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Implications for longer-term policy and implementation into the AFOLU Inventory of the IPCC 2013 Supplement to the 2006 Guidelines: Wetlands

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1. Key Points

- It should be possible with sufficient time and strategic research activities to produce better estimates of the emissions associated with altered land use and restoration activities on peat soils in Scotland.
- All peatland areas, regardless of land use, are currently regarded as managed land.
- There has been relatively little additional peatland drainage in Scotland since 1990, the predominant activity has been rewetting through restoration management.
- The legalities regarding changes to the way the national inventory is calculated require further clarification at present and should be discussed further with experts involved in Inventory compilation and IPCC panel members.
- All peatland restoration projects should be evaluated with the risks of climate change in mind; in some areas restoration efforts may only achieve mitigation of further decline of the carbon stock, which is still a worthwhile effort.

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2. Introduction

Mitigating emissions from the land use sector is an important component in the UK strategy to achieve the legally binding obligations of an 80% reduction in greenhouse gas (GHG) emissions relative to the 1990 baseline by 2050 (UK Climate Change Act, 2008). Separately, the Climate Change Act (Scotland) 2009 has set an ambitious 42% reduction interim target for 2020.

A sizeable proportion of the land use sector in Scotland is located on highly organic soils. Much of the 1.7 million hectares of Scottish peatland, which accounts for 22% of the land area, has been recognised as being in poor condition, with estimates of over 50% of former blanket bog, and over 90% of former raised bog no longer carrying peat-forming vegetation. It has been internationally recognised that such degraded peat soils are the source of relatively high net GHG emissions; whereas undisturbed peatlands generally act as net GHG sinks. Although restoration activities that aim to restore the habitat value of these ecosystems have been carried out for more than a decade in Scotland, it has so far not been possible to formally account for the carbon benefits that peatland restoration can achieve. In previous policy briefings (Artz et al., 2012 and Chapman et al., 2012), some indicative figures were given for the abatement potential derived from peatland restoration activities on the basis of published net carbon dioxide or net carbon balances in peer-reviewed publications. The recent publication of two new pieces of internationally binding guidance on GHG emissions reporting now paves the way for formal recognition of the carbon benefits of peatland restoration activities. This policy briefing intends to clarify the current status of the inclusion of peatlands in national GHG reporting and, in addition, identify areas requiring further research in order to refine net GHG emissions estimates from the land use sector in Scotland and the UK. We clarify the different reporting streams and suggest areas in current reporting methods that will require further improvements.

3. UNFCCC reporting

There are two main international reporting mechanisms. Under the United Nations Framework Convention on Climate Change (UNFCCC), countries that are Parties to the Convention submit annual national greenhouse gas (GHG) inventories to the Climate Change secretariat. These are included in the UK National Inventory Report (NIR). There is also a second reporting mechanism under the Kyoto Protocol for Parties that are included in Annex B to the Kyoto Protocol (KP), which includes the UK. This KP reporting is dealt with separately in section 6.

Emissions of GHG from, and removals by, Scottish peatlands are reported within the Agriculture, Forestry and Other Land Use (AFOLU) sector submission, and to date (up until the 2014 NIR, reporting up to 2012) have been calculated as per Volume 4 of the 2006 Guidelines. Currently the UK Department for Energy and Climate Change (DECC) contract Ricardo-AEA to prepare the main greenhouse gas emissions inventory, but the Centre for Ecology and Hydrology (CEH) is responsible for the data for the (Sector 5) tables relating to AFOLU in the UK. The Emissions Inventory for the AFOLU sector at present includes all UK land in a classification system of Forest, Cropland, Grassland, Wetland, Settlement or Other Land, (other land includes bare rock and open water) (Figure 1). In other words, a given area of land is defined by its land use rather than its soil type. This causes some potential confusion, for example, the 'Wetlands' AFOLU category under the Volume 4, 2006 Guidelines (IPCC 2006) is defined as areas of peat extraction in the UK NIR. Hence, peatlands that are not actively used for extraction are included in the other land use categories. Both near natural peatlands and peat soils which have a predominantly treeless land cover are included in the Grassland category, for example, because this category is defined in section 3.2 of the Guidance as "rangelands and pasture land that are not considered Cropland. It also includes systems with woody vegetation and other non-grass vegetation such as herbs and brushes that fall below the threshold values used in the Forest land category (minimum 20% tree crown cover, 2 m height). The category also includes all grassland from wild lands to recreational areas as well as agricultural and silvopastoral systems, consistent with national definitions".

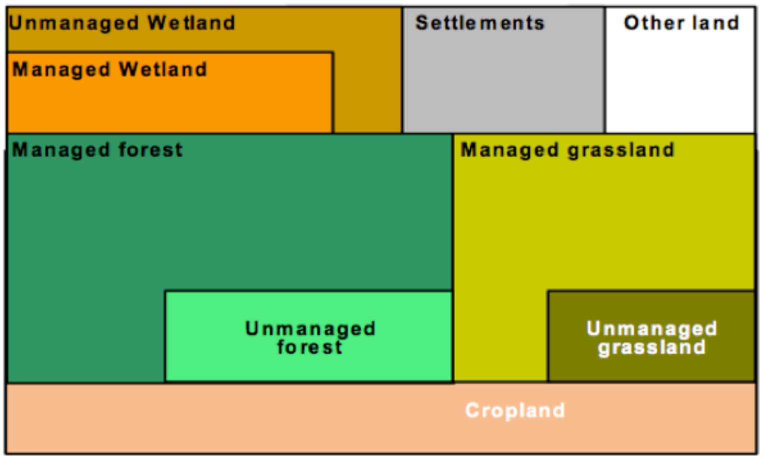

Figure 1: Land use reporting categories in the National Inventories under UNFCCC. Unmanaged land is not reported, however the UK reporting assumes all land to be managed. Reproduced from IPCC (2013b).

For reporting purposes, the main land use categories in Figure 1 are further sub-divided, either into 'land remaining in the same category' or into 'land converted from one category to another'. The distinction relates to when the change has occurred: areas where land use has changed must be reported in the 'land converted to' category for 20 years. The reported values include "all emissions by sources and removals by sinks from managed lands, which are considered to be anthropogenic, while emissions and removals for unmanaged lands are not reported" (2006 Guidelines, Volume 4, Chapter 1).

At present, UK UNFCCC reporting assumes all land to be managed. 'Managed land' is defined by the IPCC as 'land where human interventions and practices have been applied to perform production, ecological or social functions'. At present, almost all areas on peat soil are currently accounted for in the NIR under either forest land, where afforested, or otherwise under the grassland category. All forest land in the UK is considered to be managed. Similarly, the NIR considers all grassland to be managed, because most of the UK grassland results from some sort of human intervention (historical forest clearance, management for grouse, deer or sheep etc) rather than being naturally grassy (e.g habitats such as savannah, bush, prairie, steppe etc). Arguably this is not entirely true for near natural peatlands such as some of the Lewis peatlands or parts of the Flow Country where the current land cover may have been somewhat altered by human activity but certainly is not a result of these, and is something that could be considered further.

The recent publication of the "2013 Supplement to the 2006 Guidelines: Wetlands" (hereafter called the 2013 Wetlands Supplement; IPCC, 2013a), addresses the emissions and removals from drained and rewetted organic soils in a more comprehensive manner than the 2006 Guidelines. The 2013 Wetlands Supplement not only provides an update on the 2006 default Tier 1 emission factors, but also addresses additional sources of emissions not previously included in the calculations of emissions and removals from the Agriculture, Forestry, and Other Land Uses (AFOLU) sector on organic soils (including peatlands) under UNFCCC accounting. The IPCC update clearly has implications for the calculations of emissions and removals in the National Inventory Report, and we address this issue in section 5.

4. How Scottish peatlands are included in the NIR – the current position

The UK annual National Inventory Reports (NIR) can be found at http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/8108.php, and include the submissions for 2014, which still follow the 2006 guidelines and report GHG emissions up to and including 2012. The NIR submission is done retrospectively, with figures up to and including changes during 2012 having been submitted in 2014. Hence, the changes to the NIR reporting due to the implementation of the new 2013 IPCC Wetland Supplement and Kyoto Protocol guidelines will first affect the UK NIR return for 2013, due in 2015. This necessitates a different approach to the calculations for a number of the different land use categories that peat soils contribute to, and will affect both the emissions factors and the area figures for each of these land use categories. We have extracted the relevant figures from the common reporting format tables (CRF) submitted together with the NIR in Table 1.

We previously reported to Scottish Government in 2012 on the potential for GHG reductions through peatland restoration to inform the 2nd report on policies and procedures in preparation at that time (e.g. Chapman et al., 2012; Artz et al, 2012). The source of discrepancies between the likely emissions resulting from peatlands between the IPCC Wetlands Supplement Tier 1 figures and our previous estimates have been examined elsewhere (Artz et al, 2014), but there are also clear differences between the area figures for peatlands under different land uses cited in the NIR and our previous estimates of drained and/or managed peatland areas (Table 1). These are predominantly due to the much coarser classification system used in the NIR. For example, land uses leading to a more grassy vegetation were subdivided in Chapman et al. 2012 on the basis of the land cover classes in the LCS88/LCM data, but these are combined into a single 'grassland' category with subdivision into 'grassland remaining grassland' or 'other land use categories converted to grassland' in the NIR.

Secondly, the Common Reporting Format tables for the latest UK submission in 2014 unfortunately do not differentiate between organic and mineral soils for all of the AFOLU categories. Table 1 shows the current area allocations to a category under AFOLU accounting on organic soils (where possible) alongside our previous estimates of such land uses on peat soils. There are some large discrepancies between the figures. The area estimated to be Forest land on organic soil (whether remaining or converted to forest) in the NIR for Scotland (196 kha) is considerably lower than our previous estimate of 337 kha. The reasons may lie in the differences between the input data for these calculations. The NIR compiling team at CEH use activity data from the Countryside Survey except for the Forest land area, which originates from Forestry Commission Scotland. In contrast, Chapman et al. (2012) used a multi-layered approach of identifying forest land cover from a combination of the Land Cover of Scotland 1988, augmented by the Land Cover Map 2007 and Forestry Commission Scotland data. In addition, the underlying soil maps are not the same, with Chapman et al. (2012) using a combination of the 1:250,000 and 1:25,000 (in areas with cover) Soils of Scotland maps, whereas the Inventory compilers use data from Forestry Commission Scotland for the Forest land categories. It is possible that some of the difference could be due to old growth (pre-1920) forestry that is not split between organic and mineral soils in the NIR, but it is more likely that privately owned forest on peat soil in Scotland is covered in less detail in the NIR.

In the grassland category, the NIR does not distinguish between organic and mineral soils (Table 1) and this makes comparison of the data difficult. For example, much of the large area of drained and grazed peatlands, which is currently under moorland or grassland land cover (totalling 700 kha in Chapman et al., 2012), is reported in the Inventory within the 'undisturbed grassland' category, without subdivision into organic or other soils. "Undisturbed grassland" in the LULUCF inventory CRF tables, however, does not equate to "unmanaged grassland", instead being defined as grassland on which the last land use change was long enough ago that the soil has reached a new carbon equilibrium[1]. If, for example, a peatland was newly drained, it would be placed in the 'Land converted to Grassland' category at that point, but after a given period of time in this new category (default 20 years[1]), it is assumed that a new equilibrium is established and for reporting purposes such land then moves from the Land Converted to Grassland category to Land Remaining Grassland. However, the concept of an equilibrium carbon content is more applicable to mineral than organic soils, as intact peat bogs can continue to sequester carbon indefinitely (or until climatic conditions alter) and disturbed organic soils can continue to release carbon until no more peat is left. Undisturbed, managed Grassland could include large areas, which are managed in some way for grouse, deer, or as rough grazing for sheep.

The Agricultural GHG platform (http://www.ghgplatform.org.uk/Projects/AC0114.aspx) developed revised areas of histosol (here deemed synonymous with peat soil) drained for cropland and improved grassland for the UK administrations (Anthony et al, 2013; Table 1). The team used overlays of the Land Cover Map 2007 or alternatively the agricultural census data from the Integrated Administration and Control System (IACS) from 2010 with the soil maps to calculate areas of agricultural change on histosols. They assumed that the entire improved grass area mapped onto histosols would have been drained, an assumption that cannot be tested at present without knowledge of the drainage grip locations across the Scottish peatlands. Some of these areas may be "undisturbed grassland" in the current NIR categorisation. The Agricultural GHG project was not able to derive areas of drained unimproved grassland on organic soils, and so these cannot be reported at present. It is likely that these areas will also be on "undisturbed grassland" in the NIR. The authors assumed that 15% of rough grassland and/or heather moorland located on histosols is also drained, which would equate to an additional 130,000-140,000 ha of drained grassland on peat for Scotland. These latter figures compare reasonably well with Chapman et al. (Table 1). It is likely that the eroded peat categories in Chapman et al. would fall within the dwarf shrub heath and/or rough grassland categories in Anthony et al. (2013) thus explaining some of the difference in these figures. The Anthony et al. (2013) data have been proposed for use in the 1990 – 2013 inventory with T1 emission factors from the 2006 AFOLU Guidelines (to be submitted in 2015).

In the cropland category, the NIR has not, to date, differentiated cropland in Scotland based on soil type, and all cropland areas on organic soils have been reported in the mineral soil category. However new data on the area of organic soils drained for arable agriculture has recently become available from the Defra Agricultural GHG platform (Anthony et al., 2013), indicating 1.7-7.6 kha of Cropland on drained organic soils in Scotland, which is very similar to the estimate by Chapman et al., (Table 1). Anthony et al. do not calculate an estimate for the area under peat extraction as this was outwith the remit of their work. The area given in the NIR, which is derived from GoogleEarth imagery, is similar to the estimate of Chapman et al. (2012), however, and this category only affects a very small area (1.6 – 3.5 kha) in total.

[1] i.e 20 – 100 years for changes giving SOC loss or 20 – 525 years for changes leading to SOC gain. Of course this criterion is not appropriate for organic soils that either continue to lose SOC when drained or gain SOC when accumulating.

Table 1. *Potential areas of drained organic soils under each of the IPCC 2013 categories. Non-peatland land use on peaty soils (organic soil < 50 cm depth) have been excluded as data are not yet available on the areas involved and as such areas are not suitable for peatland restoration*

AFOLU category (applied to all organic soils)	Area in Scotland on organic soil in 2012 according to the 2014 NIR submission (Webb et al., 2014)	Land use category if assessed using LCS88/LCM2007/FCS Inventory (from Chapman et al, 2012)	Likely area on peat soil in Scotland based on LCS88/LCM2007/FCS Inventory intersects with soil maps (from Chapman et al., 2012)[1]	Likely area according to project AC0114 (Anthony et al., 2013)
Forest land remaining forest land	179.6 kha	Forest land on peat soils	337 kha	Not included
Other land use categories converted to Forest land	15.26 kha (Sum of land converted to Forest land from Cropland [0.83], from Grassland [2.14 from pasture plus 11.35 from semi-natural]; and from settlements [0.94])			
Cropland remaining cropland	Not separately calculated for organic soils in Scotland. Inventory states 'included elsewhere'. New data on drained histosols means that this will change in the 1990 – 2013 inventory (to be submitted 2015) and there will be separate reporting CL on mineral soils and organic soils (which are assumed to be drained) Total cropland area remaining cropland for Scotland is 712 kha.	Arable land on peat soils	3.5 kha	7.6/1.7 kha (LCM2007/ IACS 2010)
Other land use categories converted to Cropland	Not separately calculated for organic soils in Scotland. Inventory states 'included elsewhere'. It is assumed that policy against drainage of organic soils for arable use will prevent any new conversion of land to CL on organic soils Total area of other land uses converted to cropland for Scotland is 247 kha.			
Grassland remaining Grassland	Not separately calculated for organic soils in Scotland. Inventory states 'included elsewhere'. Total grassland area remaining grassland for	Wet or dry heath or moorland cover on peat soils	573 kha	482 kha (dwarf shrub heath on histosol)

	Scotland is 795 kha for which emissions or removals as a result of historic land use change are reported, plus 4156 kha of 'undisturbed' grassland, which has not undergone land use change. Total area of Grassland remaining Grassland is 4951 kha.	Rough or smooth grass on peat soils Improved Grassland on peat soils Eroded peat	124 kha 44 kha 268 kha * (total 1,009 kha)	379 kha/480 kha (LCM2007/ IACS 2010) 48/56 kha (LCM2007/ IACS 2010) Not estimated separately (total 909-1,018 kha)
Other land use categories converted to Grassland	Not separately calculated for organic soils in Scotland. Inventory states 'included elsewhere', and all land use conversion to Grassland is assumed to be on mineral soils. Total area of land converted to grassland for Scotland is 355 kha (23.41 from Forest Land, 306.25 from Cropland and 25.91 from Settlements)			
Wetlands remaining wetlands (On-site emissions from peat extraction) – no land converted to wetlands reported	1.60	Commercial peat extraction (bare peat) on peat soils Domestic peat extraction on peat soils	3.5 kha 35 kha	
Rewetted soil	Not applicable for 2013 NIR	Unable to assess remotely	Total area for 1990-2012 was 31 kha (from Chapman et al; 2012), though requires updating with past SRDP and other projects not yet captured, would need to be split by land use category	

- * Data includes any polygon with erosion features so there is a lot of uncertainty over this figure
- [1] Data assume 300ha+ of 'undamaged peatland' that would currently be included in the Inventory under 'managed grassland', hence total area is less than the total peatland area in Scotland.

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To summarise, the most challenging reporting category for peatlands is the IPCC Grassland category. Chapman et al. estimated that there could be as much as 1 million hectares of damaged peatland in Scotland that might potentially fall under the definition of 'grassland on drained organic soil'. Anthony et al presented a very similar total figure between 909 and 1,018 kha. In Table 1, the split of this 1 million ha figure is given for each of the different observable land cover types. At present, the ca 1000 kha under grassland types of land cover are currently part of the overall 4807 kha of grasslands on both mineral and organic soils in Scotland. As a first step, for the 2015 inventory submission (covering 1990 – 2013), the area of grassland on drained organic soils will be reported using the data for drainage-improved grassland from Anthony et al. (2013). It is acknowledged that this underestimates the area of grassland on drained organic soil because it does not include drainage for unimproved grassland. However it is an improvement on the previous assumption that there is no grassland on drained organic soils in Scotland. The current DECC project on Wetland Supplement implementation will aim to provide more up to date data on the area of drained, unimproved grassland in Scotland by late 2015.

Chapman et al. considered a peatland area disturbed when its vegetation cover was not indicative of a blanket bog or similar vegetation. Hence, their 1 million hectare figure includes any area of peatland that would, at some point, have been blanket bog, but is currently covered by other vegetation (except forest or arable crops). Anthony et al. (2013) took a very similar approach but only considered likely agricultural areas (rough and improved grazing as well as cropland), with the difference being that they did not assume that all rough grassland or shrub/moorland on histosols was drained.

Although peatlands have been used and altered by humans at local level for as long as settlements have existed, large scale conversion of peatlands through drainage, grazing and burning practices in Scotland dates back as far as the Highland Clearances, with the most effective changes having been introduced by large scale drainage practices in the early parts of the 20th Century (Holden et al., 2004). One of the primary difficulties is that there are no reliable data on where drainage of peat soils took place prior to 1990. There are some reports of the annual area of drains that were put into place since the 1920s (Green, 1974; 1973; Robinson, 1990), but these do not differentiate hill drains on upland peat from other drainage systems, and the original Ministry of Agriculture, Fisheries and Food (MAFF) records have been lost. These reports (Robinson, 1990) suggested that as much as 1 million hectare of upland Scotland was improved through drainage practices and hence these figures are likely indicative of the cumulative damage to the peatlands of Scotland. In both the 2013 Wetlands Supplement and the 2006 Guidelines, drainage or drained (soil) is defined as, "*Artificial lowering of the soil water table".* In the Supplement *'drainage'* is used to describe *"the act of changing a wet soil into a dry soil".* A drained soil is *"a soil that formerly has been a wet soil but as a result of human intervention is tending to become a dry soil".* All currently drained peatland is considered to be managed land and therefore emissions from drainage should be reported.

Therefore, the discrepancies between the figures in the subcategories of Chapman et al. and Anthony et al are cause for serious concern. Measured emissions from damaged peatlands that would currently be reported by the UK under 'Grasslands' as per the IPCC definition potentially span a wide gradient of values ranging from near carbon neutral to strongly net emitting, depending on the drainage intensity. As the calculation of the net GHG emissions from any land cover category is sensitive to a reliable area estimate, it is imperative that a consensus be reached on the area figures for future NIR reports. This would, however, require some further research efforts as follows:

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Research requirements to enable reliable estimation of the area of drained peatlands

Hill drains are very easily recognised on aerial images of ca. 25 cm resolution and there are relatively straightforward ways to automate image recognition processes to enable mapping across Scotland. The Scottish Government has obtained aerial image data for the whole of Scotland, at 25 cm resolution in both true colour and colour infrared, from Getmapping and these data are now available to the Main Research Providers (MRP). Staff at the James Hutton Institute have evaluated these for automated drainage mapping and are already generating the data for a small number of Scottish water catchments. A similar mapping exercise is already underway in Wales, led by the British Geological Survey. It would be highly beneficial to carry out such a study for the whole of Scotland to ensure valid data inclusion in the next NIR submission.

Such a mapping exercise would enable detection of the location of drains and drain spacing. We also need to know how far from the ditches the water table is affected as this determines the total area affected by drainage. As a first approximation an average figure such as the default value used in the carbon calculator for wind farms might be sufficient, but it might be possible to develop a more detailed model including the effect of slope if this amount of detail was justified.

A final complication is the coarseness of the available data. Figures of the peat soil areas sourced from the mapping of peat soils based on the 1:250,000 scale National Soil Data for Scotland are somewhat uncertain. The data originate from the Soil Survey of Scotland, which mapped the soil as discrete soil series mapping units (i.e. soils originating from the same geological base material). In most cases, the mapping units are complexes of two or more dominant soil types. The data originate from 0.5 to 3 soil profile inspections per square kilometre, and subsequent interpretation of the likely soil types at the landscape scale was performed by the soil surveyor on the basis of the on-the-ground relationship between the visited landforms/vegetation with the profile inspections (Macaulay Institute of Soil Research, 1984). While this approach tends to work well at coarse resolution, it is known that, in areas where peat and shallower peaty soils occur as a patchwork landscape, the soil maps have very high uncertainty in the absolute location of peat deposits. A good example of this is the west of Scotland in particular, where peat deposits tend to occur in more fragmented patches amongst shallower organo-mineral soils. In contrast, the mapping of exact location of the large expanses of blanket peat in the Flow Country, Western Isles and the Shetland Islands is much more certain. Hence, when an overlay with land cover data is produced, one can never be sure that a given land use class is actually on the peat within a mixed polygon; it is only a probability estimate. The areal figures in Table 1 take this into account to a certain degree in that any area calculations have been done using the percentage peat within the relevant polygon; however, there remains an assumption that there is co-location of current land use with underlying soils (see illustration in Figure 2). Unfortunately, the significance of this error at national level is not known, especially when overlays are produced. A particular challenge for example remains in distinguishing the grouse moors established by human activity on former peatlands from moorland that would be in that state without any human intervention. If it cannot be ascertained where the peat is located in a given mapping unit, then an overlay with land cover that shows that area to be moorland at present could still mean that that particular area is either natural moorland habitat on shallower organo-mineral soil, or a conversion to moorland on former peatland.

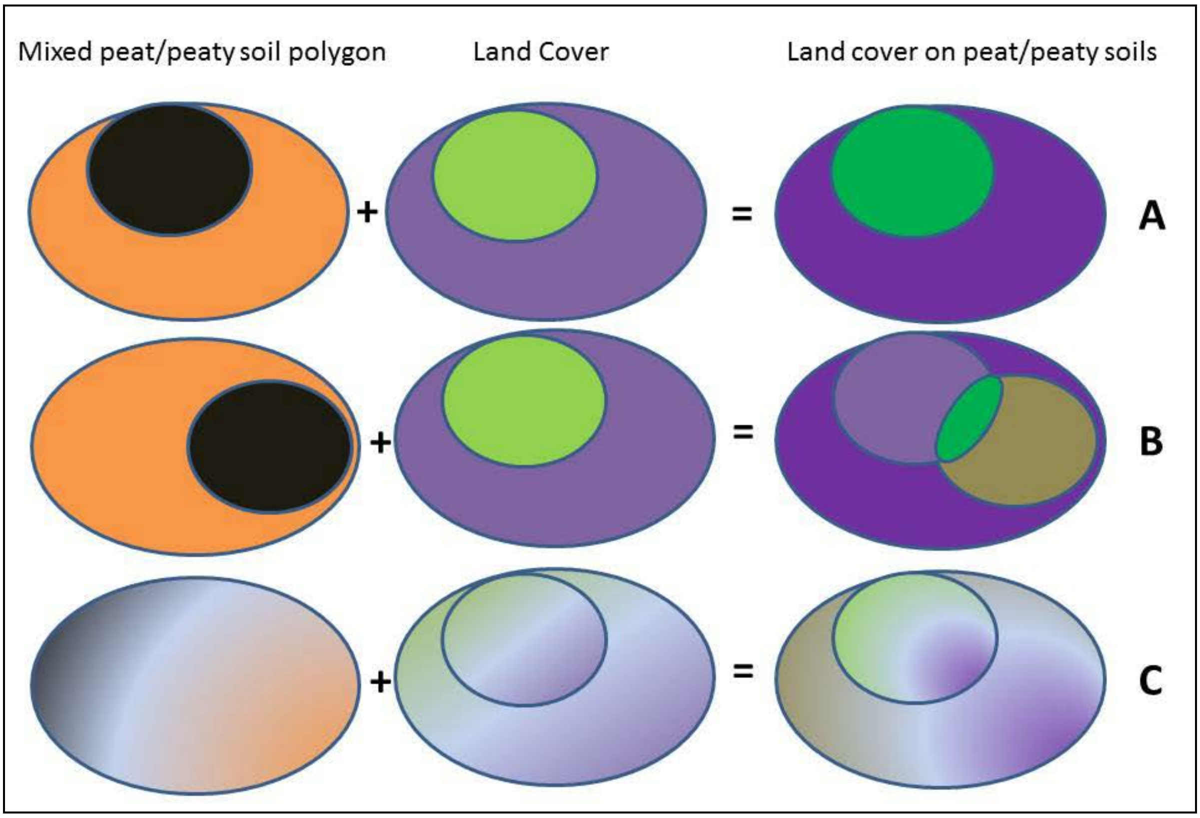

Figure 2. Overlaying data sources with different resolution and uncertainties presents challenges. The 1:250,000 Scale National Soil Data contain mixed soil polygons in several parts of Scotland. For some cases, peat may be a component part of a peaty soil polygon, where the peat component is approximately 30%. The Land Cover maps (LCM2007/LCS88) have higher resolution and single land use assignments. However there are potential misclassification errors of up to 40% between certain land use categories. Hence, overlays of such data sources may present a more certain picture than is really the case. In scenario A, the assumption has been made that the ca 30% peatland vegetation cover within an otherwise moorland vegetation polygon matches exactly with the underlying soil (30% peat in the National Soil Data). Hence the result is that 30% of the polygon is assigned to peatland on peat and 70% to moorland on shallower organo-mineral soil. In scenario B, the location of the peat in the underlying soil is not taken to necessarily co-locate with the current land cover, resulting in four potential classes ranging from a small peatland on peat, via a degraded peatland on peat and an area of bog vegetation on shallower soil, to a large area of moorland on shallower organo-mineral soil. In reality, both of these are false assumptions as both A and B assume the land cover classification to be entirely correct. Taking into account the potential misclassification error as well results in a probability map (scenario C) of the four potential categories. A map of the uncertainties associated with the mapping of the peat resource in Scotland can be found in the WISE Peatland Choices report (Artz et al 2013).

There is also further uncertainty in the land cover maps themselves, in that there are some potential misclassification errors of the habitats. For example, there exists a considerable classification error between the moorland and peatland land cover categories in the land cover maps (both LCS88 and LCM2007, see illustration in Figure 2). These two errors combined (uncertainty over the exact location of the peat soil, and uncertainty over the correct land cover assignment) means that, at best, some of these figures will remain probabilistic. In addition to the challenges posed to fully implement the necessary changes to the activity data in the NIR, there are also challenges associated with the new accounting rules in terms of the newly included carbon and other GHG pools.

5. Changes to emissions calculations and required Inventory assessments

The net emissions from a parcel of land under AFOLU accounting are calculated by multiplying the relevant land area (termed 'activity data') for any given category with its associated emission factor for a particular greenhouse gas (see 2013 IPCC Wetland Supplement for details). The first significant change introduced in the 2013 IPCC Wetland Supplement is to the soil-based emission factors under Tier 1 "default" emission reporting. These have significantly altered, and in some cases, there are now ways of calculating emissions from sources that were not previously included. Although some of the UK NIR reporting already uses country specific emission factors for organic soils, the new IPCC guidelines still prompt a critical re-assessment of these factors (see Table 2). As the soil-based emissions are calculated by land use (i.e. the sum of emissions from a particular land use on the relevant soil types [mineral and organic]), **changes to drained organic soil categories would therefore change the NIR emissions totals** (Chapter 1, 2013 IPCC Supplement).

In addition to potential changes to the emission factors for carbon dioxide (CO_2) and nitrous oxide (N_2O), there are a significant number of additional emissions detailed in the Wetlands Supplement that were not considered in the 2006 Guidelines. These include the direct emissions of methane (CH_4) from the site and from drainage ditches, carbon losses via aqueous pathways as dissolved organic carbon (DOC), which is subsequently oxidised off-site to CO_2 and emissions from managed peatland fires (i.e. muirburn). There may, therefore, be a significant increase in the baseline for the soil-based emissions from the land-use sector under the new reporting guidelines (Table 2). DECC have recently commissioned a project to scope the delivery of higher Tier factors for the UK as part of the Wetland Supplement implementation work. In addition, assessment is now required on whether some of the newly included emission categories are already accounted for using higher Tier methodology. The current status is summarised in Table 2. Tier 2 methodologies are country specific (or if possible region/devolved administration specific based on measured data) and Tier 3 methodologies are model-derived using more detailed parameters.

Table 2. *Likely impact of the 2013 IPCC Supplement: Wetlands on emission factor calculations for the NIR under UNFCCC reporting on AFOLU categories*

Land use category	Current methodology used in the UK Inventory	Likely impact of the 2013 IPCC Supplement: Wetlands
Forest Land (managed forests)	Tier 3 methodology currently used, based on the Forest Research CARBINE model. This model assumes all organic soils are drained. There have been some issues with modelling SOC stocks under Forest on organic soils, which are being looked at, but fundamentally there is a lack of field data to inform the modelling, and it is not clear whether or not SOC losses from drainage are outweighed by increased litter inputs when trees are planted on drained organic soils in the UK.	Would require assessment whether all new C pools in the 2013 Supplement (e.g. CH_4 from ditches, DOC and N_2O) are included in the CARBINE model as well as a technical assessment of the modelled soil-based emissions to ensure soil-based emissions match current scientific estimates. CARBINE is based on a modified version of the Roth-C model, which was initially not written for highly organic soil types. Some emissions may not be straightforward to model in CARBINE. Net emissions should be calculated separately for mineral and organic soils; at present the CRF only show a single net uptake figure into timber (i.e. across all soil types), versus soil-based emissions split by soil type. This makes it impossible to separately assess the likely implications of

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Land use category	Current methodology used in the UK Inventory	Likely impact of the 2013 IPCC Supplement: Wetlands
		rewetting versus restocking activities on organic soils.
Cropland	To date has used Tier 2 UK specific emission factors for cropland on drained organic soil of 12.8 t C/ha/y for thick peat (> 1 m deep and 21% C by mass) and 1.09 t/ha/y for thin peat (< 1 m deep and 12 - 21 % C by mass). However the work supporting this model is quite old and assumed that all loss of peat volume is due to oxidation of carbon, and assumes that drainage has no effect on peat bulk density. This is not completely true as some loss of volume is due to peat wastage and shrinkage. Therefore default T1 emission factors will be used for the next inventory. DECC has suggested that these be taken from the 2006 Guidance pending work to develop Tier 2 factors. There has been an assumption that there is no cropland on peat in Scotland. New areas taken from the Ag GHG platform (Table 1) will be used in future inventories (from the 1990 – 2013 inventory onwards).	Would require incorporation of the small area of cropland on former raised bog as planned anyway (see left) and inclusion of new C pools not formerly required (e.g. CH_4 from ditches). Emissions from cropland on drained organic soils in Scotland will be implemented as CL management prior to implementation of WS guidance. This will be done using T1 factors from the 2006 Guidance initially. These are substantially lower than the 2013 Wetland Supplement T1 EFs. T2 factors need to be developed.
Grasslands (managed grasslands)	Currently assumes no grassland on drained organic soils. New areas of improved grassland on drained organic soils from the Ag GHG platform work will be used from the 1990 – 2013 inventory (Table 1). It has not been possible to assess the area of drained unimproved grassland on organic soils. DECC has asked that T1 EFs from the 2006 Guidance are used pending work to develop T2 factors for the UK. These are substantially lower (an order of magnitude) than the 2013 Wetland Supplement values.	Emissions from grassland on drained organic soils in Scotland will be implemented using T1 factors from the 2006 Guidance initially. T2 factors need to be developed. Area estimates of unimproved grassland on drained organic soils need to be developed. Tier 3 development for emissions arising for land conversion to Cropland are subject to ongoing DEFRA study (SP1113, until 2014) although this does not consider drainage and so may not be applicable.
(Wetlands) / Peatland managed for extraction	Currently uses default (Tier 1) emission factors of 0.2 t C/ha/y for oligotrophic (assumed to represent fuel peat) and 1.1. t C/ha/y for minerotrophic (assumed to represent horticultural peat). These are an order of magnitude lower than 2013 Wetland Supplement EFs. Off-site emissions for fuel peat are reported under the Energy sector.	Would require inclusion of new C pools not formerly required (e.g. CH_4 from ditches). It will need to be discussed whether the 2013 WS T1 or a higher Tier methodology will be used.
Rewetted organic soil	Not included to date.	Will be required to be included at either Tier 1, including net CO_2 and CH_4 emissions on site (assumes N_2O negligible) or higher Tier methodology if possible in the medium term.

The net emissions for forest land are accounted for using a Tier 3 methodology in the NIR, though it could be argued that the methodology is quite simplistic. Until recently the calculations used the CEH C-Flow model. However, in the current UK Inventory, both the soil-based and biomass-driven emissions and removals from forest land are estimated using Forest Research's CARBINE model (http://www.forestry.gov.uk/fr/infd-633dxb). This new model includes a larger suite of tree species, can include pre-1920s forest and is better at modelling forest management. The output from CARBINE does not differentiate soil organic carbon (SOC) lost due to drainage from SOC change for other reasons. In addition, the details of the values used as input parameters to drive the model or indeed the model structure are not available for review at present and therefore it is not possible to comment here on whether CARBINE addresses all the relevant sources and sinks. The newly included pools, emissions from ditches or DOC in the 2013 IPCC guidelines are probably not currently included in the CARBINE model. Forest Research and CEH are however in the process of documenting the CARBINE model, and reports on this will be available shortly. There are known to be some issues with modelling emissions from drained peatland soils under forests, which stem from a shortage of field data to assess whether SOC losses from peat oxidation are outweighed by increased litter inputs from trees. CARBINE suggests that, after an initial period of around 30 years when losses outweigh gains, SOC stocks start to recover because of increased litter inputs. The model outputs suggest that this recovery continues until around 200 years when forest growth stabilises, after which SOC losses start to prevail again. However, there is considerable variation in this outcome that is partially dependent on site soil, climatic, and planting conditions.

For example, in a very productive (high yield class) forestry plantation on peat, the net emissions may appear to approach zero or even turn the site into a net carbon sink, in spite of the large carbon losses from the soil. In such a scenario any net emissions savings from restoration may appear to be relatively small or even negative (i.e. result in an increased atmospheric burden). Conversely, for other sites where the growth models suggest that only lower yield classes would be achieved, the current model suggests that restocking peat soils would not produce carbon benefits (Mike Perks, pers. Comm.). There will be more on this in a forthcoming briefing note on CARBINE. However, it must be stressed that in any of these scenarios the on-site carbon sink in the timber is only temporary as it is removed during harvest. While there may be some offset of other carbon through the use of such timber in harvested wood products, which can be thus accounted for, the loss of carbon from the peat soils is a continual process. Successful restoration should result in a net carbon sink for as long as climatic conditions are suitable for peat accumulation, whilst there are no harvesting losses. It may be necessary to compare the CARBINE outputs with potential net emissions, or even net sequestration rates that may be achievable through peatland restoration in order to make an informed decision on where peatland restoration is a preferred choice over restocking.

For cropland, only woody perennial crops would be considered as providing biomass C accumulation, and from 2013, litter incorporation via crop returns will be considered, as Cropland Management will be incorporated into the inventory under Tier 2 methodology. Additional non-CO_2 emissions from any burning practice will also be considered. There have been no CO_2 emissions from burning crop residues for several years because this practice has been outlawed. However, emissions from wildfires on cropland are reported. Emissions from ditches or DOC on drained cropland peat are not currently included in the NIR methodology and would thus require to be assessed under the new IPCC guidelines.

In grasslands, further research is needed before changes in grass residue returns can be incorporated into accounting for Grassland management. Prescribed burning of grassland cannot be incorporated at present. Grazing land (for cattle, sheep) is not generally burnt. Burning for heather management is not currently incorporated in the inventory because of lack of activity data, nor indeed are emission factors for prescribed burning available. Moxley et al (2014) highlight a current PhD study at CEH, which may give some insights on the GHG emissions attributable to prescribed burning. Emissions via aquatic pathways are not currently included.

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In the category 'Peatlands managed for extraction', there is no biomass. The off-site GHG emissions from peat extracted for fuel are already included in the Energy sector inventory and so do not apply here. The soil-based emissions are currently reported using the Tier 1 approach (Thomson et al., 2012) and it is proposed that this remain so. IPCC Tier 1 assumes instantaneous oxidation of horticultural peat so these emissions are accounted under the Wetlands category. This does mean that the new emissions classes of CH_4 from the site and ditches, as well as DOC losses, will now need to be included at Tier 1.

As a consequence of the many differences observed in how emissions from peatlands are calculated for Inventory purposes, relative to the crude emission estimates we presented in earlier policy briefings, we are currently not able to calculate the potential net abatement of peatland restoration activities from an Inventory perspective.

Further technical discussions will be required between the NIR Inventory compilers at CEH and key data contributors such as Forest Research, Forestry Commission Scotland and the James Hutton Institute, but also experts involved in the compilation of the 2013 Wetlands Supplement as well as contributors to the SP1113 Defra project. DECC currently have a project on WS implementation, which will provide further area and higher Tier emission factor figures by late 2016, which will also shed further light on the most manageable way to implement the new 2013 IPCC guidelines.

In summary, the implementation of the new Guidelines requires some updates to the National Inventory activity data on each of the possible land use categories on peat soils, and additionally on the emission factors used in the calculations. All peatland areas, regardless of land use, are currently regarded as managed land. Arguably, intact peat bogs could be considered unmanaged but the extent of these is still unclear. It may be feasible to include peatland restoration in the Inventory under a Tier 1 methodology in the first instance, with a view to develop a higher Tier methodology in the medium term, as discussed further in Section 9. Firstly, however, we will discuss the potential to include peatland restoration activities under KP reporting.

6. Kyoto Protocol (KP) reporting

Since 2010, the UK is also required to provide annual reports to both the EU and the UNFCCC on its progress towards its Kyoto Protocol targets within the National Greenhouse Gas Inventory (see Figure 3 for an explanation of how KP reporting and UNFCCC reporting fit together). Article 3.3 of the Kyoto Protocol requires Parties, in meeting their emissions reduction commitments, to account for Afforestation, Reforestation and Deforestation (ARD)[2] since 1990. Accounting for ARD under Article 3.3 requires a definition of forest, knowledge of forest type and planting/deforestation rates, geographical location, and a method to distinguish deforestation from areas harvested and replanted. In addition, Article 3.4 of the Kyoto

[2] *Afforestation/Reforestation (AR) – where afforestation is the direct human-induced conversion of land that has not been forested for a period of at least 50 years to forested land through planting, seeding and/or the human-induced promotion of natural seed sources. Reforestation (R) is the direct human-induced conversion of non-forested land to forested land through planting, seeding and/or the human-induced promotion of natural seed sources, on land that was forested but that has been converted to non-forested land. For the first commitment period, reforestation activities were be limited to reforestation occurring on those lands that did not contain forest on the 31st December 1989. Deforestation (D) - is the direct human-induced conversion of forested land to non-forested land.*

Protocol allowed Parties flexibility to choose Forest Management (FM)[3], Cropland Management (CM)[4], Grazing Land Management (GM)[5] and Revegetation (RV)[6] towards meeting commitments, but this was not mandatory. The UK elected Forest Management as an activity under Article 3.4 in the first commitment period (2008-2012), but did not elect Cropland Management, Grazing Land Management or Revegetation. For the second commitment period (2013-2020), Forest Management has become a mandatory activity and the EU requires its member states to report on GM and CM.

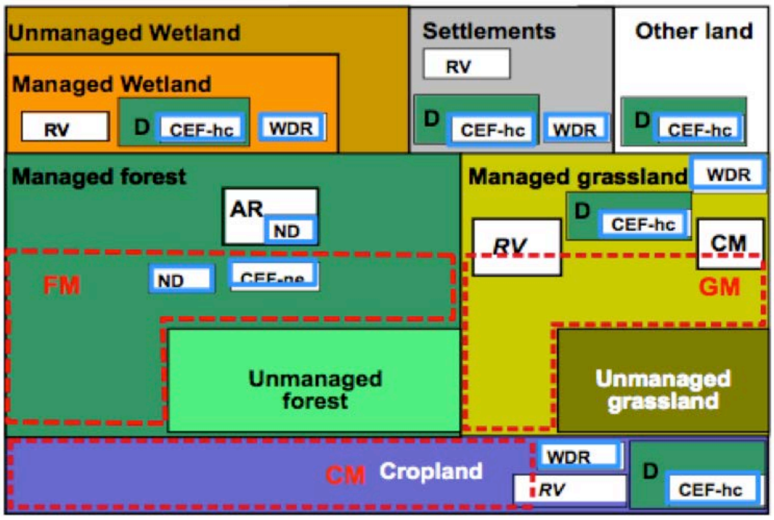

Figure 3: Activity reporting categories in the National Inventories for KP reporting in relation to the UNFCCC reporting categories as presented in Figure 1. Unmanaged land is not reported. Please refer to footnotes above for abbreviations. CEFC – carbon equivalent forest conversions – have not been adopted by the EU (Decision no. 529/2013/EU). Reproduced from IPCC (2013b)

The recent 2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol (hereafter called the 2013 KP Supplement; IPCC, 2013b) provides supplementary methods and good practice guidance for estimating anthropogenic greenhouse gas emissions for the second commitment period (2013-2020). The 2013 KP Supplement now also adds the additional, optional, Article 3.4 activity of wetland drainage and rewetting (WDR)[7] (Figure 3). This will facilitate the formal inclusion of activities that raise the water table in soils, including peatland restoration, in KP reporting in the UK (if elected). The UK is required by the EU to report on Grazing land management (GM) and cropland management (CM) for the second commitment period. At present the NIR does not report emissions from GM (except for liming of improved pasture). The EU requires reporting on Grassland and Cropland Management from its member states, so emissions from management of these areas will need to be reported. The Defra SP1113 project

[3] *Forest management (FM) - is a system of practices for stewardship and use of forest land aimed at fulfilling relevant ecological (including biological diversity), economic and social functions of the forest in a sustainable manner.*

[4] *Cropland management (CM) - is the system of practices on land on which agricultural crops are grown and on land that is set aside or temporarily not being used for crop production.*

[5] *Grazing land management (GM) - is the system of practices on land used for livestock production aimed at manipulating the amount and type of vegetation and livestock produced*

[6] *Re-vegetation (RV) - is a direct human-induced activity to increase carbon stocks on sites through the establishment of vegetation that covers a minimum area of 0.05 hectares and does not meet the definitions of afforestation and reforestation contained here.*

[7] *Wetland drainage and rewetting (WDR) - is a system of practices for draining and rewetting on land with organic soil that covers a minimum of 1 ha. The activity applies to all lands that have been drained since 1990 and to all lands that have been rewetted since 1990 and that are not accounted for under any activity as defined above, where drainage is the direct human-induced lowering of the soil water table and rewetting is the direct human-induced partial or total reversal of drainage.*

(Moxley et al., 2014) aimed to develop methodologies for reporting emissions from CM and GM, but did not include consideration of drainage.

Implementing reporting of WDR, if the UK chooses to do this, poses two difficulties. The first is in the accounting rules and various changes in these rules that take effect from 2013. Accounting for emissions and removals is subject to a hierarchical approach (Table 3). Deforestation is placed at the top of the hierarchy and any land that has been subject to deforestation since 1990 must be accounted under Deforestation (D), irrespective of its current use. Following this in the hierarchy are lands subject to Afforestation and Reforestation (AR), then Forest Management and finally at the lowest level are the elective 3.4 Activities. As the accounting process is thus not primarily stratified by land type but rather by a hierarchical series of activities, the resulting accounting rules are rather complex. To complicate matters, accounting for emissions and removals differs between the activities (see below).

Table 3. *Allowed conversions of Article 3.3 and 3.4 activities*

Initial land use	**Reporting of final land use if peatland restoration is carried out**
Forest land	D or FM (if restoration can be carried out without affecting the minimum definition of Forest Land)
Cropland	CM, RV, WDR**
Grassland	GM, WDR**
Wetland (Peat extraction)	RV, WDR**

**When elected, WDR only applies on land that is not accounted for under any Article 3.3, or other elected Article 3.4 activity. Reproduced from IPCC (2013).

The activity of WDR can only be reported on parcels of land not already accounted for under the already included activities (Table 3) as it is lowest in the hierarchy. However, whereas the *activity* WDR can only be applied to land not already accounted for under other activities, the *practices* of drainage and rewetting can be carried out on all land with organic soil irrespective of the KP activity the land falls under. The rules result in some challenges in accounting for peatland restoration that has taken place on areas that are currently reported under the mandatory activities (AR/D, FM) in the UK Inventory. If the practice of restoration through rewetting is carried out on forested land, the emission accounting must adhere to the specific rules associated with the relevant land Activity (AR/D or FM). For example, where the land use during the baseline year (1990) was forest land on peat, the restoration to an open, treeless peatland ecosystem would not be reported under WDR, but under Deforestation (D) and reporting would have to follow the accounting rules set for D.

There is a clause in decision FCCC /KP/CMP/2011/10/Add.1 (page 19) which offers a route to formally account for peatland restoration from former afforested peatlands without incurring a Deforestation debt: *"Parties may include in the accounting of Forest Management under Article 3.4 anthropogenic greenhouse gas emissions by sources and removals by sinks resulting from the harvest and conversion of forest plantations, accounted for under Forest Management, to non-forest land, provided that all of the following requirements are met:*

- *The forest plantation was first established through direct human-induced planting and/or seeding of non-forest land before 1 January 1990, and, if re-established, that this last occurred on forest land through direct human-induced planting and/or seeding after 1 January 1960.*
- *A new forest of at least equivalent area as the harvested forest plantation is established through direct human-induced planting and/or seeding of non-forested land that did not contain forest on 31 December 1989.*
- *A debit under Article 3.4 would be generated if the newly established forest does not reach at least the equivalent carbon stock that was contained in the harvested forest plantation at the time of harvest, within the normal harvesting cycle of the harvested forest plantation.*
- *All lands and associated carbon pools subject to the provision shall be identified, monitored and reported, including the georeferenced location and the year of conversion and accounted for as Forest Management under Article 3.4 and not under Article 3.3."*

Therefore, as long as an equivalent area of forest, with equivalent carbon stock, is re-established elsewhere, restoration of former afforested peatlands could be accounted for under Forest Management. **At present,**

this concept of "carbon equivalent forest conversions" however has not been adopted in the EU. However, if adopted in future, it could be applicable to areas that are deforested for windfarms where there is a planning condition that the developers plant compensatory forest elsewhere and for plantation forestry removal for peatland restoration. If this option remains closed within the EU, it may also be worth assessing whether peatland restoration activities can be carried out in such a manner that the area overall still meets the UK national criteria of Forest land (tree crown cover of 20% or the potential to achieve this, 2 m minimum height) in which case this land use would still be accountable under Forest Management (FM). This may allow restoration of former plantation forestry to e.g. a bog woodland scenario, which in certain cases would fulfil the criteria of Annex 1 habitats such as 7120 Degraded raised bogs still capable of natural regeneration or 91D0 Bog woodland, but would require replanting with the appropriate native species. Whether this is achievable in practice, however, would require further assessment by specialists within FCS/FR.

As Cropland management (CM) areas are likely to map closely to areas of cropland under UNFCCC reporting (see section 4), it is likely that implementation of KP reporting is relatively straightforward. However, obtaining activity data for privately owned land may pose a problem (see below).

A slightly more complex issue arises with degraded peatlands that would fall under UNFCCC Grassland categories but not necessarily KP Grazing land management (GM). The distinction here is that, while any land that could be considered "rangelands and pasture land that are not considered Cropland", for example, grouse moors or upland sheep farming on degraded upland blanket bog, would fall under UNFCCC Grassland categories, the KP category of Grazing land management (GM) is defined as a "*system of practices on land used for livestock production aimed at manipulating the amount and type of vegetation and livestock produced*". This clearly includes pastures that have resulted in improved grassland on peat soils. Rough grazing, i.e. rough grassland on former peatland, is included as well. It is not entirely clear whether land uses such as grouse moors, which would be the majority of the wet/dry heathland conversions in Table 1, should be included. Vegetation on grouse moors is manipulated to favour grouse, which could potentially be considered non-domesticated poultry livestock, and grouse moors may in addition be grazed by farmed livestock. Similarly, deer are managed in much of the Highlands as non-domesticated livestock (although not necessarily the vegetation). A narrow interpretation of the KP category of GM would only include land that supports domesticated livestock such as cattle, sheep and pigs. A broad interpretation would also include land managed for non-domesticated livestock, arguably including all grouse moors. A clear consensus on to how to interpret this KP category has not been reached as yet. If rewetting and restoration activities are carried out on blanket bogs that currently support livestock, accounting would need to follow GM rules under the hierarchical rules.

Obtaining activity data for GM may pose a methodological challenge whether following the narrow or the broad interpretation. Drainage and rewetting practices on grouse moors and areas used for deer grazing may escape KP accounting. Agricultural census data in Scotland can be obtained through querying the Integrated Administration and Control System (IACS) dataset held by the Rural Payments & Inspections Directorate (RPID). However, in some cases, certain parcels of land that would or could fall under GM rules may not receive subsidies, if the grazing is not agriculturally productive e.g. equestrian grazing; management for deer, and grouse moors where no sheep are present. Reliance on IACS data alone could thus result in underestimation of any restored hill-drained areas, and as well as the emissions associated with GM activities.

Forest land areas are obtained from the National Forest Inventory (NFI) supplemented with data for grant assisted planting and unconditional felling licences. This allows land that is or has been forested to be classified as AR, D or FM, although does not currently include Forest covering less than 0.5 ha. It is assumed that all forested land on organic soils is drained.

Rewetting of peat extraction areas as well as areas with unclearly defined land use (e.g. grouse moors, areas used for deer grazing) has been carried out in Scotland (e.g. under the Peatland Action programme) and could be accounted for under WDR. However, not all rewetting activities on peat soils have attracted funding from the Peatland Action programme as there are several examples of privately or EU-funded rewetting programmes and hence providing activity data for WDR category may be challenging as well. There is no national database of restoration projects that captures the required information. It would be useful to establish such a repository, but in the first instance, data on WDR could use data from the Peatland Action programme and known restoration sites such as captured in Chapman et al (2012).

Issues caused by differences in accounting rules between KP categories

The second challenge is in the different accounting rules for the different KP activities: AR/D uses gross-net accounting; FM uses a reference level approach and all other activities use net-net accounting. Net-net accounting, as applied to all activities except AR/D and FM, looks at the net-difference between the net emissions/removals during the commitment period and the net emissions/removals during the 1990 base year. The new WDR category will also use net-net accounting. Rewetting and drainage (under WDR or CM, GM or RV) only pertains to areas where the drainage status (drained or undrained/rewetted) differs between the commitment period and 1990.

In this context 'drained' means that the water table is lower compared to 1990, either because a hitherto undrained area has been drained or because an already drained area was drained (considerably) deeper. 'Rewetted' means the water table is higher than in 1990, either because a drained area has been rewetted or because the drainage level is (considerably) higher. Maintenance of ditches to retain existing drainage levels is not considered to constitute 'drainage' in this context.

In the UK, the majority of the uplands were already drained prior to 1990 (Holden et al., 2004). By 1990, many of the tax incentives to develop forestry plantations on peatlands had already been revoked as the degree of damage to these habitats and the species they support had become apparent. Similarly, many of the upland drainage schemes were no longer actively supported by policy. Hence, only a very small degree of peatland drainage took place post 1990, although the exact figures are unknown. A possible exception may be drainage for the construction of wind farms. In such cases it will be necessary to establish whether drainage occurred in addition to that historically present. With this caveat, WDR accounting (or respective practices under GM, CM or RV) would only apply to those areas that have been rewetted or drained since 1990.

In the case of afforested, reforested and deforested peatland, AR/D uses gross-net accounting, i.e. assesses the gross change in net emissions/removals over the commitment period without including a historic reference such as the 1990 base year. Gross-net accounting looks at the total emissions/removals that occur in the commitment period, i.e. all emissions/removals between 2013 and 2020 regardless of when the activity that triggered them took place. FM for the first commitment period also used gross-net accounting, under the new KP Guidelines, however, accounting in the second commitment period is against a Forest

Management Reference Level (FMRL). Emissions and removals for FM are calculated against a (hypothetical) scenario of emissions/removals during the commitment period in absence of mitigating management measures. The UK proposed a FMRL of -8.3 Mt CO_2e per year, based on a business as usual (BAU) scenario from 2010 (Anon, 2011; Anon, 2011b). The FMRL for the UK includes emissions from thinning, harvesting at the appropriate yield (ca. 59 years for conifers) or for unconditional felling licences, wildfire losses and restocking. The FMRL includes the emissions associated with the living biomass, dead organic matter, soils and biomass burning. Fertilization and liming are reported as not occurring and emissions from Forest Land on drained histosols are not estimated separately, however the UK could propose a technical correction to the FMRL to include these emissions. It would be beneficial to the UK to make such a correction as this would maximise the benefit of rewetting.

These asymmetric accounting rules may lead to perverse results when drained and afforested peatlands are restored. For example, when rewetting and restoring a drained and afforested peatland leads to inclusion under the Deforestation land use category, the gross-net accounting of Deforestation means that only the emissions and removals occurring AFTER the forest removal are accounted, as the emissions and removals BEFORE forest removal (carbon sequestration in growing trees and the soil-based emissions from existing drainage) are included in the FMRL. Therefore, although there may be in reality a large harvesting related peak in emissions this is not accounted for as it is included in the FMRL. The subsequent decrease in CO_2 emissions that occurs after the peat soil has been rewetted is then not seen as a credit, whereas the CH_4 emissions that start after rewetting do constitute a debt.

The change in the FM accounting rules from gross-net to FMRL means that the positive climatic effect of rewetting formerly afforested peat has become undetectable in the emission accounting figures. The current CO_2 emissions from the drained peat soil are de facto not accounted for as they are embedded in the FMRL. Current FMRL based accounting only reports on emissions and removals where they deviate from the reference perspective

With deforestation and rewetting, the land moves from a system that does not account for CO_2 emissions from the drained peat soil to a system that does account for the emissions after rewetting. Therefore, even where rewetting would cause a realistic net reduction in greenhouse gas emissions, under the accounting rules a net increase would be reported. A solution to the problems associated with the new reporting guidelines anomaly has, thus far, not been found (but the issue has been raised by various member states (John Couwenberg, pers. Comm.). One possibility could be to review the FMRL such that rewetting activities on formerly afforested peatlands are considered part of the business-as-usual. This may however only be possible if restoration of formerly afforested peatlands could continue to be accounted for as Forest Management rather than Deforestation (see above for criteria).

The implications of the embedded soil-based emissions in the FMRL for any potential emissions abatement inclusion from peatland restoration on plantation forests established prior to 1990 and the likely implications of the mandatory nature of deforestation activities need to be assessed in more detail, possibly within the current DECC project on Wetland Supplement implementation. A possible outcome may be that the UK starts efforts to change the KP accounting rules for rewetting of currently forested peat soils.

7. How to account for peatland rewetting in the UNFCCC and KP reporting framework.

Rewetting of afforested peatland, as has taken place in the Flow Country over the last 15 years, has potential to mitigate GHG emissions in the LULUCF Sector. Under UNFCCC reporting, these areas would initially have been classified under the Managed Forest Land category, with associated emissions (Table 4). After restoration, the land will be transferred to another land use category, most likely to Grassland (Table 4). There is some flexibility in the UNFCCC definitions and attribution is currently under review by CEH staff involved in NIR reporting. The emissions associated with the restored land will then appear in the Land Converted to Grassland category. Land transfers from "Land converted to X" to "Land remaining X" after 20 years, so 20 years after restoration the land areas would move to "Grassland remaining Grassland", but emission and removals from changes in SOC continue after this – the UK NIR assumes that carbon equilibrium is reached after 100 years for SOC loss and after 525 years for SOC gain. However, these times to equilibrium are more applicable to mineral than organic soils could be reviewed for organic soils. Section 3.2.1 of the Wetland Supplement gives Tier 1 methodology, which suggests that removals by rewetted organic soils continue at a constant rate indefinitely. Under KP reporting, the same activity would be most likely be reported as either Deforestation although it might be reported as Forest Management, if the minimum rules for forest cover are met or if the EU adopts carbon equivalent forest conversions.

Another useful example is the restoration of grouse moors, where old drainage ditches are filled in to rewet the site and encourage recolonisation by peatland vegetation. The emissions from such areas would continue to be reported under "Grassland remaining Grassland" (Table 4). If the areas are used for e.g. sheep grazing, KP accounting would be under Grazing land management (GM). In the absence of animals traditionally classed as livestock (sheep, cattle, pigs), inclusion is dependent on the decision whether grouse moor management falls within the definition of Grazing land. It is likely that this classification issue is only relevant to the UK and Ireland.

Table 4 shows the various categories under which emissions resulting from the current land use or restoration practices on peatlands will likely be reported under UNFCCC and KP. It highlights the fairly limited potential for emissions to be classified under the WDR category, due to the hierarchical nature of KP reporting.

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Table 4. *Reporting categories for potential peat land use scenarios in Scotland*

Possible Scottish scenario	UNFCCC reporting category and emissions factor	KP reporting activity
Afforested peat soil, restocked	Forest land remaining Forest land, Tier 3	Forest Management (FM) or Afforestation/Reforestation (AR)
Afforested peat soil, restored to peatland	Forest land converted to Grassland, Tier 1 or higher if available for rewetted organic soils)	Deforestation (D) or Forest Management (FM) if criteria for latter can be met (maintained canopy cover at minimum national definition for forest).
Cropped peatland, remaining cropland	Cropland remaining Cropland, Emissions reported will initially be using T1 for CL on drained peat in England. Activity data for this in Scotland has only just become available from the AC0114 work. Tier 2 possible at later stage	Cropland Management (CM)
Cropped peatland, restored to peatland	Cropland converted to Grassland, Tier 1, or higher Tier if data available for rewetted organic soils	CM
Eroded bog, no change	Grassland remaining Grassland, Tier 1/2	Grazing land Management (GM) if livestock is present
Eroded bog, restored	Grassland remaining Grassland, Tier 1, or higher Tier if data available for rewetted organic soils	GM (if livestock is present)
Improved or rough grassland on peat soils, no change	Grassland remaining Grassland, Tier 1/2	GM (if livestock is present)
Improved or rough grassland on peat soils, restored	Grassland remaining Grassland, Tier 1, or higher Tier if data available for rewetted organic soils	GM (grazed) or WDR (ungrazed; if WDR is implemented)
Wet or dry heather moorland cover on peat soils, no change (includes domestic extraction)	Grassland remaining Grassland, Tier 1/2	GM (if grazed).
Wet or dry heather moorland cover on peat soils, restored (includes domestic extraction)	Grassland remaining Grassland, Tier 1, or higher Tier if data available for rewetted organic soils	GM (grazed) or WDR (ungrazed; if WDR is implemented)
Commercial peat extraction, no change	Wetlands remaining Wetlands, Tier 1	WDR (if implemented)
Commercial peat extraction, restored	Wetlands converted to Grassland, Tier 1, or higher Tier if data available for rewetted organic soils	WDR (if implemented)

8. Requirements for activity data to reflect peatland restoration activities since 1990.

Updating the KP reporting with relevant data on peatland restoration under AR/D or FM (mandatory) or the elective categories of GM, CM and WDR is, in theory, not an enormous challenge. As outlined already, there has been relatively little additional peatland drainage in Scotland since 1990, the predominant activity has been rewetting through restoration management. The main hurdle is to gather the required activity data, i.e. the information on where rewetting has taken place since 1990. This requires a more detailed look at available 'restoration' data as there will be areas where drain blocking and scrub management has taken place under the current SRDP Land Managers Options, often with a view to improving habitat quality, but where the water table was not raised. Hence, IACS data would need to be carefully assessed to identify where actual rewetting (i.e. raising of the water table) occurred. Whether any such management resulted in a rewetted peatland may be difficult to assess in practice, as there was no water table monitoring requirement under SRDP.

Further activity data on rewetted soils would need to be gathered from restoration activities carried out under the Peatland Action programme (formerly the Green Stimulus Peatland Restoration Project), and restoration projects that form part of wind farm construction projects under Habitat Management Plans (data on which are compiled through Scottish Natural Heritage). Data on areal extent and location for the latter two should therefore be relatively easy to compile. At present, the only published compilation of restoration projects is from Chapman et al (2012), which suggested that a peatland area of 31 kha has been restored since 1990, which is very much an underestimate of the known restoration work to date. These data would all be required to be allocated to their respective KP Article 3.3. and 3.4 activities as well as the UNFCCC reporting categories. This is nota trivial task and should be considered high priority.

9. Requirements for the development of higher Tier emission factors.

Our previous policy briefing on the proposed Tier 1 emission factors in the 2013 Supplement concluded that in general these did not adequately describe the nature of, and likely emissions from, Scottish peatlands (Artz et al., 2014). Where national estimates of the rewetted area are available, the development of Tier 2 emission factors is encouraged. The 2013 Wetlands Supplement suggests that it may be appropriate to sub-divide activity data and emission factors according to the present vegetation composition which is a representation of the water table depth and soil properties, or by land use prior to rewetting (e.g. Forest Land, Grassland, Cropland, Extracted peatland). By far the largest category of managed former peatlands that may benefit from restoration activities is currently accounted for in the Grassland category. Our previous assessment of the potentially restorable areas (Chapman et al., 2012; Table 1) indicates a wide range in the condition of these 'Grasslands', ranging from only mildly disturbed peatland areas to severely eroded uplands. Much additional evidence is being gathered at present to fill gaps in scientific knowledge on emissions (see section 10 below). Thus, it should be feasible to develop Tier 2 emission factors for rewetting of different starting conditions in the Forest land, Cropland, Grassland and Wetlands (peat extraction) categories listed in Table 1.

In the rewetted soils chapter of the 2013 Wetlands Supplement, it is suggested that countries can apply the default 20 year transition period to rewetted organic soils. This period only defines the point when the land moves from Land converted to X to Land remaining X, not necessarily when the emission/removal stops. The chapter suggests emissions/removals can continue indefinitely at a constant rate.

Hence, in reality, drained land will continue to lose SOC until all the peat is oxidised. Blocking drains on land which was losing SOC in 2015 will reduce emissions in 2016, 2017 and every subsequent year, until peat accumulation re-establishes, providing a CO_2 sink and CH_4 emissions become comparable with those observed from pristine peatlands.

Previous spreadsheet-based calculations of the likely abatement potential from peatland restoration followed this rationale (Chapman et al., 2012). Instead of the IPCC default period for changes in land use or the SOC transition periods used by the NIR team (i.e 20 – 100 years for changes giving SOC loss or 20 – 525 years for changes leading to SOC gain), Chapman et al. (2012) used transition periods ranging from 25 to 80 years, based on the starting condition of the peatland prior to restoration. It would be useful to assess whether these assumptions are valid as more greenhouse gas emission monitoring data from completed restoration projects become available. However, at present, there are no UK data beyond 10 years post-restoration and even data from younger rewetted sites are very sparse.

A meta-analysis carried out by IPCC (2014a) on flux measurement data revealed that there is no significant difference in emissions (CO_2 and CH_4) from rewetted and undisturbed peatlands. Different emission factors may be in order for methane emissions during the transition period. In nutrient poor sites (e.g. peat extraction areas) CH_4 emissions tend to be lower than in natural, undrained peatlands during the first years after rewetting, whereas in nutrient rich sites they tend to be higher. Chapman et al. (2012) assumed increased CH4 emissions for a duration of 10 years in all cases of rewetting with a maximum at 5 years after rewetting. Similarly, the scale of peatland restoration activities may also influence emission abatement periods, for example, where only minor surface drains are blocked this presumably does not tend to result in a noticeable methane emissions spike. Although the IPCC meta-analysis produced robust results, there are currently not enough data to validate this assumption for the UK. As more evidence becomes available, it should be incorporated into the Tier 2 methodology if peatland restoration is accounted for.

The report by Thomson et al. (2012) summarised some of the UK data available on emissions from various land uses on peat soils up to 2011, but a lot of further evidence has become available since then. For example, the recent publication by Haddaway et al. (2014) compiled emission estimates for CO_2, CH_4, N_2O and DOC from temperate, lowland peatlands and subjected these to a formal meta-analytical review where the difference between emissions from different land use categories was statistically assessed. This review showed significantly higher fluxes of CO_2 through ecosystem respiration, increased N_2O fluxes and marginally higher fluxes of DOC but significantly lower methane fluxes in drained peat soils when compared with undrained peat soils. Restoration led to significantly higher methane fluxes, but lower N_2O fluxes, however this was based on an assessment of only up to four published studies from restoration projects on peat extraction or forestry drained peatlands. We have compiled an additional summary of ongoing research on GHG fluxes from peatlands in the UK and Ireland under land use or undergoing restoration in section 10 below.

10. Research gaps for the development of higher Tier methodologies

For the most significant areas of land use conversion on peat soils (forestry, wet/dry moorland conversion with or without erosion features and unimproved grassland) there is generally insufficient scientific data to compile higher-level emission factors at present. However there are a significant number of ongoing studies on peatlands that cover most of the land-use categories required for reporting, including restoration sites

(Table 6). Estimating the potential net emissions from forestry conversions on former peatland currently presents the biggest challenge (Table 6).

While the IPCC used data from a number of sites with forestry on peat in the temperate region (see Artz et al., 2014 for references) the majority of these studies represent a land use that differs quite significantly from the forestry practices in Scotland, with the exception of the Yamulki et al (2012) study. Therefore, such existing data cannot be used to verify the emissions calculations for Forest land on drained organic soils produced by CARBINE or the previously used C-Flow model. Most of the studies detailed in the IPCC report are on naturally occurring peatland forests but where tree growth was encouraged by drainage practices. Based on the sparse research evidence available, there appears to be a difference in the net emissions from such forests when the peatland vegetation understorey is present. Two examples used in the IPCC report under the boreal category but that would fall within the IPCC classification of the temperate zone (Lohila et al., 2011 and 2007) show that, while a peatland forest with remaining understorey is still a net sink of CO_2, a site with more aggressive drainage and where the understorey had largely disappeared acted as a carbon source. Similarly, a newer study by Meyer et al. (2013) indicated a benefit of up to 2t CO2eq ha-1 yr-1in net ecosystem CO_2 uptake from a plantation forest on former agricultural fens, however this did depend on the calculation method used.

In the UK, most afforestation on peatlands took place after drainage, using commercial plantation spacing, which resulted in the complete loss of the original peatland vegetation. In soil cores taken from afforested peatlands, the original peatland vegetation can only rarely still be identified (often only as a thin layer of decaying *Sphagnum*) where it was folded into the soil column as a result of ploughing prior to planting (Roxane Andersen, pers. Comm and personal observations R Artz). It is not clear whether CARBINE or indeed any other model accounts for this lost pool of carbon. CARBINE does model emissions from organic soils and litter inputs from both trees and any understorey vegetation, but it is unknown whether the parameterisation includes the oxidisation of the original litter and vegetation layer in the years after ploughing and planting. Given the scarcity of field data to parameterise CARBINE for these sorts of organic soils, it would be unlikely that this is adequately modelled. Full net ecosystem exchange assessments from afforested peatlands are still rather rare (Forest Research, 2014), and it is these that will be required to fully assess the net carbon benefits of restoring peatlands after afforestation, instead of restocking. From 2015, the data produced by FR for the National Inventory Reporting will include a split figure from CARBINE for timber biomass carbon on mineral and organic soils (Heath Malcolm, pers. Comm.) and this may help to inform the relative merits of rewetting versus restocking.

In Table 6, we have compiled the current state of ongoing research that addresses the various soil-based emissions that require reporting. As this table indicates, while there are a significant number of research efforts, there are significant gaps, most notably in the emissions associated with DOC losses from the site and subsequent conversion to CO_2 and CH_4, and with the direct emissions of CH_4 from ditches in forestry plantations. A technical review of the CARBINE model should assess how these component fluxes are parameterised.

The main difficulty is that data from different growth stages of forestry will be required to fully assess the net emissions of carbon from forestry on peat. There are only a few studies to date that have investigated the net ecosystem carbon dynamics of peatland afforestation. Examples are as yet unpublished the work of the research group at University College Dublin (Matt Saunders, Pers. Comm.), which uses eddy covariance techniques over an 18 year old Sitka spruce stand on formerly already managed peatland at Cloosh Forest.

Similarly, the newly established work at the Dyke Plantation, Forsinard, Scotland will involve the installation of an eddy covariance system over an end of rotation mixed stand of Sitka Spruce and Lodgepole Pine to assess both pre- and post-felling emission dynamics (pers Comm Roxane Andersen, ERI Thurso; see Table 7 for site details). Emissions monitoring at Flanders Moss (an afforested former lowland raised bog, Yamulki et al 2012) also provided emissions data, although this site has now been felled.

There is a similar evidence gap for emissions from areas of heather moorland cover which account for the largest extent of converted peatlands. Although our compiled summary of ongoing research (Table 6) returned an impressive number of research sites, it is difficult to assess whether studies that have been carried out thus far on predominantly English and Welsh sites (Table 7) might be representative of the likely emissions in Scottish moorlands on degraded blanket bogs as there are climatic differences, and habitat degradation has been (slightly) less severe. In addition, many of these studies are still in progress, with relatively few data published at present. The only published examples relevant to Scotland and Ireland that are climatically comparable, are from a lowland raised bog that has mild anthropogenic impacts (Auchencorth) and a relatively intact blanket bog (Glencar). Emissions data from these relatively undisturbed sites will hardly represent the state of emissions from Scottish moorlands in all of the various degradation classes. Very few studies to date have assessed the GHG emissions resulting from differences in grazing pressures on converted peatlands (Clay et al., 2013; Worrall et al., 2012). Peat erosion can currently only be identified on the basis of land cover maps that indicate erosion as a dominant or subdominant feature. The resulting emissions from eroded peatlands have been investigated as distinctive landforms within a wider landscape, revealing higher emissions from these erosion gullies compared to the surrounding land (e.g. Worrall et al., 2011; Whitfield et al., submitted). In order to use these results for inventory purposes, however, the actual area affected would need to be established, which would require a significant, national, mapping effort, based on remote sensing (identified as a data need in a recent commissioned SNH report by Cummins et al., 2011).

The category of unimproved grassland in the stricter sense (i.e. showing vegetation that is distinctly grass-dominated) and the smaller category of improved grasslands on peat soils are subject to similar delineation difficulties. We were unable to identify a single publication or experiment from the UK or Ireland to date that has assessed emissions associated with either of these land use categories on bog peat, although there are a few ongoing studies on fen peat habitats (Table 6).

Fen peat soils (minerotrophic peats) are relatively common in Scotland, though small in total area. The only available activity data that can be found on fen habitats remaining as fen are reported in the Fen Management Handbook (SNH, 2011). There are no databases that can be readily used to distinguish fen soils that have been converted in Scotland as these habitats have not been exhaustively surveyed and are not distinguishable from other peat soils in the soils inventories. Hence, any cropland or other use of former fen peat soils in Scotland is unlikely to be differentiated from more common wetland types in the NIR or future KP reporting.

While there is very little data available on the emissions from commercially and domestically extracted peatlands, these occupy relatively small areas in Scotland and thus the research efforts could be limited to one or two short studies to clarify whether there are unforeseen high emissions from such categories. Existing work indicates that emissions from former extraction sites are relatively low, as most of the reactive soil organic carbon has already been extracted, vegetation is generally low in cover or lacking and the remaining peat mass is highly decomposed (IPCC 2013a; Wilson et al., 2013; Artz et al., unpublished data from Middlemuir Moss, Table 6/7). Studies on domestic peat extraction sites are extremely rare with a recent Irish research project the only example found (Table 6/7); it is commonly assumed that domestic extraction, if following best practice guidance, causes relatively low additional emissions from the site after the fuel peat is removed. This statement does, however, require additional evidence, and a recommendation from this review would be to commission a study of the relevant emissions from at least one relevant domestic peat cutting site.

Similarly, while there is some ongoing research on arable land conversions on fen peat from England (Table 7), arable crop conversions on bog soils have not been studied in the UK or Ireland so far, and we would currently have to rely on Tier 1 values calculated using limited data gathered elsewhere in Scandinavia and central Europe (see Part 1 of this briefing, Artz et al., 2014). This may be adequate given the small extent of cropland on peat soils in Scotland.

Finally, it must be pointed out that one particular category, the gaseous emissions associated with the biological conversion of dissolved and particulate organic carbon in streams and ditches in relation to the different land use conversions, is currently poorly characterised throughout all land use categories. The scientific community to date has predominantly focused on measuring DOC production and transport under business as usual versus restored scenarios. Several publications, in addition to ongoing research efforts, focus primarily on the production of DOC and Particulate Organic Carbon (POC) (Turner et al., 2013; Ramchunder et al., 2013; Worrall et al. 2013, 2011, 2009; Clay et al., 2012; Armstrong et al., 2012; Mueller et al., 2012; Wilson et al., 2011; Tipping et al., 2010; Koehler et al., 2009; Wallage et al., 2006; Dawson et al., 2004 and ongoing research at Moorhouse and Auchencorth experiments in Table 6/7). Very few research projects, however, investigate the ultimate fate of this carbon pool, with notable exceptions from Billett and Harvey, 2013; Dinsmore et al. 2013 and Billett et al. 2010. There are even fewer studies in the UK and Ireland on gaseous emissions from ditches (stagnant or periodically running/dry, e.g. Cooper and Evans, 2013; McNamara et al., 2013, Table 7), man-made pools (ongoing work at Forsinard, Table 7), or resulting from transport through peat pipes (e.g. Holden et al., 2013; Billett et al., 2012; Dinsmore et al., 2011) that could feed into higher level reporting at present. At Tier 1 there is an assumption that DOC in streams is almost entirely converted to CO_2 and therefore some of the data from the publications available could be used on this basis until conversion rates can be calculated with more relevant estimates.

Losses of carbon through conversion of biomass by burning, either via direct losses of gaseous carbon by combustion or via indirect means by production of altered forms of carbon that are transported in DOC pools, cannot be calculated at present, as fuel consumption in muirburn practices are not reported. Although there are IPCC default values for fuel load for e.g. scrub land, there are no activity data readily available on the areas where muirburn is practiced. The IPCC was not able to present figures for fuel consumption and we are similarly unable to show evidence of ongoing research, despite several studies addressing prescribed burning (e.g. Worrall et al., 2013, 2011; Ramchunder et al., 2013; Ward et al., 2012; Clay et al., 2010).

11. Conclusion

In summary, it should be possible with sufficient time and strategic research activities to produce better estimates of the emissions associated with altered land use and restoration activities on peat soils in Scotland. The legalities regarding changes to the way the national inventory is calculated require further clarification at present and should be discussed further with experts involved in Inventory compilation and IPCC panel members. Higher-level emission factors may be calculated for many of the potential UK scenarios of land use on peat soils, if the inventory can accommodate this. Emission data from restored peatlands are still being gathered at present, with very few data published to date (Table 6/7). Although there is now a considerable research effort to address this using paired experiments (before-and-after, or paired control-treatment, designs), it will remain crucial to carry out any future meta-analysis of such data with the starting and likely end points, and the time scale over which restoration had taken place, into account. Finally, Charman et al. (2013) suggest that the UK peatlands, being at the global lower end of its bioclimatic envelope, may be most at risk from climate change if this pushes the precipitation/evapotranspiration balance beyond the point of the very narrow envelope where net accumulation takes place. All peatland restoration projects should be evaluated with this in mind; in some areas restoration efforts may only achieve mitigation of further decline of the carbon stock, which is still a worthwhile effort.

Table 6. Emissions monitoring carried out in the UK and Ireland on the proposed areas of land use requiring data collection for potential development of higher Tier emission factors. Numbers refer to sites in Table 7. ***Sites in bold are from ongoing and/or unpublished research,*** *whereas sites in normal font refer to completed and published studies. Sites in brackets are from studies providing ancillary or indirect data. N/A = not applicable.*

IPCC Land use category	Suggested national split	CO_2 on-site	CH_4 on-site	CO_2 resulting from DOC/POC conversion	CH_4 resulting from DOC/POC conversion	CH_4 from ditches/ pools	N_2O fluxes	Emissions from prescribed burning
Forest land	Forest land (bog)	**2,5,**11,15,19,**79,(80), 82,83**	**2,5,**11,**79,(80), 82,83**	**(5), (14)**	**(5), (14)**		**2,**11,**79, (80)**	N/A
	Forest land (fen)	No data	No data	No data	No data	No data	No data	N/A
Grassland	Wet or dry heath or moorland conversion (mild drainage effects, low grazing density) – bogs	**17/**17,**18/**18,**20/**20, **25,26,27,28,36,38, 40,42,44,46,48,50, 52, 58,59,62,63,64, 70/71,85,86,88**	**17/**17,**18, 20/**20, **25,26,27,28,36, 38,40,42,44,46, 48,50,58,59,61, 62,63,64,70/71, 85,86,88**	**(9),**17,20,**(25), (26),(27),(28), (36),(38),(52), 58,59,64**	**(9),**17,20,**(25),(26),(27), (28),(36),(38) (51), 58,59, 64**	**61**	17,**18/**18,**25,26,27,36,38,40, 42,44,46, 48,50,70/71**	Possibly by subtraction from Clay et al. 2012
	Mild drainage effects, low grazing density) – fens	No data	No data	No data	No data	No data	No data	N/A
	Domestic peat extraction on peat soils – bogs	No data	No data	No data	No data	No data	No data	N/A
	Domestic peat extraction on peat soils – fen	No data	No data	No data	No data	No data	No data	N/A
	Rough or smooth grass on bog	**94?, 96?**	**94?, 96?**	No data	No data	No data	**94?, 96?**	N/A
	Rough or smooth grass on fen	**31,34**	**31,34**	**31,34**	**31,34**	**31,34**	**34**	N/A

Table 6 (continued).

IPCC Land use category	Suggested national split	CO_2 on-site	CH_4 on-site	CO_2 resulting from DOC/POC conversion	CH_4 resulting from DOC/POC conversion	CH_4 from ditches/ pools	N_2O fluxes	Emissions from prescribed burning
Grassland	Improved Grassland – bog	No data	No data	No data	No data	No data	No data	N/A
	Improved Grassland - fen	**35**	**35**	**35**	**35**	**35**	**35**	N/A
	Eroded peat –bog	20, 28,29	20, 28,29	20, 28	20, 28	No data	20	No data
	Eroded peat –fen	No data	No data	No data	No data	No data	No data	No data
Cropland	Arable cropland – bog	**55**	**55**	**55**	**55**	**55**	**55**	N/A
	Arable cropland – fen	32,33	32,33	32,33	32,33	32,33	32,33	N/A
Peat extraction	Peat extraction – bog	**16/**16,**21,54,67,**80,**88,**91,**93**	**16,21,54,67,**80,**88,**91,**93**	**54**	**54**	**54**	**54,** 91, **93**	N/A
	Peat extraction – fen	No data	No data	No data	No data	No data	No data	N/A
Rewetted	Restored bog	**3,4,5,8,**12,**16,22,23,24,37,39,41,43,45,47,49,51,53,60,65,69,** 90,**92,95,97,98**	**3,4,5,8,**12,**16,22,23,24,37,39,41,43,45,47,49,51,53,60,65,69,**90,**92,95,97,98**	**(3),(4),(5),8,(13),(37),(38),(39),53,60,65**;	**(3),(4),(5),8,(13),(37),(39),53,60,65**;	**4,8,53,65**	12,**37,39,41,43,45,47,49,53,52,** 90,**92**	N/A
	Restored fen	**77, 81**	**77, 81**	No data	No data	No data	No data	N/A
Near-natural *	Near natural bog	**1,6,7,61,70,72,73,76,78,84,87**	**1,6,7,**10,**61,70,72,73,76,78,84,87**	**1,6,7,(76),** (Waldron et al. , 2009)	**1,6,7,(76),** (Waldron et al. , 2009)	**1,6,7**	**1,6,7,78**	N/A
	Near natural fen	**30,56,57,66,67,75**	**30,56,57,66,67,75**	**30,56,57,(66)**	**30,56,57,(66)**	**30,56,57**	**56,57**	N/A

* not accounted for in UK National Inventory as not required under UNFCCC/KP but applies to sites without major human intervention for > 50 years or nearby disturbance, for future comparisons with emissions from restored and damaged peatlands.

***Table 7.** Existing, historic or planned GHG budget measurements on peatlands in the British Isles (North to South)*

Site number in Table 6	Site	Peatland type	Condition	Contact person (institution)	Fluxes measured, equipment and frequency	Measurement timespan (since – until)	Publications to date:
	Scotland						
1	Forsinard (Cross Lochs)	Blanket bog	Near natural	Pete Levy/Kerry Dinsmore (CEH Edinburgh) Mike Billett (University of Stirling) Roxane Andersen (University of the Highlands and Islands) Joe Holden, Andy Baird, Pippa Chapman, Ed Turner (Leeds University), Mike Billett (Uni Stirling); Kerry Dinsmore (CEH Edinburgh)	EC for CO_2/H_2O and CH_4 (CEH) Fluvial fluxes (CEH) Static chambers for CO_2, CH_4 and N_2O (UHI) CO_2 and CH_4 fluxes using static chambers (both between and in pools – floating chambers in latter)	Semi-continuous since 2008 Since 2011 2013-2015	Fluvial Fluxes manuscript in prep by Kerry Dinsmore
2	Forsinard (Forestry) Dyke Plantation	Plantation on deep peat, formally blanket bog	Afforested; to be continued post felling 2014-15	Neil Cowie (RSPB) /Roxane Andersen (UHI)/ Matt Saunders (JHI)	EC for CO_2 (RSPB, UHI, JHI, SNH), Static chamber measurements for CO_2, CH_4 and N_2O (UHI)	From 2014 onwards	None yet
3	Forsinard (Restored, ca. 7-10 years) – Talaheel, restored 1998	Blanket bog	Restored from forestry plantation (felled/grip blocked)	In preparation, Timothy Hill, (University of St Andrews) Yit Teh (University of St Andrews, and University of Aberdeen from June onward), Jens-Arne Subke (University of Stirling Jens-Arne Subke (University of Stirling)	EC for CO_2 and static chambers for CH_4 Static chambers CO_2 and CH_4 Downstream DOC export non-methane BVOC	2013-2016 2011-2012 2013-16	None yet
4	Forsinard (Restored, Early) – Lonielist, restored 2003/04	Blanket bog	Restored from forestry plantation (felled/grip blocked)	Matthew Saunders (James Hutton Institute) Yit Teh (University of St Andrews, and University of Aberdeen from June onward), Jens-Arne Subke (University of Stirling) Jens-Arne Subke (University of Stirling) Joe Holden, Andy Baird, Pippa	EC for CO_2/ H_2O and CH_4 Fluvial fluxes (UHI) Static chambers CO_2 and CH_4 Downstream DOC export non-methane BVOC	2014- 2011-2012 2013-16	None yet

				Chapman, Ed Turner (Leeds University), Mike Billett (Uni Stirling); Kerry Dinsmore (CEH Edinburgh)	CO_2 and CH_4 fluxes using static chambers (both between and in pools – floating chambers in latter)	2013-2015	
5	Forsinard – (North) Raphan	Blanket Bog	Afforested, then restored in 2013 (felled/gripped blocked) and open bog	Yit Teh (University of St Andrews, and University of Aberdeen from June onward), Jens-Arne Subke (University of Stirling	Static chambers CO_2 and CH_4 Downstream DOC export non-methane BVOC	2011- 2013-2016	None yet
6	Flow Country (Leir)	Blanket bog	Natural pools	Joe Holden, Andy Baird, Pippa Chapman, Ed Turner (Leeds University), Mike Billett (Uni Stirling); Kerry Dinsmore (CEH Edinburgh)	CO_2 and CH_4 fluxes using static chambers (both between and in pools – floating chambers in latter)	2013-2015	None yet
7	Flow Country (Munsary)	Blanket bog	Natural pools	Joe Holden, Andy Baird, Pippa Chapman, Ed Turner (Leeds University), Mike Billett (Uni Stirling); Kerry Dinsmore (CEH Edinburgh)	CO_2 and CH_4 fluxes using static chambers (both between and in pools – floating chambers in latter)	2013-2015	None yet
8	8. Forsinard (same catchment as project 1 Cross Lochs)	Blanket bog	Grip blocked (never afforested)	Kerry Dinsmore/Mike Billett (CEH Edinburgh) Joe Holden, Andy Baird, Pippa Chapman, Ed Turner (Leeds University), Mike Billett (Uni Stirling); Kerry Dinsmore (CEH Edinburgh)	Fluvial fluxes CO_2 and CH_4 fluxes using static chambers (both between and in pools – floating chambers in latter)	Since 2008-2010 2013-2015	Same in prep manuscript as mentioned above (site 1)
9	Forsinard (gripped sites at Big House)	Blanket bog	Gripped	Pete Levy/Kerry Dinsmore/Mike Billett (CEH Edinburgh)	Fluvial fluxes	Since 2008	Same in prep manuscript as mentioned above (site 1)
10	Loch More	Blanket bog	Near natural?	Historic site	EC by Tuneable diode laser spectrometry for CH_4	1994	Hargreaves and Fowler, 1988
11	Flanders Moss (West)	Lowland Raised bog	Afforested (drained and undrained sites)	Sirwan Yamulki (Forest Research)	Static chambers for CO_2, CH_4 and N_2O; dipwell DOC	Since 2008	Yamulki et al., 2013
12	Flanders Moss (East)	Lowland raised bog	Restored (felled/grip blocked	Sirwan Yamulki (Forest Research)	Static chambers for CO_2, CH_4 and N_2O; dipwell DOC	Since 2008	Yamulki et al., 2013; but also see reply by Artz et al., 2013

13	Flanders Moss (West)	Lowland raised bog	Afforested – being restored (former site 11)	Nadeem Shah (Forest Research)	Fortnightly drainage water chemistry from 3 watercourses including Total C and DOC	Since 2008 – ongoing	None yet
14	Upper Halladale near Forsinard	Blanket Bog (mainly podzols with some gleys and blanket peat)	Afforested	Nadeem Shah (Forest Research)	Monthly streamwater chemistry from 6 sites including Total C, DOC and TIC	Since 1995 – ongoing	Manuscript in preparation
15	Various afforested blanket bogs in the Forsinard area (chronosequence)	Blanket bog	Afforestation, timeline from 1-9 years since afforestation	historic	EC for CO_2	1995/1996 (short term 33easurement, upscaled to annual fluxes)	Hargreaves et al., 2003
16	Middlemuir Moss	Lowland raised/intermediate bog	Unaided regeneration after mechanical peat extraction	Rebekka Artz (James Hutton Institute)	Static chambers for CO_2, CH_4 (CH_4 data not published to date)	2003-2006	Artz et al., 2008, (unmodelled CO_2 fluxes, ranges only)
17	Auchencorth Moss	Lowland raised bog	Semi-natural, affected by old drainage channels (no longer active), and peripheral peat cutting, low level sheep grazing	Pete Levy/Kerry Dinsmore/Mike Billett (CEH Edinburgh)	EC for CO_2 (CEH) EC for CH_4 (CEH) Fluvial fluxes (CEH) Static chambers for CO_2, CH_4 and N_2O (CEH) Peat and Riparian soil CO_2, CH_4, DOC, DIC concentrations 14C and 13C analysis on aquatic CO2	Continuous since 2002 (some previous) Since 2011 Continuous since 2005 (some previous) 2005-2010 2011-2013 2010-11	Hargreaves et al., 2003; Billett et al., 2004; Dinsmore et al., 2010; 2009b; Drewer et al., 2010; Billett et al., 2010; Billett and Harvey, 2013; Garnett et al, 2012; Leith et al. (in press); Skiba et al., 2013
18	Whim Moss	Lowland raised bog	Nitrogen impact experiment, adjacent to peat extraction site	Pete Levy (CEH Edinburgh)	Static chambers for CO_2, CH_4 and N_2O (CEH) EC for CO_2	2008-2010? Since 2012 (?)	Kivimaki, 2011 (PhD thesis); Carter et al., 2012;

							Sheppard et al., 2013
19	Afforested (26 years since planting), Mindork Moss, Newton Stewart	Blanket bog	Afforestation	historic	EC for CO_2	1995/1996 (short term 34easuremen t, upscaled to annual fluxes)	Hargreaves et al., 2003
	England						
20	Moorhouse	Upland blanket bog Upland blanket bog (Cottage Hill Syke) Upland Blanket bog (Hard Hill)	Grazing, burning Undrained, but eroded/gullied in places Grazing, burning	Niall McNamara & Nick Ostle (CEH Lancaster) Pete Levy (CEH Edinburgh) Fred Worrall (Durham) Andy Lloyd/Andreas Heinemeyer (York) Gareth Clay; Fred Worrall (Durham); Martin Evans (University of Manchester)	EC for CO_2 ; Fluvial fluxes Static chambers for CO_2, CH_4 NEE by eddy covariance (CO_2); Aquatic exports DOC, CH_4, CO_2 POC and DOC Soil respiration (hourly) NEE by EC Static chambers for CO_2, Fluvial fluxes, Aquatic export of CO_2	Fluvial fluxes and chambers since 1993 Since 2008 2011-2014 2006-2007 2006-2008 2006-08	McNamara et al, 2008; Ward et al., 2007; Anon, 2013 Not yet published Worrall et al., 2009c,d; 2007b; Moody et al., 2013 Not published – only PhD thesis Clay et al. , 2010; 2013
21	Thorne Moors (Defra Lowland Peat project)	Lowland raised bog	Cutover	Pippa Chapman/Andy Baird (Leeds)	Static chambers CO_2 and CH_4 Water table, soil temp, AWS	Sept 2011-Oct 2012 and then May 2013-June 2014	Gemma Dooling PhD – to be submitted summer 2014; then part of Defra lowland project
22	Thorne Moors (Defra	Lowland raised	Rewetted	Pippa Chapman/Andy Baird (Leeds)	Static chambers CO_2 and CH_4	Sept 2011-Oct	Gemma

	Lowland Peat project)	bog	formerly cutover (restored 2003)		Water table, soil temp, AWS	2012 and then May 2013-June 2014	Dooling PhD – to be submitted summer 2014
23	Thorne Moors (completed)	Lowland raised bog	Rewetted formerly cutover (restored 1997)	Pippa Chapman/Andy Baird (Leeds)	Static chambers CO_2 and CH_4	Oct 2011 – Oct 2012	Gemma Dooling PhD – to be submitted summer 2014
24	Hatfield Moors	Lowland raised bog	Rewetted formerly cutover (restored 2008)	Pippa Chapman/Andy Baird (Leeds)	Static chambers CO_2 and CH_4	Oct 2011 – Oct 2012	Gemma Dooling PhD – to be submitted summer 2014
25	Nidderdale	Blanket bog (grouse moor managed)	Burning (control) versus mowing treatments	Andreas Heinemeyer (York)	Static chambers for CO_2, CH_4 and N_2O, aquatic fluxes (DOC and POC) – flow rates thus total fluvial C export (monthly)	Since 2012 Sporadic 35easurement up-scaled to annual	Unpublished – summaries on website
26	Whitendale (=Forest of Bowland)	Blanket bog (grouse moor managed)	Burning (control) versus mowing treatments	Andreas Heinemeyer (York) Fred Worrall (University of Durham)	Static chambers for CO_2, CH_4 and N_2O, aquatic fluxes (DOC and POC) – flow rates thus total fluvial C export (monthly) DOC	Since 2012 Sporadic measurement up-scaled to annual 2007	Unpublished – summaries on website Worrall et al. (2007a)
27	Mossdale	Blanket bog (grouse moor managed)	Burning (control) versus mowing treatments	Andreas Heinemeyer (York)	Static chambers for CO_2, CH_4 and N_2O, aquatic fluxes (DOC and POC) – flow rates thus total fluvial C export (monthly)	Since 2012 Sporadic 35easurement up-scaled to annual	Unpublished – summaries on website
28	Bleaklow	Upland blanket bog	Eroded moorland, and restoration sites	Martin Evans (University of Manchester) & Fred Worrall (University of Durham)	Fluvial fluxes Static chambers for CO_2, CH_4	Since 2008?	Worrall et al. 2009b, 2011; Dixon et al., 2014; Clay et al. 2012

29	Goyt valley	Upland blanket bog	Eroded bog	Martin Evans (University of Manchester) & Fred Worrall (University of Durham)	Static chambers for CO_2, CH_4	2008-2009	Clay et al., 2012
30	Wicken Fen – Sedge Fen (Defra Lowland Peat project)	Low-nutrient semi-natural fen	Semi-natural	Joerg Kaduk (Leicester), Ross Morrison (CEH Wallingford), Mike Peacock (OU)	EC for CO_2, CH_4 Static chambers for CO_2, CH_4 (terrestrial and ditches), aquatic DOC, DIC, POC, dissolved gases	Since 2008	None yet
31	Bakers Fen – adjacent to Wicken Fen (Defra Lowland peat project)	Rich fen (very shallow residual peat, 36easure. 50 cm depth)	Restored (former arable land), to extensive grassland	Joerg Kaduk (Leicester), Jon Evans (CEH), Mike Peacock (OU)	EC for CO_2 (plus CH_4) Static chambers for CO_2, CH_4 (terrestrial and ditches), aquatic DOC, DIC, POC, dissolved gases	EC CO_2 since 2009, all other 36easurement since 2013	Morrison et al. 2013
32	Rosedene (Defra Lowland Peat Project) (= Methwold fen)	Rich fen, mineral enriched deep peat	Arable land use on drained and ploughed deep peat	Davey Jones (Bangor), Joerg Kaduk (Leicester), Chris Evans (CEH)	EC for CO_2 Static chambers for CO_2, CH_4 and N_2O on terrestrial sites (chambers and funnels) and floating chambers on ditches, aquatic DOC, DIC, POC, dissolved gases Trials with DCD	EC since 2011/12, other 36easurement since 2013	Morrison et al. (in submission) http://www.biogeosciences-discuss.net/10/4193/2013/bgd-10-4193-2013.pdf Taft et al., in prep
33	Redmere (Defra Lowland Peat project)	Rich fen, mineral enriched shallow peat	Arable land use on drained and ploughed, wasted, peat	Davey Jones (Bangor), Ross Morrison and Chris Evans (CEH)	EC for CO_2 Static chambers for CO_2, CH_4 and N_2O on terrestrial sites (chambers and funnels) and floating chambers on ditches, aquatic DOC, DIC, POC, dissolved gases	EC since 2011/12, other 36easurement since 2013	Taft et al., in prep
34	Tadham Moor	Intermediate fen	Extensive grassland	Richard Harding (CEH Wallingford)	EC for CO_2,	2000-2003	Lloyd et al, 2006

				Tom Misselbrook (Rothamsted North Wyke)	EC for CO_2,Static chambers for CO_2, CH_4 and N_2O from land and ditches Aquatic DOC, DIC, POC, dissolved gases	Since 2013	
35	Tadham Moor (Defra Lowland Peat Project)	Intermediate fen	Intensive grassland (about 1 km away from site 33)	Tom Misselbrook (Rothamsted North Wyke)	Static chambers for CO_2, CH_4 and N_2O from land and ditches Aquatic DOC, DIC, POC, dissolved gases	Since 2013	None yet Anon, 2013
36	Exmoor National Park (Spooners)	Upland blanket bogs	Control (not restored – wet/dry moorland)	Ed Hornibrook & Adam McAleer (University of Bristol) and David Smith (South West Water plc) DOC: Emilie Grand-Clement (Exeter University) CH4: Adam McAleer (Bristol University) CO2: Naomi Gatis (Exeter University)	Static chambers for CO_2, CH_4 and N_2O. Membrane equilibrators for pore water CO_2 and CH_4. Fluvial fluxes of CO_2 and CH_4. $\delta^{13}C$ of CH_4 and CO_2. Peat bulk density and %C, %N. Automatic pump samplers (event based) for DOC, colour and pH; Static chambers for CH4; Closed Chambers for CO2	2013-2015 DOC since Oct 2011; Since Oct 2011 for CH4; Since 2012 for CO2	In prep.
37	Exmoor National Park (Spooners)	Upland blanket bogs	Restored by grip blocking	Ed Hornibrook & Adam McAleer (University of Bristol) and David Smith (South West Water plc) DOC: Emilie Grand-Clement (Exeter University)	Static chambers for CO_2, CH_4 and N_2O. Membrane equilibrators for pore water CO_2 and CH_4. Fluvial fluxes of CO_2 and CH_4. $\delta^{13}C$ of CH_4 and CO_2. Peat bulk density and %C, %N. Automatic pump samplers (event based) for DOC, colour and pH; Static chambers for CH4; Closed Chambers for CO2	2013-2015 DOC since Oct	In prep.

				CH4: Adam McAleer (Bristol University) CO2: Naomi Gatis (Exeter University)		2011; Since Oct 2011 for CH4; Since 2012 for CO2	
38	Exmoor National Park (Aclands)	Upland blanket bogs	Control (not restored – wet/dry moorland)	Ed Hornibrook & Adam McAleer (University of Bristol) and David Smith (South West Water plc) DOC: Emilie Grand-Clement (Exeter University) CH4: Adam McAleer (Bristol University) CO2: Naomi Gatis (Exeter University)	Static chambers for CO_2, CH_4 and N_2O. Membrane equilibrators for pore water CO_2 and CH_4. Fluvial fluxes of CO_2 and CH_4. $\delta^{13}C$ of CH_4 and CO_2. Peat bulk density and %C, %N. Automatic pump samplers (event based) for DOC, colour and pH; Static chambers for CH4; Closed Chambers for CO2	2013-2015 DOC since Oct 2011; Since Oct 2011 for CH4; Since 2012 for CO2	In prep.
39	Exmoor National Park (Aclands)	Upland blanket bogs	Restored by grip blocking	Ed Hornibrook & Adam McAleer (University of Bristol) and David Smith (South West Water plc) DOC: Emilie Grand-Clement (Exeter University) CH4: Adam McAleer (Bristol University) CO2: Naomi Gatis (Exeter University)	Static chambers for CO_2, CH_4 and N_2O. Membrane equilibrators for pore water CO_2 and CH_4. Fluvial fluxes of CO_2 and CH_4. $\delta^{13}C$ of CH_4 and CO_2. Peat bulk density and %C, %N. Automatic pump samplers (event based) for DOC, colour and pH; Static chambers for CH4; Closed Chambers for CO2	2013-2015 DOC since Oct 2011; Since Oct 2011 for CH4; Since 2012 for CO2	In prep.
40	Exmoor National Park (Comerslade)	Upland blanket bogs	Control (not restored – wet/dry moorland)	Ed Hornibrook & Adam McAleer (University of Bristol) and David Smith (South West Water plc)	Static chambers for CO_2, CH_4 and N_2O. Membrane equilibrators for pore water CO_2 and CH_4. $\delta^{13}C$ of CH_4 and CO_2. Peat bulk density and %C, %N.	2013-2015	In prep.

41	Exmoor National Park (Comerslade)	Upland blanket bogs	Restored by grip blocking	Ed Hornibrook & Adam McAleer (University of Bristol) and David Smith (South West Water plc)	Static chambers for CO_2, CH_4 and N_2O. Membrane equilibrators for pore water CO_2 and CH_4. $\delta^{13}C$ of CH_4 and CO_2. Peat bulk density and %C, %N.	2013-2015	In prep.
42	Exmoor National Park (Squallacombe)	Upland blanket bogs	Control (not restored – wet/dry moorland)	Ed Hornibrook & Adam McAleer (University of Bristol) and David Smith (South West Water plc)	Static chambers for CO_2, CH_4 and N_2O. Membrane equilibrators for pore water CO_2 and CH_4. $\delta^{13}C$ of CH_4 and CO_2. Peat bulk density and %C, %N.	2013-2015	In prep.
43	Exmoor National Park (Squallacombe)	Upland blanket bogs	Restored by grip blocking	Ed Hornibrook & Adam McAleer (University of Bristol) and David Smith (South West Water plc)	Static chambers for CO_2, CH_4 and N_2O. Membrane equilibrators for pore water CO_2 and CH_4. $\delta^{13}C$ of CH_4 and CO_2. Peat bulk density and %C, %N.	2013-2015	In prep.
44	Exmoor National Park (Verney's Allotment)	Upland blanket bogs	Control (not restored – wet/dry moorland)	Ed Hornibrook & Adam McAleer (University of Bristol) and David Smith (South West Water plc)	Static chambers for CO_2, CH_4 and N_2O. Membrane equilibrators for pore water CO_2 and CH_4. $\delta^{13}C$ of CH_4 and CO_2. Peat bulk density and %C, %N.	2013-2015	In prep.
45	Exmoor National Park (Verney's Allotment)	Upland blanket bogs	Restored by grip blocking	Ed Hornibrook & Adam McAleer (University of Bristol) and David Smith (South West Water plc)	Static chambers for CO_2, CH_4 and N_2O. Membrane equilibrators for pore water CO_2 and CH_4. $\delta^{13}C$ of CH_4 and CO_2. Peat bulk density and %C, %N.	2013-2015	In prep.
46	Exmoor National Park (Long Holcombe)	Upland blanket bogs	Control (not restored – wet/dry moorland)	Ed Hornibrook & Adam McAleer (University of Bristol) and David Smith (South West Water plc)	Static chambers for CO_2, CH_4 and N_2O. Membrane equilibrators for pore water CO_2 and CH_4. $\delta^{13}C$ of CH_4 and CO_2. Peat bulk density and %C, %N.	2013-2015	In prep.
47	Exmoor National Park (Long Holcombe)	Upland blanket bogs	Restored by grip blocking	Ed Hornibrook & Adam McAleer (University of Bristol) and David Smith (South West Water plc)	Static chambers for CO_2, CH_4 and N_2O. Membrane equilibrators for pore water CO_2 and CH_4. $\delta^{13}C$ of CH_4 and CO_2. Peat bulk density and %C, %N.	2013-2015	In prep.
48	Exmoor National Park (Hangley Cleave)	Upland blanket bogs	Control (not restored – wet/dry moorland)	Ed Hornibrook & Adam McAleer (University of Bristol) and David Smith (South West Water plc)	Static chambers for CO_2, CH_4 and N_2O. Membrane equilibrators for pore water CO_2 and CH_4. $\delta^{13}C$ of CH_4 and CO_2. Peat bulk density and %C, %N.	2013-2015	In prep.

49	Exmoor National Park (Hangley Cleave)	Upland blanket bogs	Restored by grip blocking	Ed Hornibrook & Adam McAleer (University of Bristol) and David Smith (South West Water plc)	Static chambers for CO_2, CH_4 and N_2O. Membrane equilibrators for pore water CO_2 and CH_4. $\delta^{13}C$ of CH_4 and CO_2. Peat bulk density and %C, %N.	2013-2015	In prep.
50	Exmoor National Park (Blackpitts)	Upland blanket bogs	Control (not restored – wet/dry moorland)	Ed Hornibrook & Adam McAleer (University of Bristol) and David Smith (South West Water plc)	Static chambers for CO_2, CH_4 and N_2O. Membrane equilibrators for pore water CO_2 and CH_4. $\delta^{13}C$ of CH_4 and CO_2. Peat bulk density and %C, %N.	2013-2015	In prep.
51	Exmoor National Park (Blackpitts)	Upland blanket bogs	Restored by grip blocking	Ed Hornibrook & Adam McAleer (University of Bristol) and David Smith (South West Water plc)	Static chambers for CO_2, CH_4 and N_2O. Membrane equilibrators for pore water CO_2 and CH_4. $\delta^{13}C$ of CH_4 and CO_2. Peat bulk density and %C, %N.	2013-2015	In prep.
52	Dartmoor	Upland blanket bog	Pre – restoration , post restoration monitoring due to start summer 2014	DOC: Emilie Grand-Clement (Exeter University) CO_2: Naomi Gatis (Exeter University)	Automatic pump samplers (event based) for DOC, colour and pH; Closed chambers for CO_2	Since Nov 2012 for DOC; Since 2013 for CO_2	In prep.
53	Manchester Mosses (Defra Lowland Peat project), Astley Moss	Lowland raised bog	Re-wetted semi-natural	Fred Worrall & Simon Dixon (Durham University)	Static chambers for CO_2, N_2O, CH_4 (terrestrial and ditches), aquatic DOC, DIC, POC, dissolved gases	Since 2012/3	None yet
54	Manchester Mosses (Defra Lowland Peat project, Little Woolden Moss)	Lowland raised bog	Peat extraction	Fred Worrall (Durham University)	EC for CO_2 Static chambers for CO_2, N_2O, CH_4 (terrestrial and ditches), aquatic DOC, DIC, POC, dissolved gases	Since 2012/3	None yet
55	Manchester Mosses (Defra Lowland Peat project), Little Woolden Moss	Lowland raised bog	Arable crop on deep peat	Fred Worrall (Durham University)	Static chambers for CO_2, N_2O, CH_4 (terrestrial and ditches), aquatic DOC, DIC, POC, dissolved gases	Since 2012/3	None yet
56	Sutton Fen (Defra Lowland Peat project, Norfolk Broads)	Floodplain Fen	Low nutrient semi-natural	Kate Heppel /Lisa Belyea (Queen Mary University London), Andy Baird (University of Leeds)	CO_2 and CH_4, using static chambers and/or funnels (for bubbles) on fen surface and floating closed chambers on ditches; Aquatic fluxes incl DOC, DIC and	2012-13	None yet

					dissolved gases		
57	Strumpshaw Fen (Defra Lowland Peat project, Norfolk Broads)	Floodplain Fen	High nutrient semi-natural	Kate Heppel /Lisa Belyea (Queen Mary University London), Andy Baird (University of Leeds)	CO_2 and CH_4, using static chambers and/or funnels (for bubbles) on fen surface and floating closed chambers on ditches Aquatic fluxes incl DOC, DIC and dissolved gases	2012-13	None yet
	Wales						
58	Migneint CEH Carbon Catchment – Nant y Brwyn	Upland blanket bog	Blanket bog catchment with some grips (not blocked)	Chris Evans (CEH Bangor) Also earlier data from Chris Freeman (Bangor Uni)	EC for CO_2, EC for CH_4 Static Chambers for CO_2, CH_4 Fluvial fluxes incl DOC, DIC and dissolved gases	Since 2007 not quite operational Since 2007	None yet Anon, 2013
59	Migneint (Defra funded project, separate to above) – Ffynnon Eidda	Upland blanket bog	Control (open ditches)	Andy Baird (University of Leeds), Chris Evans (CEH Bangor) – Defra SP1202: Also earlier data from Chris Freeman (Bangor Uni)	Static chambers for CO_2 and CH_4, Fluvial fluxes of DOC, POC and dissolved CO_2/CH_4	Since 2010	None yet Anon, 2013
60	Migneint (Defra funded project, separate to above) – Ffynnon Eidda	Upland blanket bog	Grip blocked	Andy Baird (University of Leeds), Chris Evans (CEH Bangor) – Defra SP1202: Also earlier data from Chris Freeman (Bangor Uni)	Static chambers for CO_2 and CH_4, fluvial fluxes of DOC, POC and dissolved CO_2/CH_4	Since 2010	None yet
61	Migneint – Llyn Serw	Upland blanket bog	Control and grip blocking	Chris Evans (CEH Bangor)	Static chambers for CH_4 CH_4 fluxes from ditches	? Since 2009	None yet Cooper and Evans, 2014
62	Cors Fochno	Estuarine raised bog	Control	Simon Caporn, James Rowson, Richard Payne (Manchester Metropolitan University) Andy Baird (University of Leeds) and Kate Heppell (Queen Mary University	Static Chambers for CO_2, CH_4 Static chambers for CH_4; ebullition funnels for CH_4.	? 2008 and 2009.	? Stamp et al. (2013) GRL,

				of London)			doi:10.1002/grl.50501
63	Cors Fochno	Estuarine raised bog	Warming and drainage treatments	Simon Caporn, James Rowson, Richard Payne (Manchester Metropolitan University)	Static Chambers for CO_2, CH_4	?	?
64	Vyrnwy	Upland blanket bog	Control (degraded bog)	Phil Ineson (University of York) Andreas Heinemeyer Yit Arn Teh (Univ Aberdeen) and Jens-Arne Subke (Stirling)	Static Chambers for CO_2, CH_4 EC for CO_2, One four day comparison for CO2 only: chamber versus EC tower One day scale comparison: chamber, cloche, EC, Aircraft Static Chambers for CO_2, CH_4 Fluvial fluxes Continuous CO_2 and CH_4 chamber fluxes from pool surfaces and adjacent areas Bubble trap measurements	2009 – 2010 2009 2009 2009 2009	Stockdale, 2012 (PhD thesis) Unpublished work (EC data not at final processing stage)
65	Vyrnwy	Upland blanket bog	Grip blocked	Phil Ineson (University of York) Andreas Heinemeyer Yit Arn Teh (Univ Aberdeen) and Jens-Arne Subke (Stirling)	Static Chambers for CO_2, CH_4 EC for CO_2, One four day comparison for CO2 only: chamber versus EC tower One day scale comparison: chamber, cloche, EC, Aircraft Static Chambers for CO_2, CH_4 Fluvial fluxes Continuous CO_2 and CH_4 chamber fluxes from pool surfaces and adjacent areas Bubble trap measurements	2009 – 2010 2009 2009 2009 2009	Stockdale, 2012 (PhD thesis) Unpublished work (EC data not at final processing stage)

66	Cors Erddreiniog (Defra Peatland Project)	Fen	Low-nutrient semi-natural	Chris Evans (CEH), Mark Rayment (Bangor)	Static chambers for CO_2 and CH_4, fluvial fluxes of DOC, POC and dissolved CO_2/CH_4	?	None yet
67	Cors Erddreiniog (Defra Peatland Project)	Fen	High-nutrient semi-natural	Chris Evans (CEH), Mark Rayment (Bangor)	EC for CO_2, CH_4	?	None yet
68	Whixall Moss (site is on the border of England and Wales)	Lowland raised bog	Control (N impacted, cutover)	Simon Caporn, Richard Payne (Manchester Metropolitan University); James Rowson (Edge Hill University)	Static Chambers for CO_2, CH_4	?	?
69	Whixall Moss (site is on the border of England and Wales)	Lowland raised bog	Restoration (warming treatments also on site)	Simon Caporn, Richard Payne (Manchester Metropolitan University); James Rowson (Edge Hill University)	Static Chambers for CO_2, CH_4	?	?
70	Cerrig yr Wyn, Plinlimon	Gully mire	Control and drought treated	Chris Freeman, N Fenner (Bangor) Steve Hughes CEH Bangor	Static Chambers for CO_2, CH_4 N_2O	Since 1991(major gaps though)	
71	Cerrig yr Wyn, Plinlimon	Gully mire	Drought treated	Chris Freeman, N Fenner (Bangor) Steve Hughes CEH Bangor	Static Chambers for CO_2, CH_4 N_2O	Since 1991(major gaps though)	
72	Cors Caron	Raised bog	Near natural (west dome)	Ed Hornibrook (University of Bristol)	Static chambers for CO_2 & CH_4. Membrane equilibrators for pore water CO_2 and CH_4. $\delta^{13}C$ of CH_4 and CO_2.	2003	Hornibrook & Bowes (2007); Hornibrook et al. (2009a); Hornibrook (2009b)
73	Blaen Fign (Elan Valley)	Blanket Bog	Near natural	Ed Hornibrook (University of Bristol)	Static chambers for CO_2 & CH_4. Membrane equilibrators for pore water CO_2 and CH_4. $\delta^{13}C$ of CH_4 and CO_2.	2003	Bowes & Hornibrook (2006); Hornibrook & Bowes (2007); Hornibrook et al. (2009a); Hornibrook (2009b)
74	Gors Lwyd	Upland valley	Near natural	Ed Hornibrook (University of Bristol)	Static chambers for CO_2 & CH_4.	2003	Hornibrook &

		mire (deep peat with open pools)			Membrane equilibrators for pore water CO_2 and CH_4. $\delta^{13}C$ of CH_4 and CO_2.		Bowes (2007); Hornibrook et al. (2009a); Hornibrook (2009b)
75	Crymlyn Bog	Intermediate fen	Near natural	Ed Hornibrook (University of Bristol)	Static chambers for CO_2 & CH_4. Membrane equilibrators for pore water CO_2 and CH_4. $\delta^{13}C$ of CH_4 and CO_2.	2003	Hornibrook & Bowes (2007); Hornibrook et al. (2009a); Hornibrook (2009b)
	Northern Ireland						
	No sites identified						
	Ireland						
76	Glencar	Blanket bog	Near natural	Gerard Kiely (University College Cork)	EC for CO_2, Static Chambers for CO_2, CH_4 Fluvial fluxes Total C budget	2002-present	Sottocornola et al. 2005; Sottocornola and Kiely 2010; Koehler et al., 2009; 2011; Laine et al., 2007a,b; McVeigh et al., 2014
77	Turraun	Fen remnant (industrially cutover)	Restoration sites	David Wilson (University College Dublin)	Static Chambers for CO_2, CH_4	2002-2003?	Wilson et al., 2009
78	Cloosh	Blanket Bog	Near natural	Bruce Osborne (UCD) Matt Saunders (JHI), Ken Byrne (UCD now UL)	EC CO_2/H_2O chamber based CO_2/N_2O/CH_4	2011-2012	Byrne and Farrell, 2005
79	Cloosh	Blanket Bog	Afforested with Sitka spruce (mid-rotation stand)	Bruce Osborne (UCD) Matt Saunders (JHI), Ken Byrne (UCD now UL)	EC CO_2/H_2O chamber based CO_2/N_2O/CH_4	2011-2012	Byrne and Farrell, 2005
80	Cloosh	Blanket Bog	Sitka spruce clear-fell (felled in August 2011)	Bruce Osborne (UCD) Matt Saunders (JHI)	EC CO_2/H_2O chamber based CO_2/N_2O/CH_4	2011-2012	None yet
81	Turraun	RB/Industrial cutaway	rewetted	David Wilson (UCD)	Static Chambers for CO_2, CH_4	2001-2003	Wilson et al. 2007a,b Wilson et al.

82	Turraun	RB/Industrial cutaway	Birch scrub	Ken Byrne (UCD now UL)	Static Chambers for CO_2, CH_4 / biomass sampling	2001-	Byrne et al. (2007)
83	Lullymore	RB/Industrial cutaway	Afforested Sitka spruce	Ken Byrne (UCD now UL)	Static Chambers for CO_2, CH_4 / biomass sampling	2001-	Byrne et al. (2007)
84	Clara		Near intact	David Wilson (UCD) Florence Renou-Wilson (UCD)	Static Chambers for CO_2, CH_4		Wilson (2008)
85	Clara	Raised bog	Drained/degrad ed	David Wilson (UCD) Florence Renou-Wilson (UCD)	Static Chambers for CO_2, CH_4	2006-2007	Wilson (2008)
86	Clara	Raised bog	Drained	Shane Regan (TCD)	Static Chambers for CO_2, CH_4 Fluvial	2013-	
87	Slieve Blooms	Montane blanket bog	Neat intact	David Wilson (UCD) Florence Renou-Wilson (UCD)	Static Chambers for CO_2, CH_4	2006-2007	Renou-Wilson et al. (2011)
88	Slieve Blooms	Montane	Drained	David Wilson (UCD) Florence Renou-Wilson (UCD)	Static Chambers for CO_2, CH_4	2006-2007	Renou-Wilson et al. (2011)
89	Boora and Derrygreenagh	RB/Industrial cutaway	Drained	David Wilson (UCD) Florence Renou-Wilson (UCD)	Static Chambers for CO_2, CH_4	2007-2009	
90	Bellacorick	BB/Industrial cutaway	Rewetted	David Wilson (UCD/Earthy Matters) Florence Renou-Wilson (UCD)	Static Chambers for CO_2, CH_4, N_2O	2008-2013	Wilson et al. 2012 Wilson et al. 2013
91	Bellacorick	BB/Industrial cutaway	Drained	David Wilson (Earthy Matters) Florence Renou-Wilson (UCD)	Static Chambers for CO_2, CH_4, N_2O	2011-2013	
92	Blackwater	RB/Industrial cutaway	Rewetted	David Wilson (Earthy Matters) Florence Renou-Wilson (UCD)	Static Chambers for CO_2, CH_4, N_2O	2011-	
93	Blackwater	RB/Industrial cutaway	Drained	David Wilson (Earthy Matters) Florence Renou-Wilson (UCD)	Static Chambers for CO_2, CH_4, N_2O	2011-	
94	Glenvar	Grassland on organic soil	Drained	Florence Renou-Wilson (UCD) David Wilson (Earthy Matters)	Static Chambers for CO_2, CH_4, N_2O Fluvial fluxes	2011-	Renou-Wilson et al., 2014 submitted
95	Glenvar	Grassland on organic soil	Rewetted	Florence Renou-Wilson (UCD) David Wilson (Earthy Matters)	Static Chambers for CO_2, CH_4, N_2O Fluvial fluxes	2011-	
96	Lanesborough	Grassland on organic soil	Drained	Florence Renou-Wilson (UCD) David Wilson (Earthy Matters)	Static Chambers for CO_2, CH_4, N_2O Fluvial fluxes	2011-	Renou-Wilson et al., 2014
97	Scohaboy Bog Natural Heritage Area, located in county	Ex-forestry on raised bog (clear-felled,	Rewetted	Caitlyn Rigney (UL); Ken Byrne (UL)	Static Chambers for CO_2, CH_4,	2014-	

	Tipperary	windrowed, timber not removed)					
98	Pollagoona Bog located in county Clare	Ex-forestry on blanket bog (clear-felled, windrowed, timber not removed)	Rewetted	Caitlyn Rigney (UL); Ken Byrne (UL)	Static Chambers for CO_2, CH_4,	2014-	

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Abbreviations

AFOLU	Agriculture, Forestry and Other Land Use
AR/D	Afforestation, Reforestation and Deforestation
CEH	Centre for Ecology and Hydrology
CM	Cropland Management
CRF	Common reporting format tables
DECC	Department for Energy and Climate Change
DOC	Dissolved Organic Carbon
FCS	Forestry Commission Scotland
FM	Forest Management
FR	Forest Research
GHG	Greenhouse gas
GM	Grazing Land Management
GPG-LULUCF	Good Practice Guidance for Land Use, Land-Use Change and Forestry
IPCC	Intergovernmental Panel on Climate Change
KP	Kyoto Protocol
LULUCF	Land Use, Land Use Change and Forestry
NIR	National Inventory Report
POC	Particulate Organic Carbon
RV	Revegetation
SOC	Soil organic carbon
UNFCCC	United Nations Framework Convention on Climate Change
WDR	Wetland Drainage and Rewetting