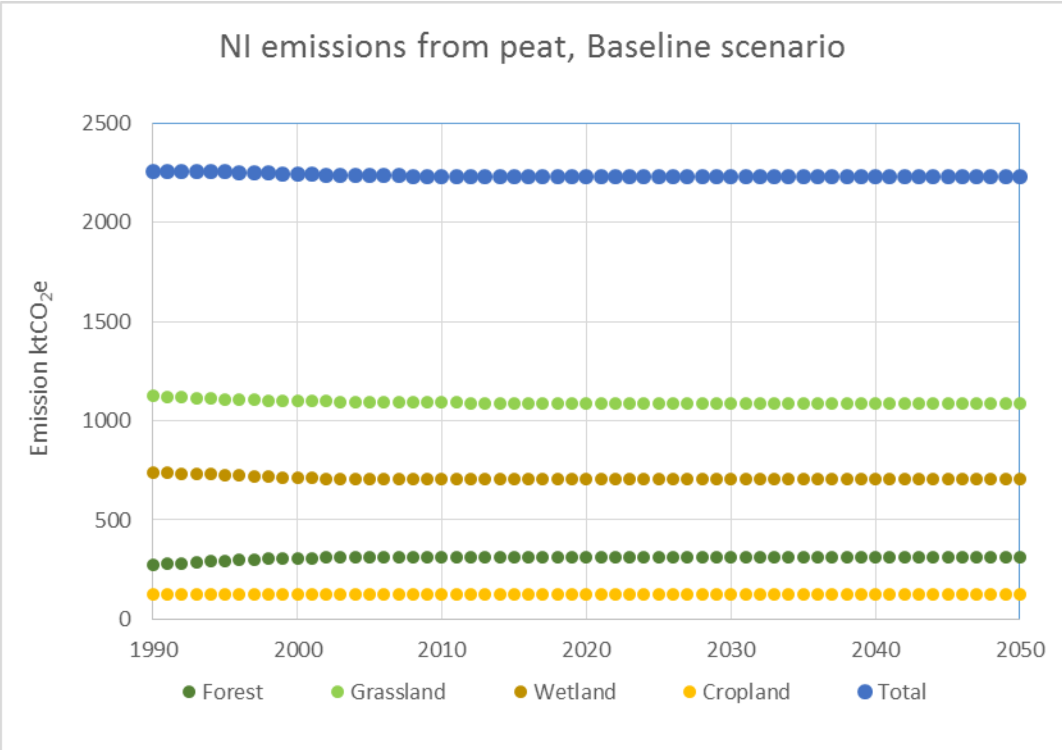

FIGURE A2.5 NORTHERN IRELAND EMISSIONS BY LAND USE, BASELINE SCENARIO

Appendix 3. Central emissions scenario. Emissions by administration and land use.

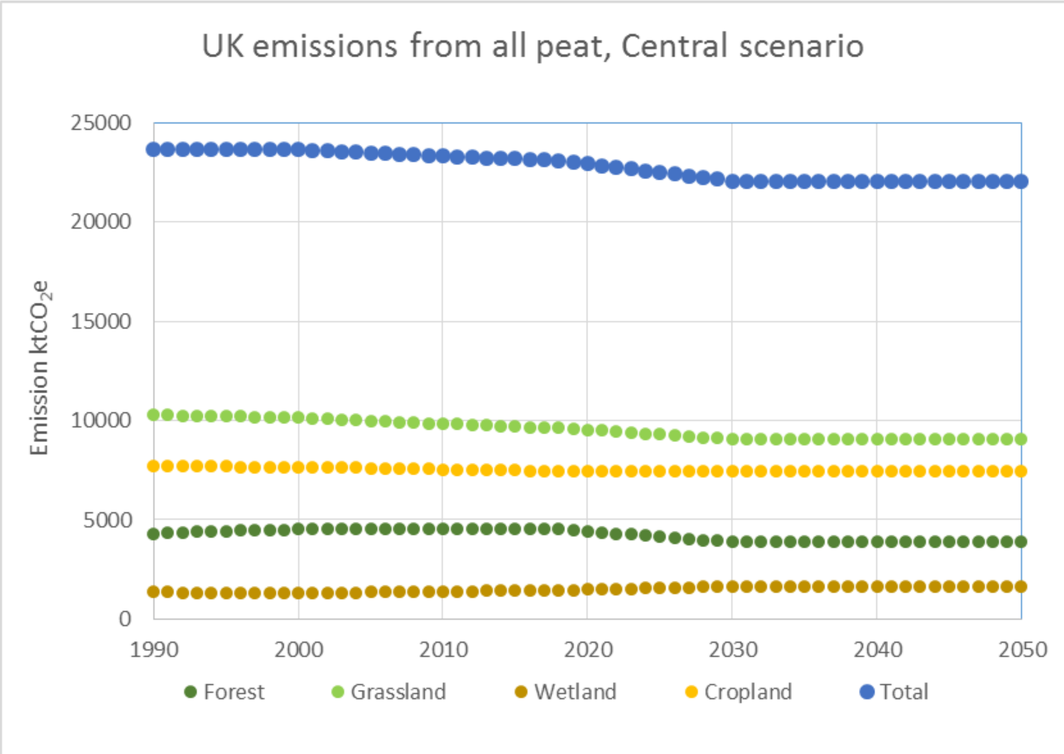

FIGURE A3.1 UK EMISSIONS BY LAND USE, CENTRAL SCENARIO

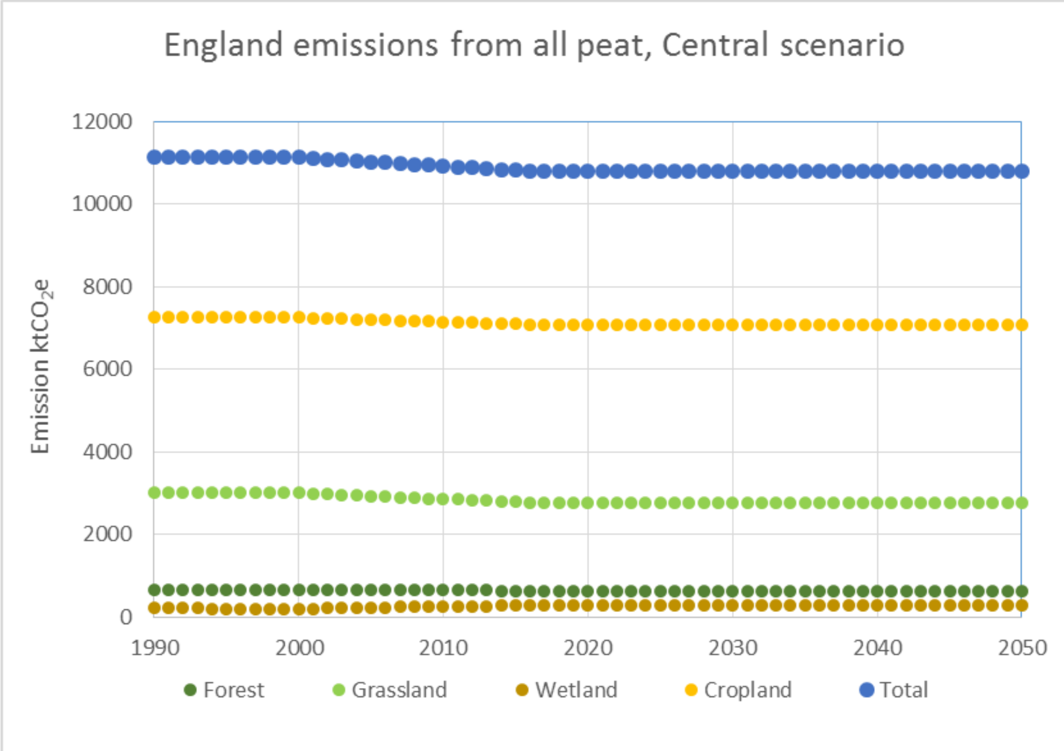

FIGURE A3.2 ENGLAND EMISSIONS BY LAND USE, CENTRAL SCENARIO

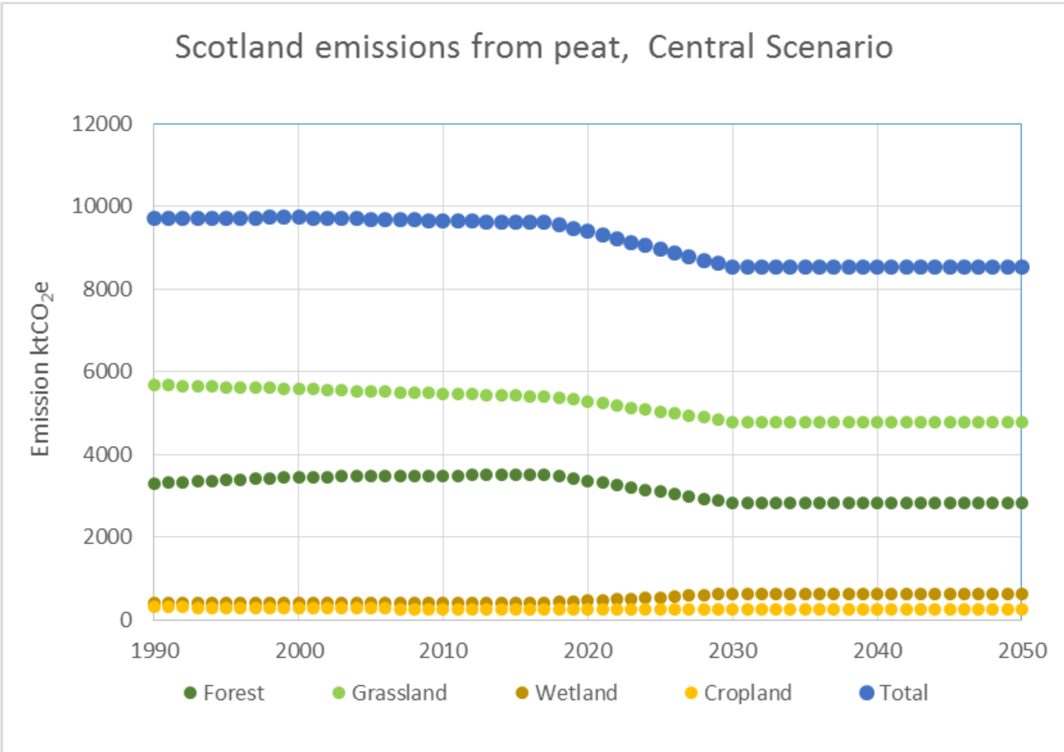

FIGURE A3.3 SCOTLAND EMISSIONS BY LAND USE, CENTRAL SCENARIO

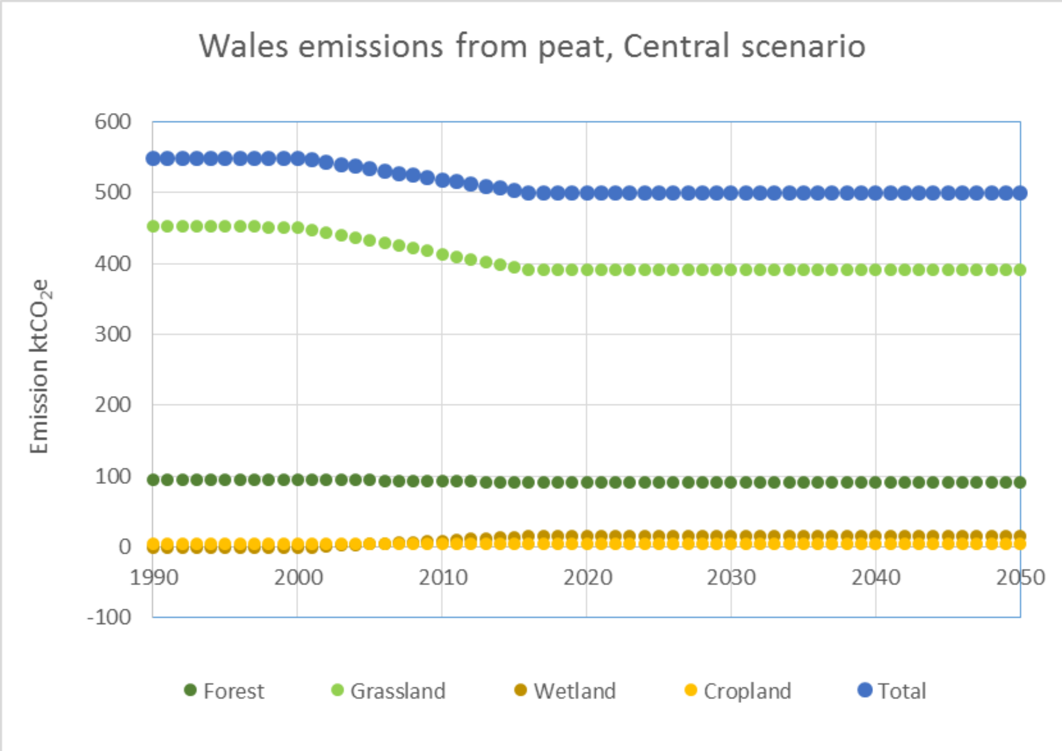

FIGURE A3.4 WALES EMISSIONS BY LAND USE, CENTRAL SCENARIO

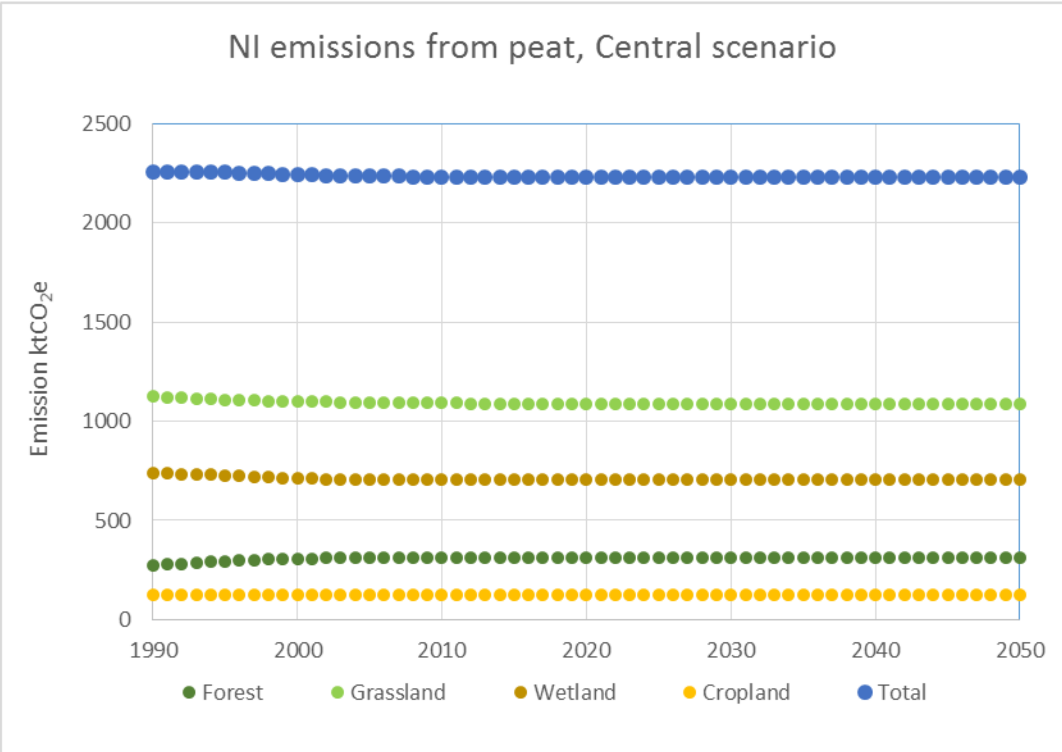

FIGURE A3.5 NORTHERN IRELAND EMISSIONS BY LAND USE, CENTRAL SCENARIO

Appendix 4 Low emissions scenario. Emissions by administration and land use

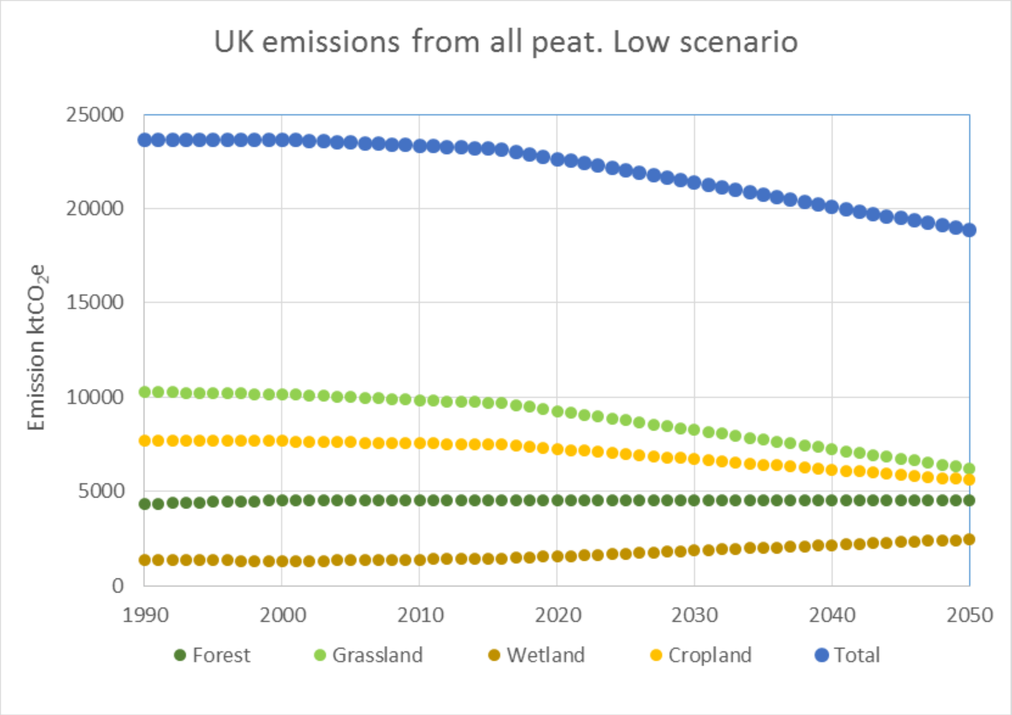

FIGURE A4.1 UK EMISSIONS BY LAND USE, LOW SCENARIO

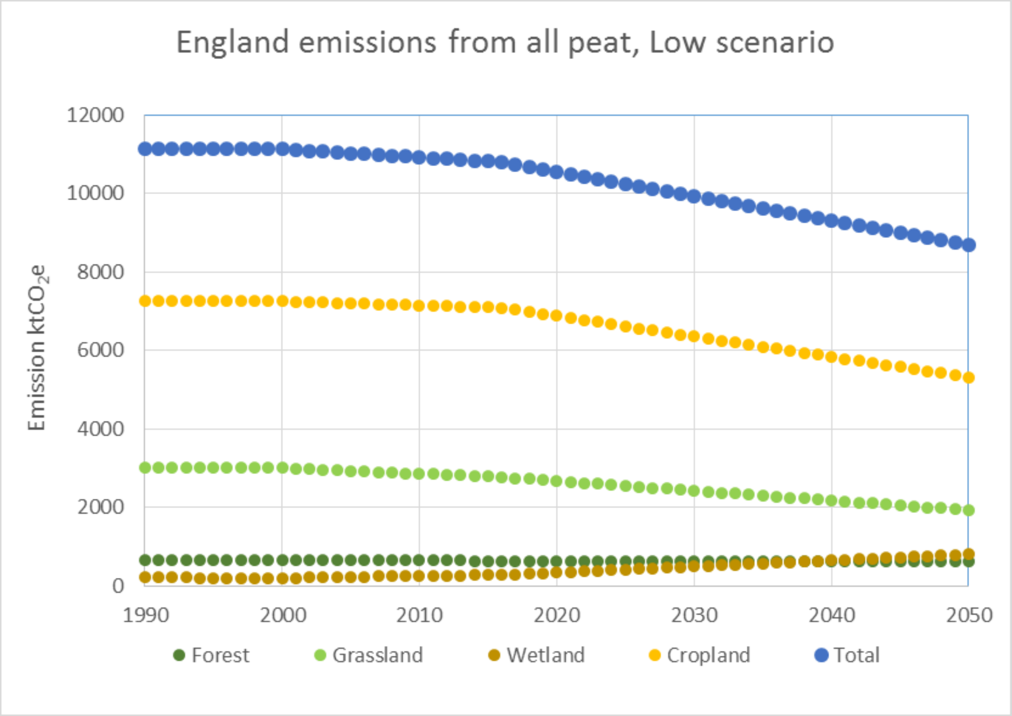

FIGURE A4.2 ENGLAND EMISSIONS BY LAND USE, LOW SCENARIO

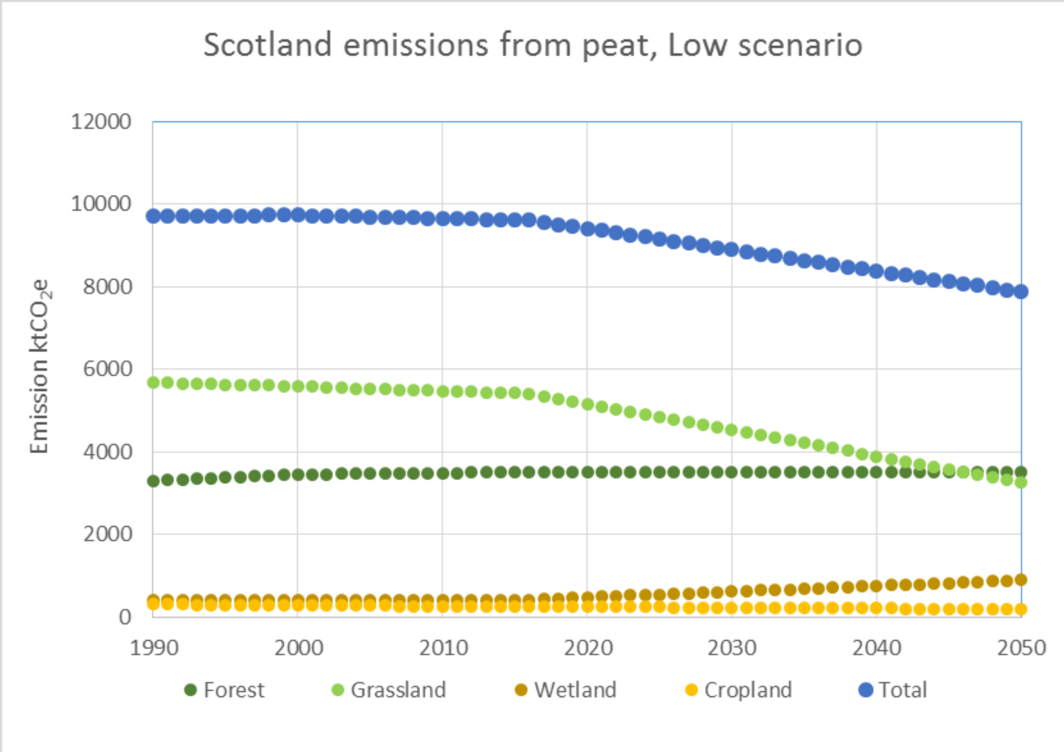

FIGURE A4.3 SCOTLAND EMISSIONS BY LAND USE, LOW SCENARIO

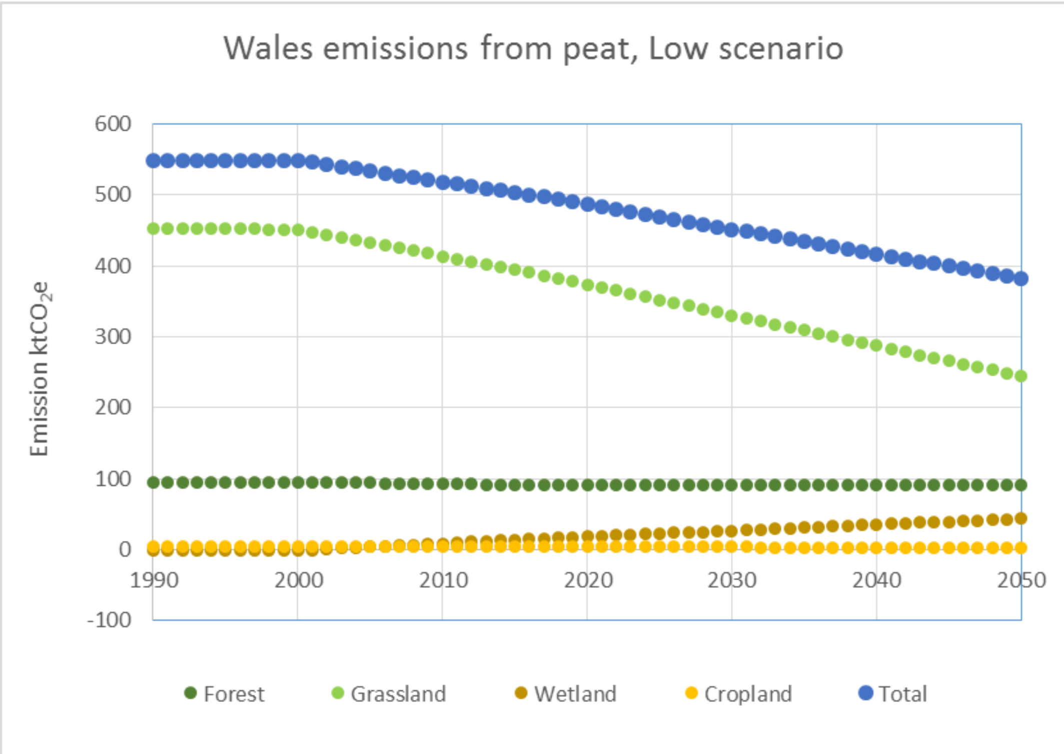

FIGURE A4.4 WALES EMISSIONS BY LAND USE, LOW SCENARIO

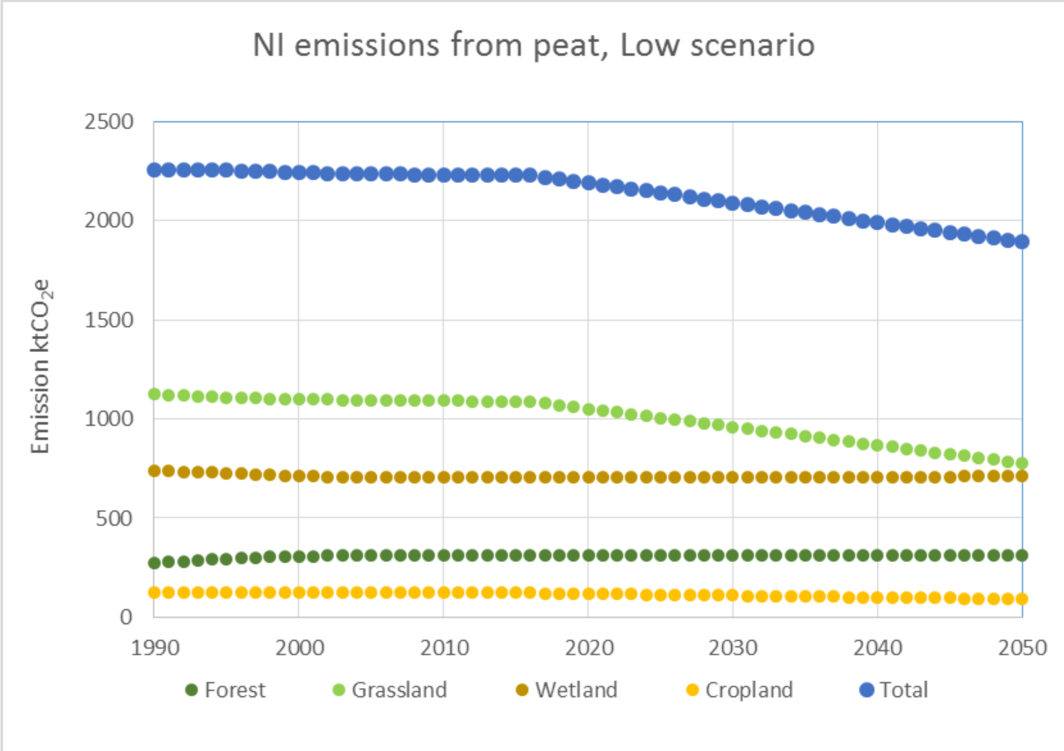

Figure A4.5 Northern Ireland Emissions by Land Use, Low Scenario

Appendix 5. Stretch scenario. Emissions by administration and land use.

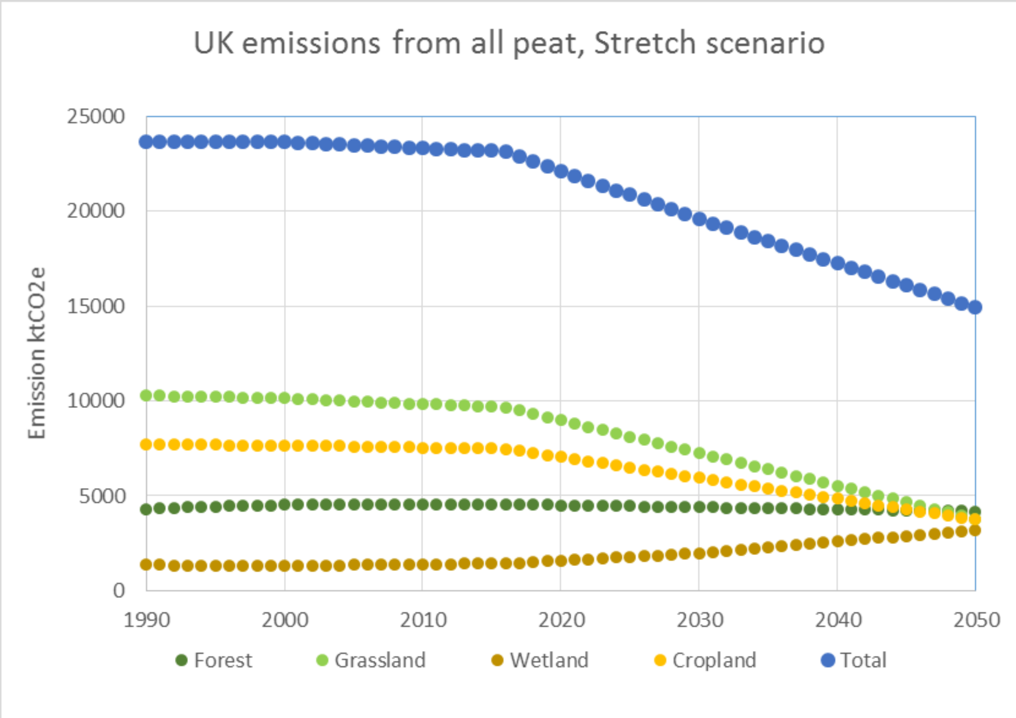

FIGURE A5.1 UK EMISSIONS BY LAND USE, STRETCH SCENARIO

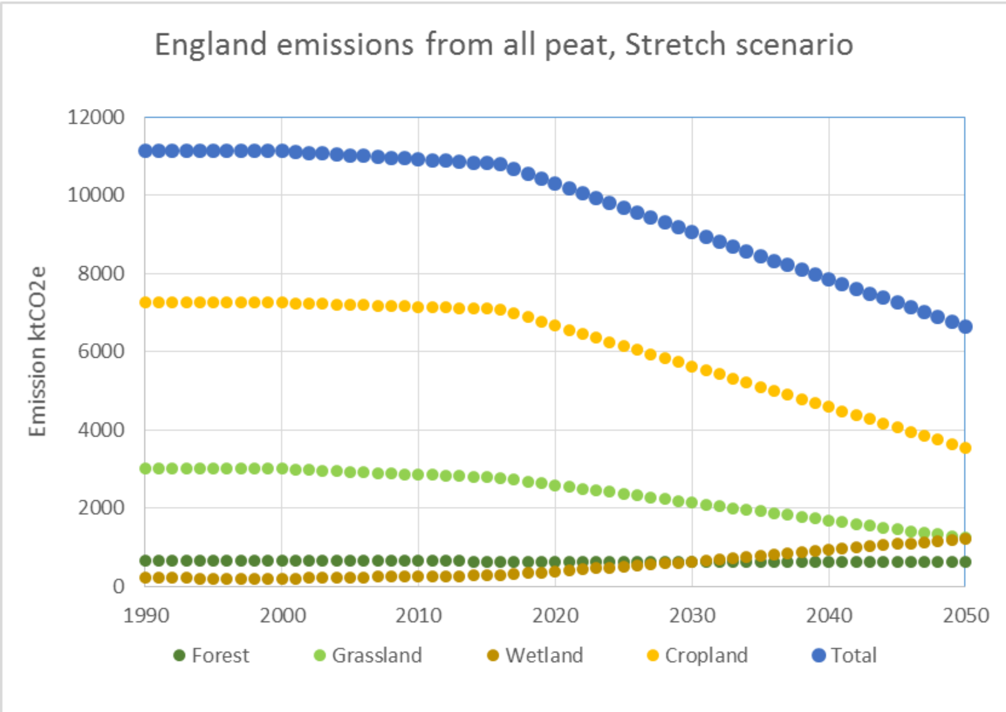

FIGURE A5.2 ENGLAND EMISSIONS BY LAND USE, STRETCH SCENARIO

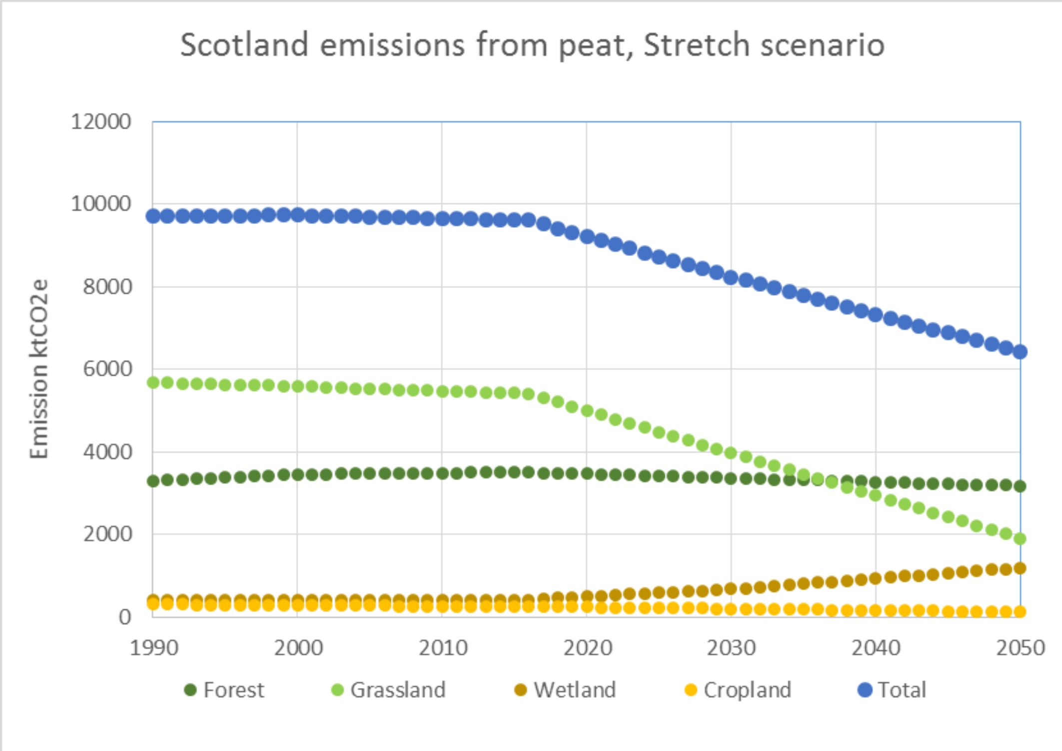

FIGURE A5.3 SCOTLAND EMISSIONS BY LAND USE, STRETCH SCENARIO

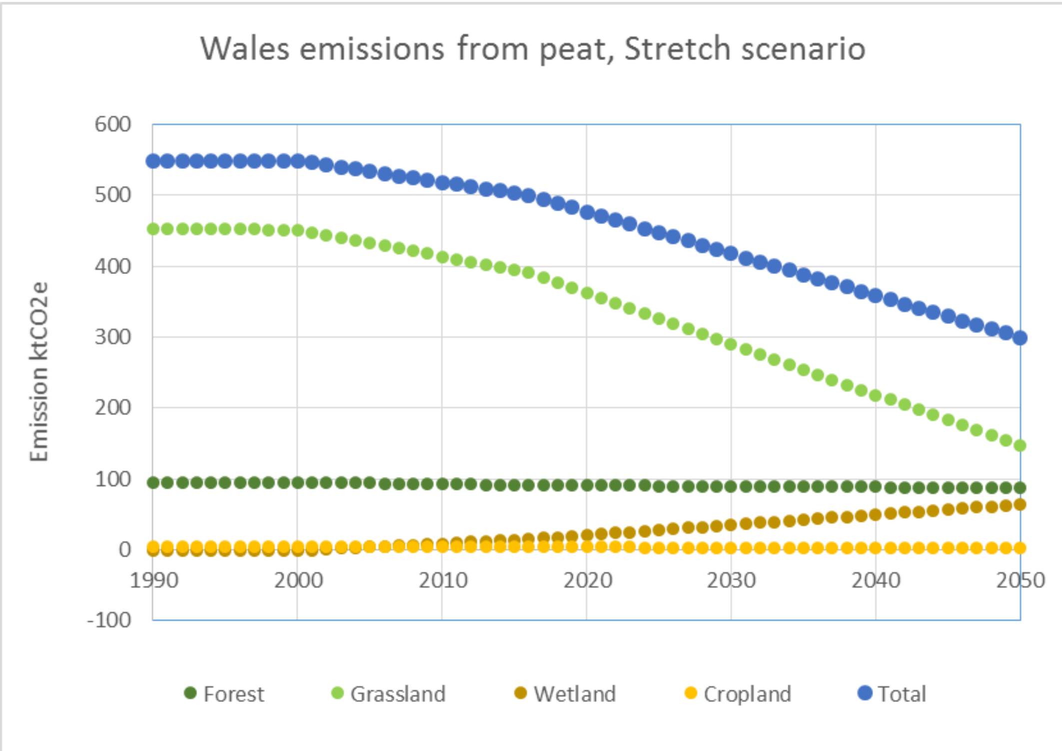

FIGURE A5.4 WALES EMISSIONS BY LAND USE, STRETCH SCENARIO

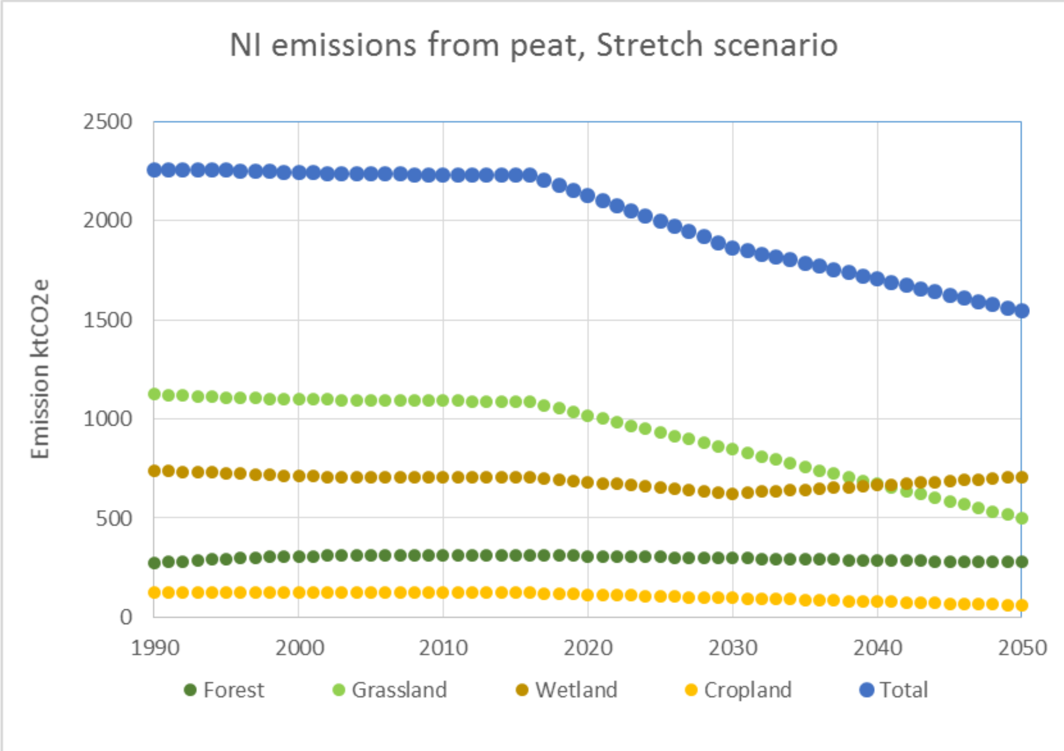

FIGURE A5.5 NORTHERN IRELAND EMISSIONS BY LAND USE, STRETCH SCENARIO

Appendix 6. High emissions scenario. Emissions by administration and land use.

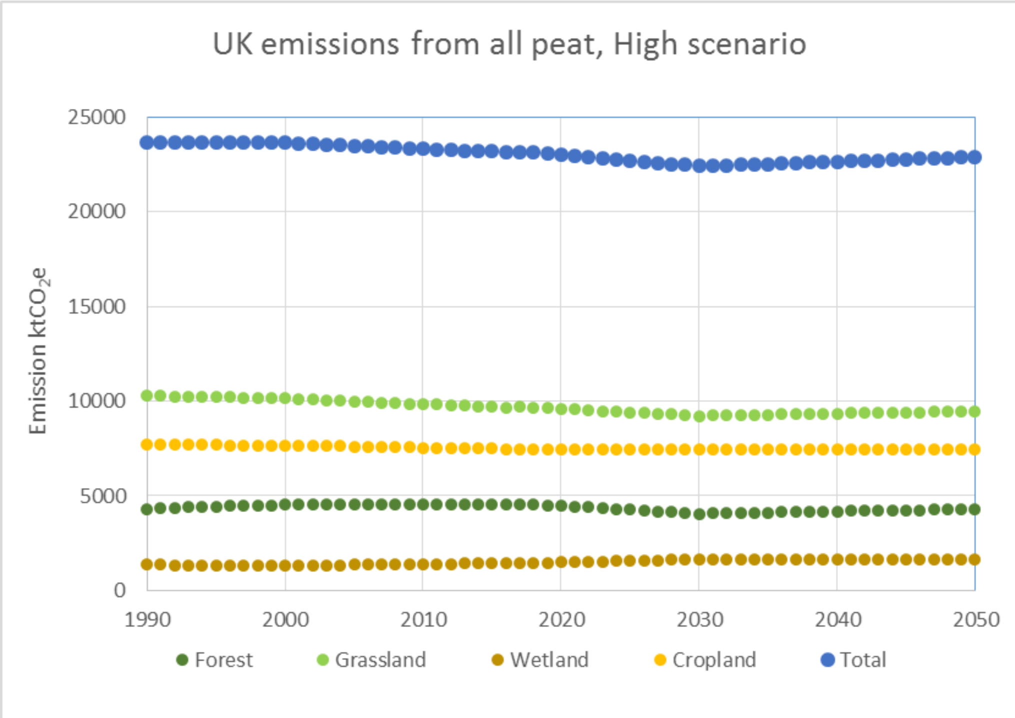

FIGURE A6.1 UK EMISSIONS BY LAND USE, HIGH SCENARIO

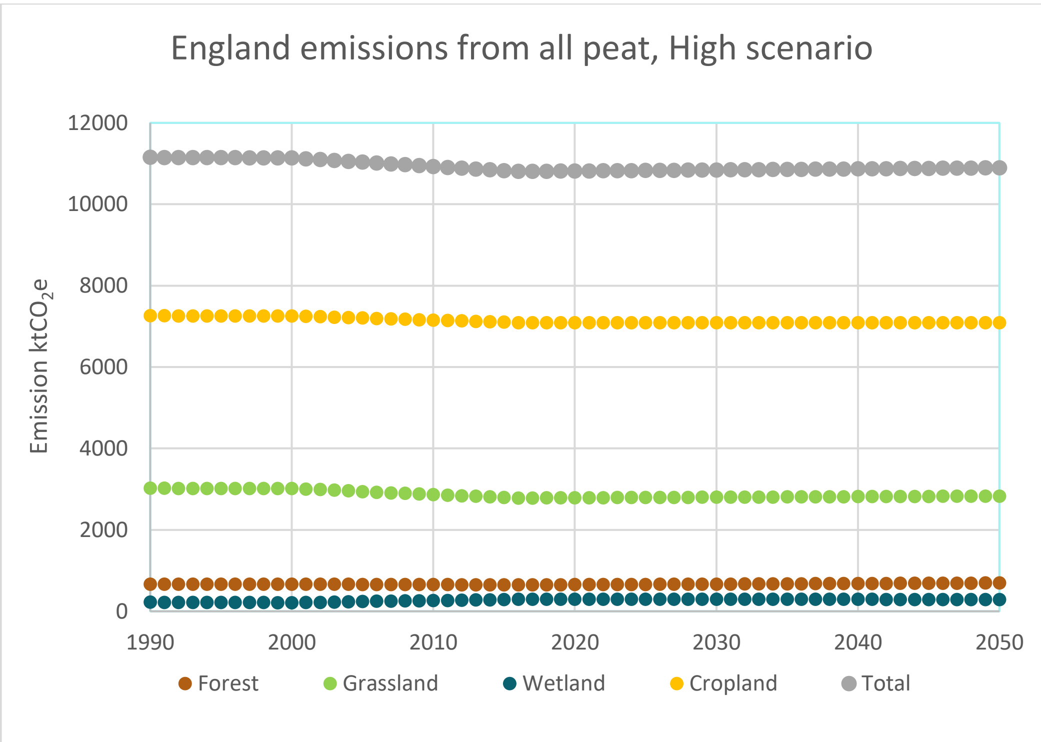

FIGURE A6.2 ENGLAND EMISSIONS BY LAND USE, HIGH SCENARIO

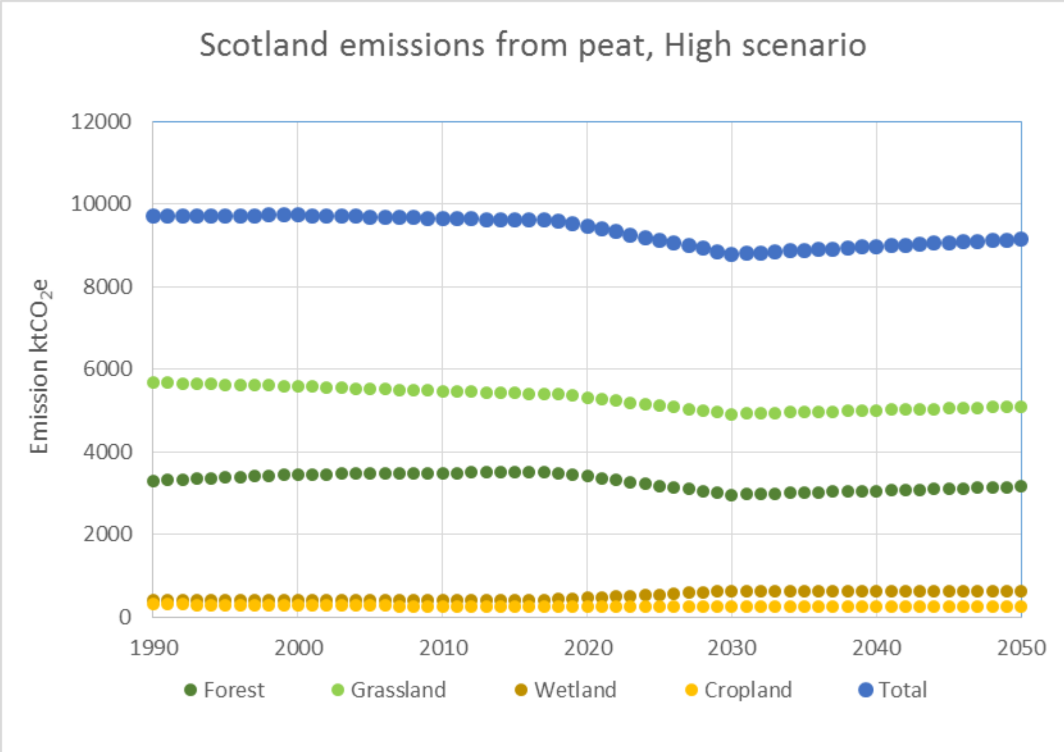

FIGURE A6.3 SCOTLAND EMISSIONS BY LAND USE, HIGH SCENARIO

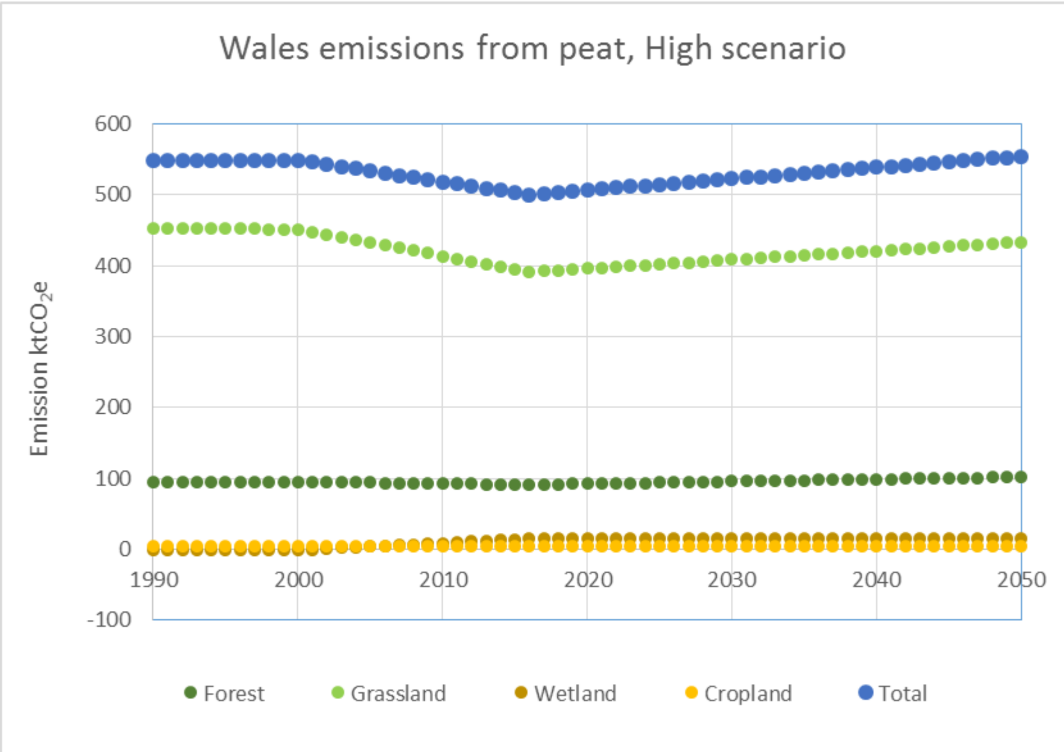

FIGURE A6.4 WALES EMISSIONS BY LAND USE, HIGH SCENARIO

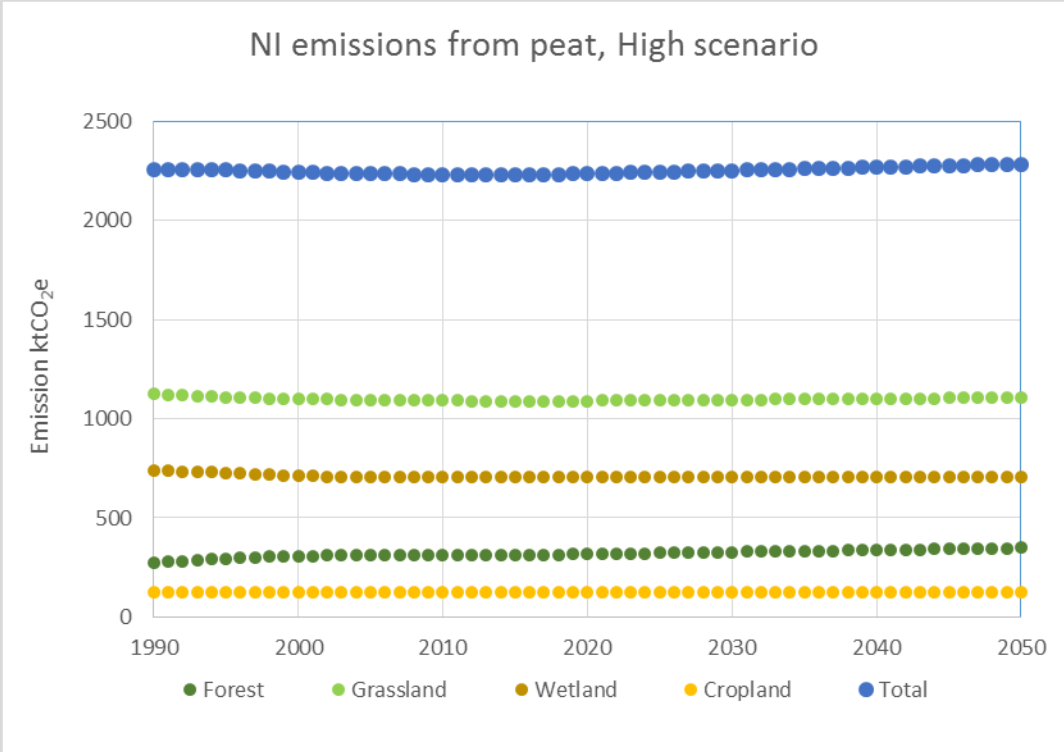

FIGURE A6.5 NORTHERN IRELAND, EMISSIONS BY LAND USE, HIGH SCENARIO

Annex 7 Uncertainty assessment of projections

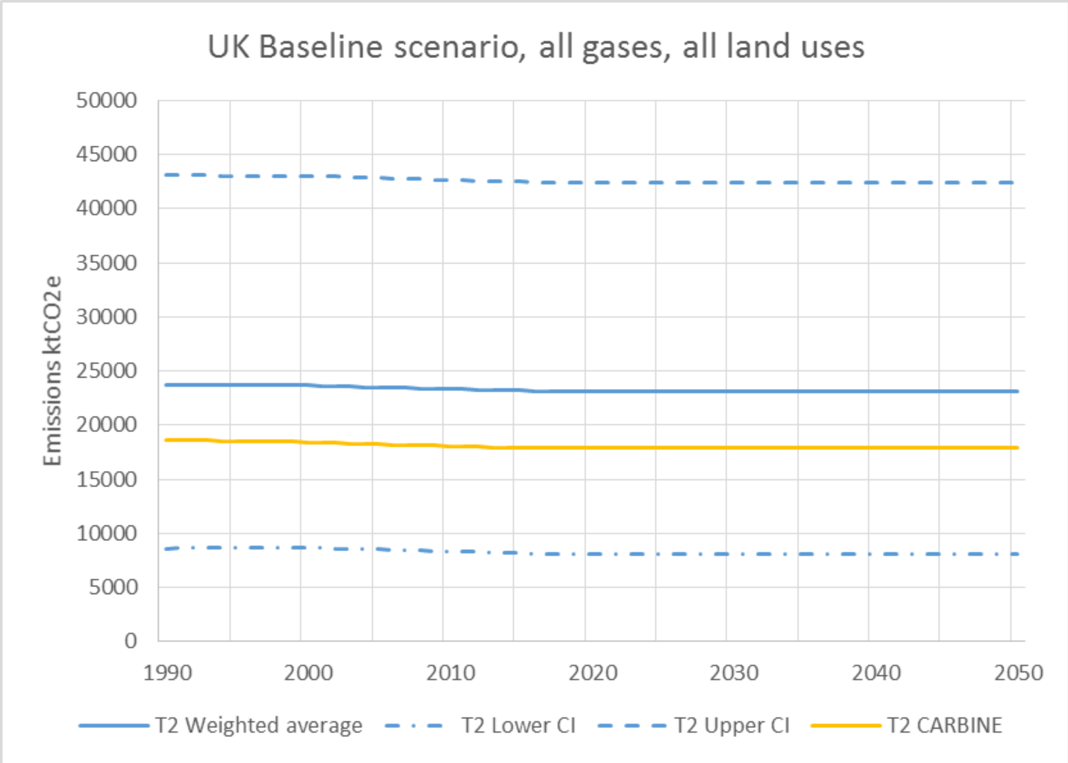

FIGURE A7.1 BASELINE SCENARIO UNCERTAINTY, UK

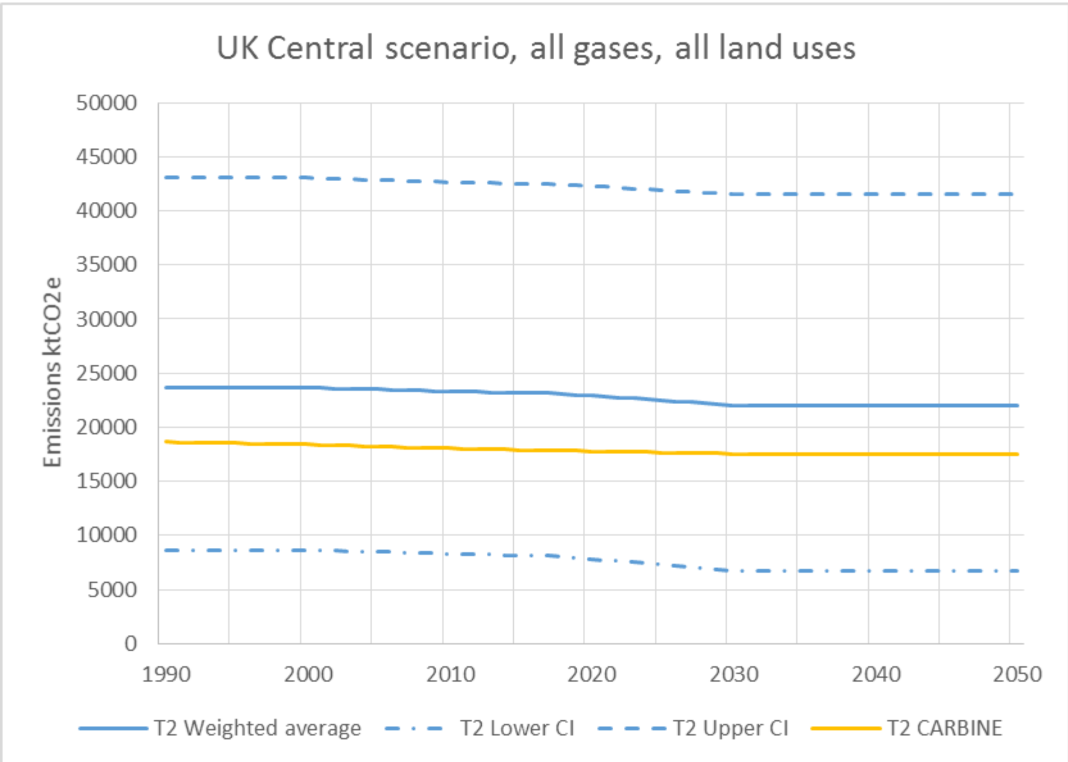

FIGURE A7.2 CENTRAL SCENARIO UNCERTAINTY, UK

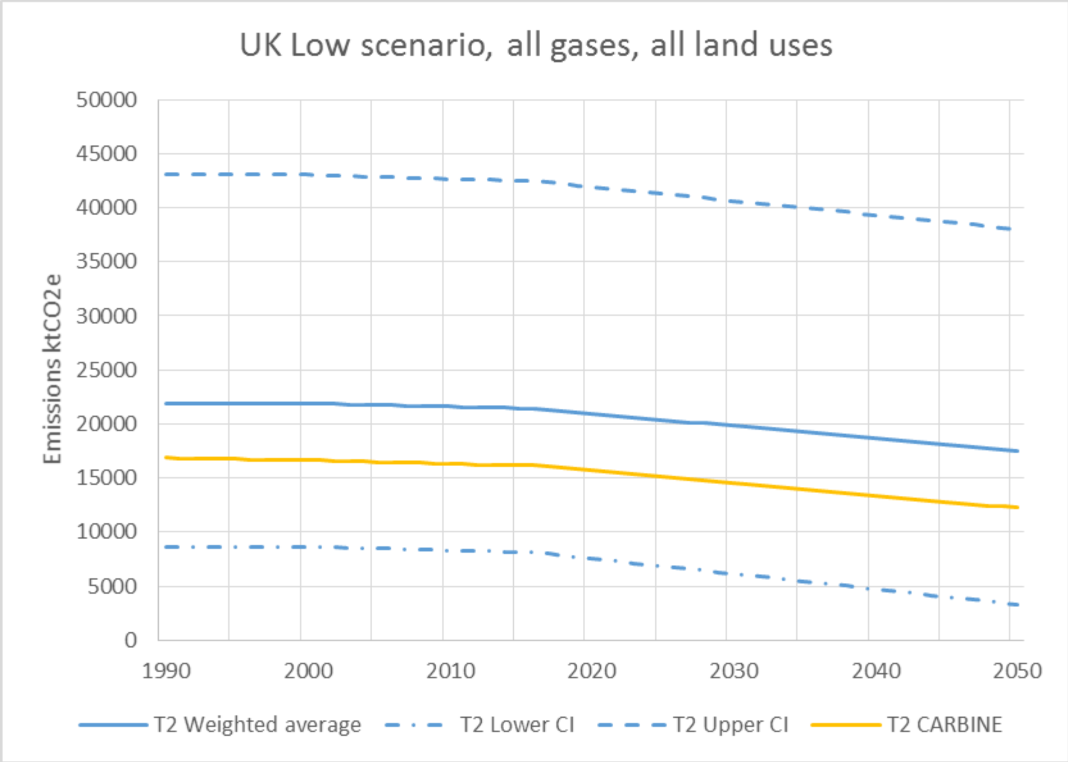

FIGURE A7.3 LOW SCENARIO UNCERTAINTY, UK

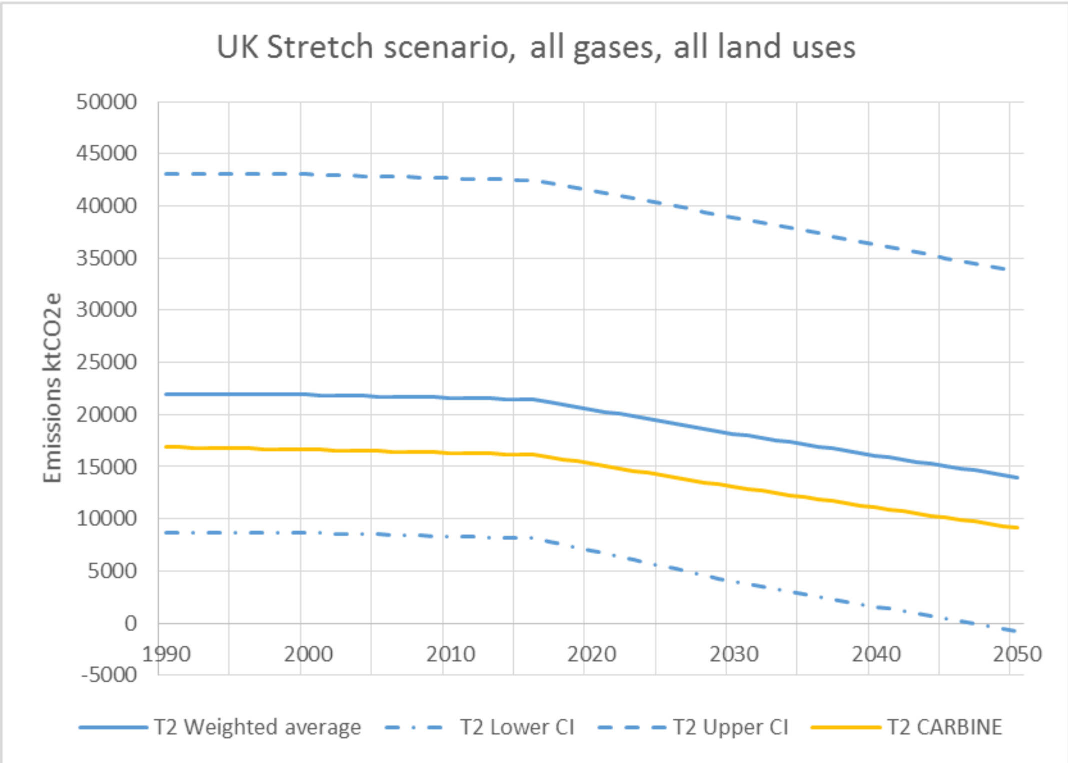

FIGURE A7.4 STRETCH SCENARIO UNCERTAINTY, UK

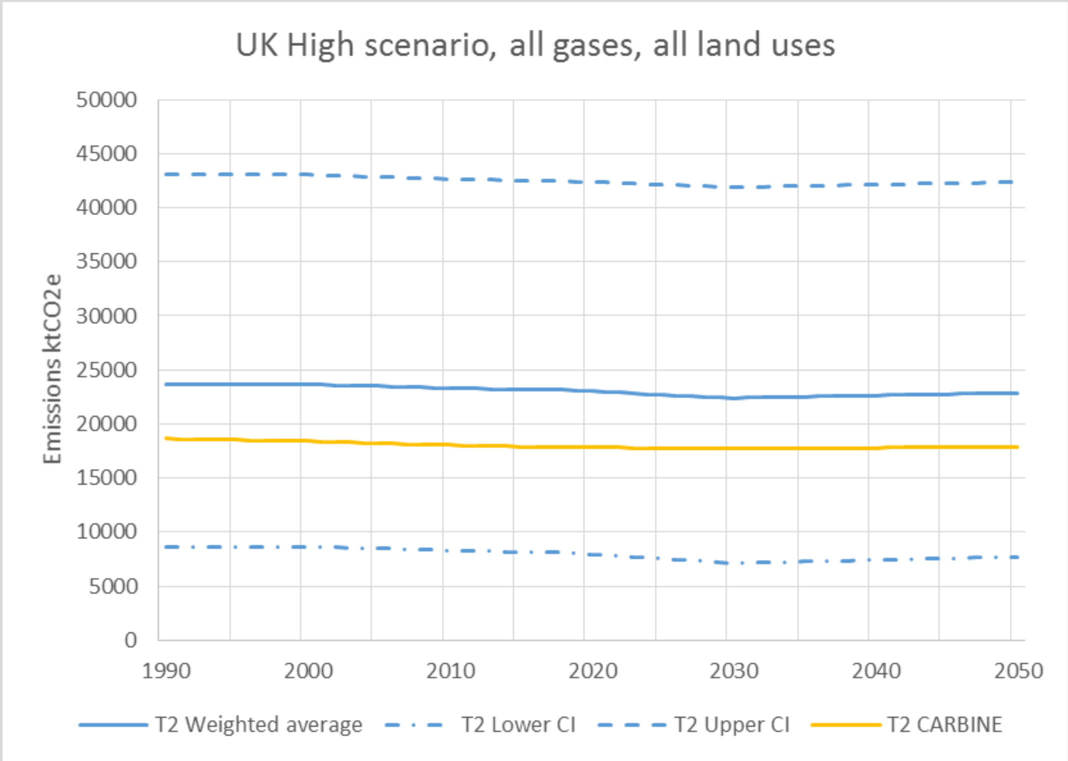

Figure A7.5 High scenario uncertainty, UK

Annex 8 Peat mapping methodology

Digitally available activity data that were known to exist at the start of this project were requested and checked for content on arrival. Where multiple data sources could be found for the same type of information, such data sources were combined in ArcGIS ready format, preserving the attributes of the parent datasets. The data sources used for this project are listed in Table 1.

Soil databases were filtered for peat soils only, preserving fields that contained deep peats (but included wasted peat where this information was available), but ignoring shallower peaty soil types. Land cover databases were used as received, however in cases of mosaic land cover data (e.g. LCS88), only the dominant land cover types were used for the purpose of this scoping project. Land cover datasets were split into those most likely containing information about the 1990 baseline year land cover, or more recent data, which were used for the calculations of likely changes.

Land cover datasets were reclassified to a common project hierarchy (Figure 2.1), using python scripts run in ArcMap. It was quickly realized that it would be unlikely that accurate and internally consistent maps of both the land cover in the 1990 baseline year and the year 2013 could be completed. This is primarily because there are no matching land cover datasets for these years that use the same classification structure for land parcels (thus creating a high risk that apparent differences between years would reflect differences in classification methods, rather than true land-use change). In addition, some of the data do not cover all of the United Kingdom, with the result that generally only the baseline year or a more recent time point could be presented with relative confidence (schematically represented in Figure 3.6). Data on drainage locations in particular were very sparse (Table 1). In areas of highly modified land cover on peat, such as intensive grassland, arable, peat extraction or forestry, we assumed that drainage has also occurred, in line with previous work in support of the UK Inventory (e.g. Anthony et al., 2014) and the IPCC Wetlands Supplement guidance (IPCC, 2014).

Dataset	**Coverage**	**Resolution**	**Reference**
1. 1:250,000 Soils of Scotland (James Hutton Institute)	Scotland	1:250,000	https://data.gov.uk/dataset/1-250000-soils-of-scotland
2. DiGMapGB (Digital Geological Map of Great Britain) Version 7.22 (British Geological Survey)	GB	1:50 000	http://www.bgs.ac.uk/products/digitalmaps/dataInfo.html
3. Peaty Soils Locations © BGS & NSRI (excerpt from 2)	England	1:50,000	http://www.bgs.ac.uk/products/digitalmaps/dataInfo.html
4. Unified peat map for Wales (British Geological Survey, Forestry Commission, Natural Resources Wales)	Wales	Uncertain	Received from CEH (C. Evans)
5. Unified peat map for Northern Ireland (British Geological Survey, AFBI)	Northern Ireland	1:50,000	Received from BGS (N.Archer)
6. National Forest Inventory (Forestry Commission)	GB	Approximately 1:50,000	National Forest Inventory
7. CEH Land Cover Map (2000)	UK and Isle of Man	Approximately 1:25,000	https://eip.ceh.ac.uk/lcm/lcmdata
8. CEH Land Cover Map (2007)	UK	Approximately 1:25,000	https://eip.ceh.ac.uk/lcm/lcmdata
9. Land Cover of Scotland (1988)	Scotland	1:25,000	http://www.huttonltd.com/products/digital-data-products-for-lease/land-cover-of-scotland-1988-(lcs88).aspx
10. NRW Phase I Habitat Map	Wales	Uncertain	Received from CEH (C. Evans)
11. Northern Ireland Peat Survey 1988	Northern Ireland	Uncertain	Received from Northern Ireland Environment Agency (C. McGinn)
12. Isle of Man/Falklands peat soils		1:50,000	Received from BGS (N.Archer)

TABLE A3.1 DATA SOURCES USED FOR PEAT MAPPING

The peat baseline maps produced were, in some cases, new or relatively recent derived products of older datasets. As a first sense check, the areas of peat in these peat baseline maps were compared with the values in the 2011 JNCC report. With the exception of the dataset for England, the estimated areas of peat have changed significantly. For Scotland, a new model of peat locations was built using a combination of the BGS and James Hutton Institute data and a slope parameter to exclude locations on steep ground (see Scotland section). This resulted in a similar total extent of peat as in the JNCC report, however it is considerably higher than the figure presented in Chapman et al. (2009), which calculated the total area on the basis of the estimated proportion of peat in mixed soil polygons. The area of peat in Wales is slightly higher than was in the JNCC report, due to the use of recently completed mapping incorporating high-resolution survey-based data from BGS and NRW (Evans et al., 2015). The new map appears more effective at capturing smaller peat units. Finally, depending on which of the three data sources are used in combination, deep peat in Northern Ireland may either be slightly less than the JNCC figure or about 500 km2 more. Despite significant effort from this project to reconcile the various data sources of deep peat distribution, there remain significant uncertainties over the total extent and locations of deep peat across the UK.

It was not possible to break down the peat baseline maps into further levels of classification in relation to peat type (e.g. lowland raised bog, blanket bog, fen) for all of the countries or OTs/CDs. For Scotland, there is no attribute in any of the data sources that could be used to map fen peat separately. Lowland raised peat deposits could potentially be captured in future as these were mapped as part of a Scottish Wildlife Trust project (Artz et al., 2013) using the 1:250,000 Soils of Scotland dataset from the James Hutton Institute, however this work would need to be revisited using the new, modelled, peat basemap. The original mapping effort in Artz et al. (2013) used JNCC guidelines for delineation of lowland raised peat deposits from other, upland, basin and semi-confined, peat types. However, the resolution of the 1:250,000 data meant that many of the relatively small former lowland raised bogs might have been missed. The report points to the discrepancy between their results and the historical survey of Lindsay and Immirzi (1988); which included many additional, small, peatland sites. Conversely, the Lindsay and Immirzi dataset omitted many of the former lowland raised bogs that had already been converted in land cover by the time of their survey, as they only included sites still showing evidence of being a remnant lowland raised bog on the basis of land cover characteristics. Further work would be required to interrogate the new modelled peat basemap which now includes the 1:50,000 BGS dataset and the slope cutoff.

For England, the digital data derived for the Natural England (2010) report on peatland carbon storage and greenhouse gases in England, subdivides the peat resource into blanket bog, lowland raised bog and fen peats (deep and wasted). However, these area figures when combined do not make up the total of the deep peat soils (blanket bog, inclusive of upland Valley Mire = 355,300 ha; raised bog = 35,700 ha; lowland fen (deep) = 95,800 ha; lowland fen (wasted)= 1,922 ha; no data = 900 ha). All of the above bog/fen types combine to 489,622 ha not the 679,900 ha total deep peat soils). It may be that Natural England have access to complete maps of blanket and lowland raised bog peat, and can therefore assess all land cover on these classes, but lack an equivalent map of fen peat. Hence there may only be mapped areas of ‘fen habitat’ but not other land-use on fen peat, or wasted fen peat. Since the unmapped area potentially includes very large areas of deep and wasted peat under cropland and grassland, it is likely to be of high significance for overall UK peat emissions

For Wales, the 90,995 ha of deep peat has already been divided into lowland and upland peat, and data on current and modified fen habitat within each of these categories is also readily available. Hence only a fairly quick recategorisation to the project classification is required.

For Northern Ireland, the BGS and AFBI unified map does not contain information on the underlying peat type within the dataset obtained by the project. Hence data cannot be split out to the soil type hierarchical categories.

Datasets reporting on drainage location and intensity were very limited. For Tier 2, and certainly Tier 3, reporting, a simple classification system for drainage intensity would most likely be required at some point. This will need to reflect (as a minimum) the distance between ditches or a derived set of classes of drainage intensity. The only data that were obtained for this project were of partial coverage (Scotland), or did not include any indicators of drainage intensity (England, Northern Ireland). For Wales, drainage intensity was not mapped directly, but a buffer was applied around each digitised ditch (10 m either side in uplands, 50 m in lowlands). Hence all areas are either ‘drained’ or ‘undrained’, but a higher proportion of the land is ‘drained’ where the ditch density is higher. Where ditches are < 20 m apart then effectively all of the land area is ‘drained’.

The land cover datasets and potential area estimates at 1990 baseline year and changes to 2013 are discussed in each individual country’s subchapter.

We also identified a source of spatial data on peat occurrence in the Falklands, based on a geological survey undertaken by BGS during the 1990s (Aldiss and Edwards, 1999), which appears not to have been used in a previous assessment of peat extent and condition in the Overseas Territories (Bain et al., 2011). On the basis of the site surveys, an estimated 33% of the upland soil (peach-coloured) area is deep peat. In the Falklands, there is evidence that natural erosion has been exacerbated by burning, grazing (with introduced herbivores) and off road vehicles (Bain et al., 2011). Some localised drainage and ploughing has also occurred. BGS also hold mapping data for the Crown Dependencies, notably the Isle of Man which has a significant peat area In the Isle of Man, most of the relatively small area of deep peat has historically been affected by drainage, grazing, burning, afforestation and peat extraction (Weissert and Disney, 2013).

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BANGOR
Centre for Ecology & Hydrology
Environment Centre Wales
Deiniol Road
Bangor
Gwynedd
LL57 2UW
United Kingdom
T: +44 (0)1248 374500
F: +44 (0)1248 362133

EDINBURGH
Centre for Ecology & Hydrology
Bush Estate
Penicuik
Midlothian
EH26 0QB
United Kingdom
T: +44 (0)131 4454343
F: +44 (0)131 4453943

LANCASTER
Centre for Ecology & Hydrology
Lancaster Environment Centre
Library Avenue
Bailrigg
Lancaster
LA1 4AP
United Kingdom
T: +44 (0)1524 595800
F: +44 (0)1524 61536

WALLINGFORD - Headquarters
Centre for Ecology & Hydrology
Maclean Building
Benson Lane
Crowmarsh Gifford
Wallingford
Oxfordshire
OX10 8BB
United Kingdom
T: +44 (0)1491 838800
F: +44 (0)1491 692424

enquiries@ceh.ac.uk
www.ceh.ac.uk