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An assessment of the proposed IPCC "2013 Supplement to the 2006 guidelines: Wetlands" for use in GHG accounting of Scottish peatland restoration

Rebekka Artz[1], Matthew Saunders[1], Jagadeesh Yeluripati[1], Jacqueline Potts[2], David Elston[2], and Steve Chapman[1]

[1] The James Hutton Institute; [2] Biomathematics and Statistics Scotland (BioSS)

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Enquirer: Liam Kelly, Scottish Government

1. Summary

This report reviews the emission figures provided in the soon to be published IPCC Guidelines "2013 Supplement to the 2006 Guidelines: Wetlands" and compares these figures with emission figures from earlier briefings provided to the Scottish Government (Artz et al. 2012; Chapman et al. 2013). The IPCC Guidelines will enable the Scottish Government to report Scottish greenhouse gas emissions and emission savings from both wetland drainage and peatland restoration activities within the national greenhouse gas emissions (GHG) inventory, under the new elective activity of 'wetland drainage and rewetting'. These earlier briefings calculated the guideline figures of the net emissions from peatlands in different land use categories, including restored sites.

This report looks at four questions:

a) the origin of differences between the emission factors quoted,
b) whether these differences are significant,
c) whether the IPCC Tier 1 emission factors are appropriate for use in Scotland and
d) whether improved higher-level (Tier 2 or 3) emission factors could be developed for Scottish peatlands.

A) The difference between the emissions factors for wetland drainage and rewetting activities quoted in the IPCC publication and in previous Scottish Government briefings by ClimateXChange (Artz et al., 2012) is because the figures in the IPCC publication were in some instances measuring different components of land use emissions. The new "2013 Supplement to the 2006 guidelines: Wetlands" from the IPCC presents emission factors that can be used to determine the net greenhouse gas emissions associated with wetland drainage and rewetting activities. The IPCC emission factors refer either to net ecosystem exchange or to soil-based emissions for different greenhouse gases. In contrast, the emissions data in the Artz et al. (2012) ClimateXChange briefing refer only to the net ecosystem exchange of carbon dioxide from all biomass sources in peatlands. The values cannot therefore be compared directly for all land use types. The ClimateXChange briefing data did not include the emissions of other greenhouse gases, specifically methane and nitrous oxide, which the IPCC 2013 Supplement now recognises should be included in reporting.

B) The differences between the emissions factors quoted in the IPCC document and earlier CXC briefings are not significant (i.e., they are within the same statistical range), with the exception of CO_2 emissions from croplands.

C) Very few of the data used to calculate the Tier 1 emission factors in the IPCC 2013 Supplement originate from UK sources or from sites that are comparable in climate and/or management. In other words, IPCC Tier 1 emission factors may suffice for use in Scotland in the absence of other data but the development of regionally specific emission factors for Scottish conditions is desirable. As part of this work, we have established a meta-data resource that can be readily expanded as more primary data from Scotland and elsewhere are published, as well as a statistical methodology to process such data when required.

D) The current IPCC Tier 1 emissions factors for peatlands have limited applicability. It would be advisable to develop more specific (high level) Tier 2 and 3 emission factors for Scotland. Unfortunately, the availability of data to produce Scotland-specific emission factors is at present limited; thus the use of Tier 1 emission factors is the only available option. In addition to data from peatland sites, further work is also required to review the availability of data on the areal extent of each of the new wetland drainage and rewetting land use categories, as figures on the total area of, for example, drained and restored peatlands are not yet available.

Implications for Scottish Government of this briefing

We recalculated net carbon emissions for each land use category, using the primary data in the references used for the IPCC 2013 Supplement calculations, and compared the net emissions with our previously published figures. Under both methods, the figures confirm that peatland restoration will result in substantial savings of net GHG emissions.

2. Introduction

The imminent publication of the IPCC Guidelines "2013 Supplement to the 2006 Guidelines: Wetlands" will enable the Scottish Government to report Scottish greenhouse gas emissions and emission savings from both wetland drainage and peatland restoration activities within the national greenhouse gas emissions (GHG) inventory. This will be part of the new elective activity of 'wetland drainage and rewetting', since peatlands fall under the broader wetlands category. In response to the forthcoming IPCC Supplement, ClimateXChange commissioned this report in November 2013 to review the figures provided in the IPCC 2013 Supplement and compare them with emission figures from earlier briefings provided to the Scottish Government (Artz et al. 2012; Chapman et al. 2013). These earlier briefings calculated guideline figures of the net emissions from peatlands in different land use categories, including restored sites.

This report looks at four questions:

a) the origin of differences between the emission factors quoted,
b) whether these differences are significant,
c) whether the IPCC Tier 1 emission factors are appropriate for use in Scotland and
d) whether improved higher-level (Tier 2 or 3) emission factors could be developed for Scottish peatlands.

A further update to this report will consider the longer-term policy and implementation considerations.

3. Our findings

A) Why are the emission factors quoted in the IPCC document different to the emissions factors provided in recent (2012) ClimateXChange briefings for the Scottish Government?

The emission factors for peatlands quoted in the 2012 ClimateXChange briefing to the Scottish Government and in the forthcoming IPCC document are different because they are in some instances measuring different components of land use emissions. The 2012 ClimateXChange briefing calculated estimates of the net carbon stock change per unit area for the different land uses (in other words, net ecosystem exchange: the carbon fluxes associated with all components of the system, above ground biomass, soil, below ground biomass). The emission factors in the IPCC 2013 Supplement appear to be calculated from data that is either net ecosystem exchange or, in some cases, only soil-based carbon emissions per unit area (i.e. lacking, amongst other components, the annual above- and below-ground biomass terms). Additionally, the previous ClimateXChange briefings focused predominantly on the net emissions of carbon dioxide and methane but did not consistently take into account methane emissions from ditches, nitrous oxide and DOC (Dissolved Organic Carbon) net emissions. Note that accounting fully for these additional emissions – as suggested by the IPCC guidelines - is likely to increase the net benefits of peatland restoration in climate mitigation.

The figures should therefore not be directly compared, as they were derived using rather different calculations and assumptions. We are still unclear exactly how all the emission factors in the IPCC 2013 Supplement were derived. We are seeking further guidance from the IPCC report authors, as they appear to have applied different methods for calculating emissions factors for different land uses. We have attempted to recalculate the IPCC emission factors by extracting the original data from the references cited, for each relevant greenhouse gas type and land use category in the IPCC 2013 Supplement, and statistically analysing the data. The results of this process showed good concurrence with the published IPCC emission factors (see more detailed assessment below).

B) Are these differences significant?

We recalculated the relevant emissions factors from the dataset obtained from the original publications cited in the IPCC 2013 Supplement in order to compare them with the values published in the Artz et al. (2012) policy briefing. The net emissions of all gas types were generally within the same range, suggesting the differences are not significant, with the exception of croplands on organic soils where our estimate of the CO2 net emissions was 10t CO_2e ha^{-1} y^{-1} lower.

In order to examine the discrepancies in more detail, we calculated a set of total soil-based emissions using worked examples for the most relevant land use scenarios with the IPCC guideline Tier 1 emission factors for all of the included fluxes (CO_2, CH_4, N_2O, DOC). The results suggest that the impact of increased methane emissions associated with peatland restoration on the net emissions budget is low in comparison to the effect of accounting for the high methane emissions from drainage ditches and the high global warming potential (GWP) of any nitrous oxide fluxes in any of the other land use categories.

There are few likely consequences due to the differences in Kyoto Protocol accounting methods between different land use types. For the most part, net-net accounting takes place (most land use types), which calculates net emissions within the reporting year against the base year (1990). The exception is the accounting method for Forest Land, which uses gross-net accounting (emissions as per reporting year without subtracting the baseline emissions). This creates some difficulty in comparing the relative benefits of having Forest Land or restoring to peatland.

C) Are the IPCC Tier 1 emission factors appropriate for Scotland?

We are not currently in a position to comment on whether the Tier 1 emission factors in the IPCC 2013 Supplement are appropriate for Scottish peatland GHG reporting. Most of the citations used to calculate the emission factors originate from peatland sites that do not have equivalents in Scotland or occur in climatically different areas. The numbers of studies that have reported GHG fluxes from Scottish sites and sites elsewhere that could be considered to be climatically similar and/or of a related land use type are still very sparse. We were only able to identify 15 publications on CO_2, CH_4 or N_2O fluxes from peatlands in the British Isles and more than half of these reports on fluxes from peatlands without land cover conversion. The only data on converted or rewetted peatlands stem from Yamulki et al. (2013); Taft et al. (2013), Morrison et al. (2013b) and Wilson et al. (2007, 2009, and 2013).

D) Could improved (Tier 2 and 3) emission factors be developed for Scotland?

Given the current scarcity of data, it is unlikely that higher Tier emission factors could be developed in the near future that would represent a substantial improvement on the Tier 1 factors. At present, none of the limited UK studies report any data that fall outside of the limits of the reported emission factors under Tier 1 suggesting that Tier 1 values should be used until more representative data become available.

During the course of this enquiry, we produced a large database from the references cited in the IPCC 2013 Supplement and augmented this with other known data. This work is not yet complete but has significant potential to form the basis of future emissions factor development. We have also developed a robust statistical meta-analytical methodology that will account for some of the additional sources of variation (e.g. multiple measurements from the same site, multi-annual measurements, site geographical distance). This will enable the rapid development of more accurate Tier 2 and 3 emission factors when more data become available. Finally, we note that the next step in GHG accounting for elective activities under the wetland drainage and rewetting category will involve the calculation of the areas of the relevant land uses (i.e. the activity data used with the emission factor to calculate total emissions). While we have some of these data readily available, e.g. forest and cropland cover on peat soil or peat extraction areas, some other categories such as grassland, drained and rewetted organic soils will require additional data collection. While grassland cover on peat soils, for example, can be readily assessed, there are no national databases on the location, spacing and condition of drains in peatlands and thus the distinction between drained and undrained sites will be difficult to make. Similarly, there is no national database detailing the areas of peatland restoration that has taken place since 1990. The latter is the focus of an ongoing ClimateXChange project, which will collate data from private sources as well as the current SRDP programme for drain blocking and vegetation clearance activities.

Implications for Scottish Government of these answers:

Given the answers above, we suggest that in Scotland, the predominant gains from peatland restoration can be made by rewetting former peatlands that had been converted to improved grazing land, heather moorland land or, in limited areas, converted to cropland. As these land cover types all fall under the net-net accounting rules of the Kyoto Protocol, there would be considerable benefit on a per hectare basis from the restoration of former peatlands currently under cropland or grassland cover, or those currently in use for peat extraction, considering the large differences between their soil-based emissions. However, the areas available for restoration in these categories are more limited, and much larger areas across Scotland of drained heath or rough grazing and eroded bog are available for intervention and may give greater opportunities for carbon savings. For currently afforested sites, our estimates of the net emissions of CO_2 are not very robust. To fully capture the net GHG benefits of potential restoration activities on afforested peat, an assessment would need to be made of the relative annual biomass increases, harvested volume and the emissions from harvested wood products (HWP). For the most productive forestry sites on peat, it is possible that, partly due to the gross-net accounting process, rewetting may not produce large emissions benefits or may even have a negative impact. A worked example of a Tier 1-based assessment suggested that restoration of afforested sites would bring net benefits; however this requires further assessment.

4. Detailed methods of assessment of the discrepancies between the emission factors

In response to previous enquiries by the Scottish Government on the likely net emissions from Scottish peatlands, we compiled potential emission factors using published net emission values from different peatland land use combinations that were adjudged relevant to Scotland and its climatic conditions (Artz et al. 2012; Chapman et al. 2012). The publication of these policy briefings preceded the completion of the IPCC 2013 Supplement to the 2006 guidelines: Wetlands, which compiled emission factors at Tier 1 level using a global dataset. This document, recently completed and awaiting publication (March 2014), outlines a number of Tier 1 emission factors for different land use categories on peat soils and other wetlands, that at first glance, appear to be different from the emission factors presented in our 2012 policy briefings.

In this report, we discuss the nature of the 'discrepancies' between the values produced for previous policy briefings (Artz et al, 2012; Chapman et al., 2012) and the IPCC 2013 Supplement. The main difference appears to be in the handling of the data and the flux calculations. Whilst methane, nitrous oxide and DOC fluxes are comparable between all land use categories (see further details below), there are considerable differences in how CO_2 fluxes are calculated within the IPCC 2013 Supplement, and also between the IPCC 2013 Supplement and the previously supplied data in the Artz et al. 2012 policy briefing.

The methodological section of Chapter 2 (drained soils) of the IPCC 2013 Supplement, in line with the 2006 IPCC Guidelines, specifies that the total annual carbon stock change for a stratum of a land use category is calculated as follows:

$$\Delta C\text{-}LUi = \Delta C\text{-}AB + \Delta C\text{-}BB + \Delta C\text{-}DW + \Delta C\text{-}LI + \Delta C\text{-}SO + \Delta C\text{-}HWP$$

(equation 2.1 in the IPCC 2013 Supplement, Chapter2)

Where:

LUi = land use category i (i.e. forest, cropland, grassland, settlement, wetland, other land)

AB = aboveground biomass

BB = belowground biomass

DW = dead wood

LI = litter

SO = soils

HWP = harvested wood products

This equation is simply a reproduction of the primary equation (equation 2.3) found in Chapter 2, Volume 4, of the 2006 Guidelines, which specifies that the ΔC-SO term should be derived as follows:

$\Delta C\text{-}SO = \Delta C\text{-}mineral – L\text{-}organic + \Delta C\text{-}inorganic$ (equation 2.24, Ch2, Vol4, 2006 Guidelines)

Where:

ΔC-Mineral = annual change in organic carbon stocks in mineral soils, tonnes C yr^{-1}

L-Organic = annual loss of carbon from drained organic soils, tonnes C yr^{-1}

ΔC-Inorganic = annual change in inorganic carbon stocks from soils, tonnes C yr^{-1} (assumed to be 0 unless using a Tier 3 approach)

The annual loss of carbon from drained organic soils is then calculated by the following equation:

L-Organic $=\sum(A \bullet EF)c$ (equation 2.26, Ch2, Vol4, 2006 Guidelines)

Where:

A = land area of drained organic soils in climate type c, ha

EF = emission factor for climate type c, tonnes C ha^{-1} y^{-1}

In Chapter 2 of the IPCC 2013 Supplement, this last equation is replaced by the following:

CO_2-C organic, drained = CO_2-C(on-site) + CO_2-C(DOC) + L-fire(CO_2-C)

(equation 2.2, Chapter 2, IPCC 2013 Supplement)

Where:

CO_2-C(on-site) is on-site CO_2-C emissions/removals, tonnes C yr^{-1}

CO_2-C(DOC) is CO_2-C emissions from dissolved organic carbon exported from drained organic soils, tonnes C yr^{-1}

L-fire(CO_2-C) is CO_2-C emissions from burning of drained organic soils, tonnes C yr^{-1}

CO_2-C(on-site) calculated as follows:

CO_2-C(on-site) $=\sum(A \bullet EF)c$ (equation 2.3, Chapter 2, IPCC 2013 Supplement)

Therefore, Chapter 2 of the IPCC 2013 Supplement: Wetlands only provides updates on the calculation of part of the primary equation, by providing more up to date emission factors for the calculation of ΔC-SO in organic soils and by the addition of the CO_2 fluxes arising from decomposition of DOC in aqueous losses as well as fire-derived CO_2 on the land unit.

The IPCC 2013 Supplement states that soil CO_2 emission factors were calculated from fluxes of heterotrophic soil respiration (according to Annex 2 A.1 of Chapter 2 of the IPCC 2013 Supplement). Therefore, the new emission factors presented in Chapter 2 should only replace the calculations for the soil-derived emissions, all calculations for above- and below-ground biomass, dead wood, litter, and harvested wood products (where appropriate), remain as per the IPCC 2006 Guidelines for each of the land use categories. However, when we attempted to repeat the analysis produced by the IPCC working group in order to recreate their emission factors, it became clear that a large proportion of the publications included in the IPCC report do not report annual soil heterotrophic respiration fluxes (Rh) but tend to present values of net ecosystem exchange. Net ecosystem exchange (NEE) represents the balance between

Gross Primary Production (GPP) and total respiration (Rt) or it may be expressed as the balance between Net Primary Production (NPP) and heterotrophic respiration (Rh) (See Figure 1 for a more detailed explanation of these terms). The only land use category where fluxes of heterotrophic soil respiration were directly reported is in forest ecosystems, where chamber-based measurements of NEE are not possible due to the tree biomass. NEE measurements in forest ecosystems require either eddy covariance measurements using towers above canopy height or very accurate annual stand–based measurements of NPP combined with heterotrophic respiration (Rh) fluxes (NEE = NPP – Rh; see Figure 1). For all other land use categories, the majority of the citations included in the IPCC calculations report NEE and/or total respiration fluxes (Rt) as net carbon assimilation and release can be easily measured using a combination of transparent chambers (measuring NEE) and opaque chambers (measuring Rt). We queried this with Dr Chris Evans (CEH Bangor) by email, who responded to confirm that, except for the emission factor for Forest Land, all emission factor values for CO_2 were indeed derived from NEE measurements. How this affects the calculations of the net emissions at the overall land use level is unclear, as this would, at the least, double-count part of the above and below-ground biomass C pool and requires further clarification from the IPCC Chapter authors.

The Chapter 2 methodology further states that expert judgment was used to convert data that were reported as NEE, by estimating the proportion of heterotrophic respiration (Rh) from a limited number of studies (IPCC 2013, Annex 2A.1). Unfortunately, the IPCC 2013 Supplement does not give sufficient detail that would have allowed us to replicate their calculations of heterotrophic respiration fluxes as details of the conversion factors used in Chapter 2 are not given. We have made a simplistic assumption that, wherever there is vegetation included in the reported total respiration data (Rt), that the proportion of Rh within Rt is 50% (see Annex Table for details of the conversion used for individual data points). Literature values range between 30 and 70% and are dependent upon a variety of factors.

Many of the cited publications also report seasonal, rather than annual, fluxes which also hampered our ability to calculate comparable figures. The IPCC authors specify that 'Annualization of seasonal results were guided by several studies that specifically targeted winter fluxes' (Annex 2A.1), however, no details are given in Chapter 2 for the conversion factors used. Chapter 3 stated that 'seasonal fluxes (…) were converted to annual fluxes using (a further) 15% of the seasonal ecosystem respiration data from each study to estimate CO_2 fluxes in the non-growing season, although this may represent a slight overestimation given that photosynthesis may have occurred for a short time (…)' (Annex 3A.1). We adopted the Chapter 3 methodology throughout our analysis.

For CO_2 emissions from rewetted soils, Chapter 3 states that the new calculations aim to replace equations 2.24 and 2.26 found in the Chapter 2, Volume 4, of the 2006 IPCC Guidelines, i.e. the methodology used to derive the emission factors should be analogous to Chapter 2 and hence use soil heterotrophic respiration values. However, the text continues, stating that 'Equations 2.24 and 2.26 implicitly assume that organic soils can only lose carbon, while in fact, undrained and rewetted soils can accumulate soil organic carbon if covered with vegetation' (page 3.6, Chapter 3, IPCC 2013 Supplement). Annex 3A.1 also appears to suggest that net ecosystem exchange values were used for the calculation of the emission factors in Chapter 3. We queried this with Dr David Wilson (Chapter 3 author) by email, who confirmed that 'NEE values were used and that they integrate both the photosynthetic and respiratory processes. This is the CO_2-C composite term in Eq. 3.3. of the Supplement. In Ch 3, we did not separate out the autotrophic and the heterotrophic respiration components.'

We calculated the likely soil-based as well as net emissions by compiling the primary data from all relevant references used for the production of the soil emission factors in the IPCC 2013 supplement. All citations were searched for any inclusion of full net ecosystem exchange values of CO_2 (NEE), total respiration (Rt), heterotrophic respiration (Rh), methane and nitrous oxide emissions. The NEE values should give guideline figures of the ΔC-LU for each of the land use categories and addition of GWP equivalents of any methane or nitrous oxide emissions results in a total value of the net gaseous emissions on a unit area basis to enable comparisons of the full GHG benefits of restoration. All data were entered by one of four staff, with crosschecks included for a small proportion of the data entered (5%). Data were cleaned and checked for errors by the statistical team. A bespoke mixed model Residual Maximum Likelihood (REML) analysis was used to calculate average fluxes for each of the land use category ☐ gas flux combin takes into account potential sources of variation from multi-annual studies on the same site as well as multiple experiments within the same site versus single site experiments. In future, geographical location as well as other sources of variation could be included but this was not attempted as GHG publications do not use a consistent reporting format for their experimental design.

Table 1 shows the results of the calculations of CO_2 emissions based on both net ecosystem exchange and estimated soil heterotrophic respiration values. It shows that our recalculated values for Forest Land, using the literature heterotrophic respiration fluxes, matches the IPCC 2013 emission factor for CO_2. For all other categories, our results match the IPCC 2013 emission factors for CO_2 if the NEE-based data were used for analysis. This confirms the clarification provided by Drs Evans and Wilson. However, it complicates like-for-like comparisons of CO_2 emissions as the net primary production term is missing from the Forest Land categories.

Table 1. Comparison of likely emissions of carbon dioxide

Land use category	**EF in the IPCC 2013 Supplement (temperate or boreal/temperate zone)** **Recalculated as t CO_2e ha^{-1} y^{-1}** (×3.664; from t CO_2–C ha^{-1} y^{-1}) **95 % confidence interval in brackets**	**EF from new calculations using R_h or NEE-CO_2 from references cited in the IPCC 2013 Supplement (temperate or boreal/temperate zone)** **In t CO_2e ha^{-1} y^{-1}**		**Is the newly calculated EF value within range of the IPCC EFs?**
		Calculated using R_h values (assuming R_h = 50% of R_t where vegetation is present) ± SEM	**Calculated using NEE values ± SEM**	
Forest Land, drained	9.5 (7.3-12.1)	**9.2** ± **2.3**	(-2.7 ± 1.9) Using some additional references that the IPCC report puts into boreal categories, (Ojanen et al. 2012; Lohila 2011/2007) or data not included in IPCC (Hargreaves et al. 2003 (modelled data); Syed et al. 2006) due to lack of NEE data in IPCC references	Within range (assuming IPCC EF is R_h)
Cropland, drained	28.9 (23.8-34.4)	36.2 ± 4.7	**24.7 ± 3.9**	Within range (assuming IPCC EF is NEE)
Grassland, drained, nutrient-poor	19.4 (13.5-25.3)	Not calculated	Not calculated	Not determined
Peatland managed for extraction	10.2 (4.0-15.4)	7.3 ±1.3	**7.7** ± **2.5**	Within range E (assuming IPCC EF is NEE – mostly equals R_h in cutover peatlands, if not revegetated)
Rewetted organic soils	-0.84 (-2.3 – 0.66) (poor) 1.8 (-2.6 – 6.26) (rich)	Not calculated	**0.47** ± **1.06 (poor)** **0.82** ± **2.41 (rich)**	Within range (assuming IPCC EF is NEE)

In contrast, the CO_2 emission factors provided in our earlier policy briefings (Artz et al. 2012) were derived from NEE or sometimes Net Ecosystem Carbon Balance (NECB) figures. NECB represents NEE data adjusted for other C fluxes such as DOC losses or fire emissions. Therefore, these values should be roughly equivalent to the full, NEE-based, CO_2 emission factors for each of the categories. In Table 2, we present a calculation based on annual net ecosystem exchange of carbon dioxide, using the references cited in the IPCC 2013 Supplement and compare the values with our previously reported figures from the Artz et al. (2012) policy briefing. In all categories except cropland, our previously reported CO_2 emissions fall within the same range as net emissions calculated using the IPCC 2013 cited references. The differences in the cropland value are likely due to the much more limited dataset used by Artz et al. (2012). The IPCC dataset includes values from both fen and bog types, whereas Artz et al. (2012) included only bog sites.

Table 2. Comparison of the newly derived net emissions of CO_2 with the ranges published in Artz et al. (2012). Negative values signify net uptake.

Land use category	**Net emissions, from calculations using NEE-CO_2, using references cited in the IPCC 2013 Supplement (temperate or boreal/temperate zone) In t CO_2e ha^{-1} y^{-1}**	**Data from Artz et al. (2012), using NEE or NECB values (categorisation from Artz et al. in brackets)** **In t CO_2e ha^{-1} y^{-1}**	**Is the CxC value within range of IPCC references based value?**
	Calculated using NEE values		
Forest Land, drained	(-2.7 ± 1.9) Using additional references that the IPCC report puts into boreal categories, (Ojanen et al. 2012; Lohila 2011/2007) or data not included in IPCC (Hargreaves et al. 2003 (modelled data); Syed et al. 2006), as there were only 2 studies otherwise	**-9 to 4.8** (excluding extremely young and old stands)	Within range
Cropland, drained	**24.7** ± **3.9**	**+ 9.2 to +15 ('cultivated')**	Lower
Grassland, drained, nutrient-poor	Not calculated	**-0.05 to +5.5** ('drained for forestry or grazing improvements')	Not determined
Peatland managed for extraction	**7.7** ±**2.5**	**0 to +5.5** ('bare peat: eroded or harvested')	Within range
Rewetted organic soils	**0.47** ± **1.06 (poor)** **0.82** ± **2.41 (rich)**	Highly variable, dependent on site history and time since restoration ('restored' full range **-8.1 to +2.8**)	Within range
Near-natural	Not reported under KP	-1.9 ± 0.3 (Table 2 in Artz et al.)	Not applicable

For completeness, we also recalculated the emission factors for methane (Table 3) and nitrous oxide (Table 4). These were not included in the Artz et al. 2012 report, with the exception of methane fluxes in near-natural peatlands, which were estimated as slightly lower than the methane fluxes from rewetted peatlands.

Table 3. Comparison of emission factors for methane in the IPCC 2013 Supplement versus newly derived calculations

Land use category	Emission factors quoted in the IPCC 2013 Supplement (temperate or boreal/temperate zone) Recalculated as t CO_2e ha^{-1} y^{-1} (×0.025, from kg CH_4 ha^{-1} y^{-1}, Chapter 2) (×0.0187, from kg CH_4-C ha^{-1} y^{-1}, Chapter 3) 95 % confidence interval in brackets	Data calculated for the purpose of this briefing, using primary data from references cited in the IPCC 2013 Supplement In t CO_2e ha^{-1} y^{-1} ± SEM	Do values from our calculations match the IPCC EFs?
	CH_4	CH_4	
Forest Land, drained	0.06 (-0.015-0.14)	0.05 ± 0.05	Within range
Cropland, drained	0 (-0.07-0.07)	0.02 ± 0.03	Within range
Grassland, drained, nutrient-poor	0.04 (-0.02 – 0.7)	Not determined	Not determined
Peatland managed for extraction	0.15 (0.04-0.27)	0.667 ± 0.31 (0.06-1.274)	Within range (highly skewed data)
Rewetted organic soils	1.72 (0.06 – 8.32; poor) 4.03 (0- 16; rich)	2.04 ± 0.53 (poor) 7.99 ± 3.81 (rich)	Within range
Near-natural	Not reported under KP	1.57 (poor; Table 2 in Artz et al.)	

Table 4. Comparison of emission factors for nitrous oxide in the IPCC 2013 Supplement versus newly derived calculations

Land use category	**Emission factors quoted in the IPCC 2013 Supplement (temperate or boreal/temperate zone)** **Recalculated as t CO_2e ha^{-1} y^{-1} (×0.468, from kg N_2O-N ha^{-1} y^{-1}, Chapter 2)**	**Data calculated for the purpose of this briefing, using primary data from references cited in the IPCC 2013 Supplement In t CO_2e ha^{-1} y^{-1}**	**Do calculations match?**
	N_2O	**N_2O**	
Forest Land, drained	1.3 (-0.27-2.85)	2.9 ± 2.04	Within range
Cropland, drained	6.1 (3.8-8.4)	8.2 ± 1.6	Within range
Grassland, drained, nutrient-poor	2.0 (0.88 – 3.18)	Not determined	Not determined
Peatland managed for extraction	0.14 (-0.01 -0.3)	0.6 ± 0.5	Within range
Rewetted organic soils	Assumed negligible	Not determined	
Near-natural	Not reported under KP	Not determined	

Due to time constraints, we did not recalculate the emission factors for DOC losses, methane emissions from drainage ditches or losses from fire events. Finally, as a direct comparison of our previously reported net emissions (Artz et al. 2012) and the likely total emissions if calculated using the new Tier 1 emission factors in the IPCC 2013 Supplement was not feasible, we attempted a simple like-for-like comparison by calculating the total soil-based emissions for each land use category as total CO_2 equivalents. The inclusion of updated emission factors and additional terms for emissions from CO_2 from aqueous losses and methane from ditches for non-peatland land-use categories adds up to more than the new net total soil-based emissions calculated for rewetted soils (Table 5). If one assumes that harvesting or other loss of any biomass is negligible (i.e. no forest felling, thinning, or mortality; no crop harvest; no grazing; no peat cutting; no fire), one can compare the net GHG emissions and estimate net GHG benefits from restoration for all except the Forest Land category. The GHG benefits of restoring afforested peatlands can be estimated by a simple subtraction of the required net biomass increase that would be needed to balance the figures between the Forest Land and rewetted soils net emission sum.

For example, assuming no timber harvest or mortality, biomass C accumulation of at least -10.4 t CO_2e ha^{-1} y^{-1} is required for forestry on former peatland to result in a greater net benefit than the restoration of the site. Yamulki et al. (2013) estimated an NPP of -5.5 t CO_2e ha^{-1} y^{-1} from mensuration data for their forestry plantation at Flanders Moss at a Yield Class of 10 m^3 ha^{-1} y^{-1}. Adding the emissions resulting from felling and harvested wood products would add further to the net carbon losses from these systems. This suggests that, when using all components of the new Tier 1 emission factors, the conversion of forestry to peatland would bring a net carbon benefit. Peat cutting operations also carry additional emissions from stockpiled peat on site as well as the emissions from the combustion of the peat (calculated elsewhere). Hence such sites are highly suitable candidates for restoration as there is a >10 t CO_2e ha^{-1} y^{-1} net benefit to restoration under Tier 1-based accounting even without accounting for losses due to peat combustion or stockpiling.

Table 5. Comparison of full soil-based emissions based on a worked example using the equations and emission factors presented in the IPCC 2013 Wetlands Supplement (all values recalculated to t CO_2e ha^{-1} y^{-1}).

Land use category	Soil CO_2 emissions (includes CO_2 from DOC as per eq. 2.2, Chapter 2, IPCC 2013 Supplement)	Soil CH_4 emissions (includes emissions from site and ditches)	Soil N_2O emissions	**Total soil-based emissions, inclusive of GWP conversion for CH_4 and N_2O**
Forest Land, drained	10.64	0.20	1.31	**12.1 = ΔC-SO**
Cropland, drained	30.06	1.46	6.08	**37.6 = ΔC-LU**
Grassland, drained, nutrient-poor	20.53	0.70 (assuming EF for shallow-drained grasslands)	2.01	**23.2 = ΔC-LU**
Peatland managed for extraction	11.36	0.82	0.14	**12.3 = ΔC-LU**
Rewetted organic soil	0.004	1.72	Assumed negligible	**1.7 = ΔC-LU**

In summary, the CO_2 emission factors in the IPCC 2013 Supplement only differ from the data supplied in our previous policy briefing in the cropland category. It must be noted, however, that the data in our previous policy briefings did not include estimates of non-CO_2 fluxes on converted or rewetted wetlands, with the exception of the CH_4 fluxes in near-natural ombrotrophic bogs (Artz et al. 2012). The IPCC 2013 Supplement provides further emission factors for additional losses of methane (from both soil surfaces and drainage ditches), nitrous oxide, DOC and other fluxes (e.g. fire). In most cases, the additional fluxes from these sources add to the total emissions of anthropogenically altered peatlands (Table 5, worked example above) and thus the carbon benefits of restoration, at least using Tier 1 figures, may in reality be larger than previously calculated. We are in the process of compiling a database containing the >2300 data entries in the >200 publications within the IPCC 2013 Supplement and additional entries and have developed a robust methodology for the calculation of higher level emission factors.

(The Annex Table states current progress with data analysis of the references cited in the IPCC 2013 Supplement for the potential derivation of higher level emission factors.)

Annex Table. Contents of the citations referred to in the IPCC 2012 Supplement for the calculation of soil respiration-based emission factors.

IPCC Emissions category	**Gas type × Land use category**			**Applicability to Scottish scenario**
1 (R_h)	*CO_2; Forest Land, drained, temperate (should be n=8)*			
	Reference	**Comments on R_h data**	**Comments on NEE data**	
1	Glenn et al. 1993	1 forestry sites, R_h, summer fluxes only, so added 15% (Annex 2A.1 and 3.A.1 in IPCC 2013 Supplement)	No NEE data available	Unlikely
1	Minkkinen et al. 2007b	3 forestry sites×1,1,2 years (last has data from 3 microsites), R_h	No NEE data available	Possibly, but different management practice
1	Von Arnold et al. 2005a	2 forestry sites × 2 years, R_h	No NEE data available	Possibly, but different management practice
1	Von Arnold et al. 2005b	3 forestry sites × 3, 3 and 4 years, R_h	3 forestry sites, estimated annual NEE	Possibly, but different management practice
1	Yamulki et al. 2013	2 forestry sites × 2 years, R_h	2 forestry sites, annual estimate of NEE (highly likely an overestimate, Artz et al., 2013)	Yes
2 (NEE)	*CO_2; Cropland, drained, boreal & temperate (should be n=39)*			
	Reference	**Comments on R_h data**	**Comments on NEE data**	
2	Droesler et al. 2013	6 sites, all but one 1 years, one has 2 years (R_t); assumed R_h=50%	6 sites, all but one 1 years, one has 2 years (NEE)	Some may be comparable
2	Elsgaard et al. 2012	5 sites (2 of which rotational grass/crop) × 1 year (R_t); assumed R_h=50%	5 sites (2 of which rotational grass/crop) × 1 year (NEE)	Some may be comparable
2	Gronlund et al. 2008	Used subsidence estimate x 1; plus 1 R_t measurement used, assumed R_h=50%	2 'sites', one of which is an estimate of NEE (R_t measured but NPP assumed) and the other a composite dataset of 5 over 25 years from subsidence data (NECB?).	Difficult to tell, one is compound data, the other under grass at time of measurements
2	Kasimir-	Used subsidence-based	2 country estimates ×	Modelled data,

	Klemedtsson et al. 1997	data × 3	2 techniques (oxidation methods excluded), no raw data included (citing Berglund et al. 1989; Nykanen et al. 1995; Landeveld et al. (then manuscript) and unpublished work)	composite datasets for whole countries
2	Leifeld et al. 2011	Used subsidence-based data × 4	4 sites on former fen peatland, subsidence rate based on data since 1864 (NECB?)	Arable on fen not common in Scotland
2	Maljanen et al. 2001a	No R_t values, in future could maybe use bare tilled NEE as R_h	4 site types, 1 for 2 years (bare tilled), 3 for 1 year (NEE)	Possibly
ND	Maljanen et al. 2003a	Does not contain any CO_2 emissions data		NA
2	Maljanen et al. 2004	No R_t values	2 sites × 2 treat × 1 yr (NEE)	Both sites on shallow peat (30/70cm) site 2 has mineral soil added
2	Maljanen et al. 2007a	No R_t values	5 sites with NEE data (annual), but otherwise referencing earlier papers e.g. with Maljanen et al. 2003a/2004	Possibly
2	Morrison et al. 2013b	No R_t values	1 site × 1 year (NEE), but only for 220 days, assumed 15% addition adequate	Yes, but only for fen types, Arable fen not common in Scotland
ND	Petersen et al. 2012	5 sites from 3 areas × arable/rotational grassland, 1 year (R_t); assumed R_h=50%	No NEE data	ND
3	*CO_2; Grassland, drained, nutrient-poor, temperate (should be n=7)*			
	Reference	**Comments**		
ND	Kuntze et al. 1992	Cannot access this paper		
	Droesler et al. 2013	Impossible to figure out which of the sites are deep – vs shallow-drained (water table only given as low, medium, high) and/or nutrient-poor versus rich (no indication of vegetation composition or peat type (bog/fen)		
4	*CO_2; Grassland, deep-drained, nutrient-rich, temperate (should be n=39) – TO BE COMPLETED AT LATER DATE AS FENS ARE RELATIVELY SCARCE*			

	Augustin 2003	Cannot access this paper		
	Augustin et al. 1996	Does not contain CO_2 data		
	Czaplak and Dembek 2000	Not yet in file		
	Droesler et al. 2013	Impossible to figure out which of the sites are deep – vs shallow-drained (water table only given as low, medium, high) and/or nutrient-poor versus rich (no indication of vegetation composition or peat type (bog/fen)		
4	Elsgaard et al. 2012	3 sites × 1 y NEE		Possibly
	Hoeper 2002	Not yet in file		
	Jacobs et al. 2003	Not yet in file		
4	Kasimir-Klemedtsson et al. 1997	4 data points, estimated from subsidence or chamber measurements, country estimates		?
	Langeveld et al. 1997	Not yet in file		
	Leifeld et al. 2011	No grassland data in this paper		
	Lorenz et al. 1992	Not yet in file		
	Meyer et al. 2001	Not yet in file		
	Nieveen et al. 2005	Not yet in file		
	Okruszko 1989	Not yet in file		
	Schothorst 1977	Not yet in file		
	Schrier-Uijl et al. 2010a	Not yet in file		
	Schrier-Uijl et al. 2010c	Not yet in file		
	Veenendaal et al. 2007	Not yet in file		
	Weinziehrl 1997	Not yet in file		
5	*CO_2; Grassland, shallow-drained, nutrient-rich, temperate (should be n=13) – TO BE COMPLETED AT LATER DATE AS FENS ARE RELATIVELY SCARCE*			
	Droesler et al. 2013	Impossible to figure out which of the sites are deep – vs shallow-drained (water table only given as low, medium, high) and/or nutrient-poor versus rich (no indication of vegetation composition or peat type (bog/fen)		
	Jacobs et al. 2003	Not yet in file		
	Lloyd et al. 2006	Not yet in file		
6	*CO_2; Peatland managed for extraction, boreal& temperate (should be n=20)*			
	Reference	**Comments on R_h data**	**Comments on NEE data**	
N/A	Ahlholm and Silvola 1990	Cannot access this paper (plus in Finnish)		N/A
6	Glatzel et al. 2003	4 sites × 1 year (only 1	4 sites × 1 year (only	Unlikely

		site is bare, the others are spontaneously regenerated sites), growing season R_t only (=NEE on bare but not revegetated sites). Annual data estimated using 15% addition. Assumed R_h=50% on the 3 revegetated sites and 100% on the bare site	1 site is bare, the others are spontaneously regenerated sites), growing season R_t only (=NEE on bare but not revegetated sites). Annual data estimated using 15% addition.	(Canadian)
6	McNeil and Waddington 2003	Used NEE estimate from bare microsites (=R_h)	1 total site estimate incl 4 microsites (bare and revegetated), summer season NEE data.	Unlikely (Canadian)
6	Shurpali et al. 2008	1 site still bare × 2 years (still extracted, included)- the other is used for canary grass crop (not included). Assumed R_t=R_h.	1 site still bare × 2 years (still extracted, included)- the other is used for canary grass crop (not included). Assumed R_t=NEE	Possibly
6	Strack and Zuback 2013	Unrestored site has vegetation. Assumed R_h=50%	1 site, whole site (with ditches) data, NEE values, growing season and winter data added	Unlikely (Canadian)
6	Sundh et al. 2000	All still active extraction sites so NEE = R_h	8 sites, summer fluxes only (NEE), converted to annual by addition of 15%	Possibly
6	Tuittila and Komulainen 1995	Not included	1 abandoned extraction site (NEE)	Possibly
ND	Tuittila et al. 2000	No primary CO_2 data (refers to modelled CO_2 data only)		ND
6	Tuittila et al. 2004	3 site treatment types × bare peat, NEE = R_h	3 site treatment types × bare/with *Sphagnum* recolonisation, modelled summer data only, NEE values, 15% added.	Possibly
6	Waddington et al. 2010	1 bare peat site, NEE = R_h	2 sites, one abandoned cutover (included), one restored (not included), both have 3 years of seasonal NEE (+15%)	Possibly
6	Wilson et al. 2013	Bare site means NEE =	1 site (bare) x 3 yrs	Yes, but this study was not included

		R_h	NEE	in the IPCC calculations
9	*CH_4; Forest land, drained, temperate (should be n=13)*			
9	Glenn et al. 1993	3 forestry sites, data collected over season only (included), 15% added to make up annual		Possibly, but different management practice
ND	Moore and Knowles, 1990	Does not contain any data on drained forestry sites (only natural afforested peatlands and a site prepared for horticulture)		ND
N/A	Sikstrom et al. 2009	In Swedish, non-peer reviewed, could not be traced within deadline		N/A
9	Von Arnold et al. 2005a	2 forestry sites × 2 years		Possibly, but different management practice
9	Von Arnold et al. 2005b	3 forestry sites × 3-4 years		Possibly, but different management practice
9	Weslien et al. 2009	1 site (3 year average)		Silver birch forest, not so common here
9	Yamulki et al. 2013	2 forestry sites × 2 years		Yes
10	*CH_4; Cropland, drained, boreal & temperate (should be n=38)*			
N/A	Augustin 2003	Cannot access this paper		N/A
ND	Augustin et al. 1998	Does not contain CH_4 data (N_2O only)		ND
10	Droesler et al. 2013	7 sites, 1-2 years		Possibly
ND	Elsgaard et al. 2012	Does not contain CH_4 data		ND
10	Flessa et al. 1998	2 cropped sites, 1 yrs data, fen site		Unlikely, or for fen sites only
10	Kasimir-Klemedtsson et al. 2009	1 site x 3 temporal measurements (not full year), 15% added.		No, layered peat with inorganic sediment, clay pipe drainage
10	Maljanen et al. 2003a	4 sites, 1 site × 2 yrs, others 1 yr, but only 20 cm organic soil layer		No, not deep enough to be peat
ND	Maljanen et al. 2003b	Does not contain CH_4 data (N_2O only)		ND
10	Maljanen et al. 2004	2 sites × 2 treat × 1 yr		No, both sites on shallow peat (30/70cm) site 2 has mineral soil added
10	Maljanen et al. 2007	4 barley, 4 fallow sites × 1 year, some referencing earlier work (e.g. Maljanen et al. 2003b/2004; Regina et al. 2004/2006 – 1 barley		Yes for some, if deep enough

		and 1 fallow site removed to preclude double-counting	
10	Petersen et al. 2012	3 sites, 1 year each	Possibly
10	Regina et al. 2007	2 locations, barley/fallow sites × 2 years	Possibly
10	Taft et al. 2013	2 sites (fens) × 1 year (excluded for the moment as some outstanding queries to authors)	Yes, but both fens
11	*CH_4; Grassland, drained, nutrient-poor, temperate (should be n=9)*		
	Droesler et al. 2013	Impossible to figure out which of the sites are deep – vs shallow-drained (water table only given as low, medium, high) and/or nutrient-poor versus rich (no indication of vegetation composition or peat type (bog/fen)	
11	Kasimir-Klemedtsson et al. 2009	1 site × 3 temporal measurements (not full year)	No, layered peat with inorganic sediment, clay pipe drainage
	Van den Bos 2003	Synthesis paper, not sure which are the grasslands, this will require a more thorough check	
12	*CH_4; Grassland, deep-drained, nutrient-rich, temperate (should be n=44) – TO BE COMPLETED AT LATER DATE AS FENS ARE RELATIVELY SCARCE*		
	Augustin et al. 1996	Not yet in file (have paper)	
Not yet sure	Best and Jacobs 1997	Data in spreadsheet but not yet crosschecked for which to include	
	Droesler et al. 2013	Impossible to figure out which of the sites are deep – vs shallow-drained (water table only given as low, medium, high) and/or nutrient-poor versus rich (no indication of vegetation composition or peat type (bog/fen)	
	Flessa et al. 1997	Not yet in file	
12	Flessa et al. 1998	2 fen sites (fertilised/unfertilised × 1 yr)	
	Jacobs et al. 2003	Not yet in file	
	Kroon et al. 2010	Not yet in file	
	Langeveld et al. 1997	Not yet in file	
	Meyer et al. 2001	Not yet in file	
12	Nykanen et al. 1995	2 sites, 1 yr each, needs cross-checked	
12	Petersen et al. 2012	3 sites × 1 yr	
	Schrier-Uijl et al. 2010a	Not yet in file	
	Schrier-Uijl et al. 2010b	Not yet in file	
12	Teh et al. 2011	1 site, two methods for flux	
	Van den Bos 2003	Large synthesis paper, need to identify relevant grassland sites	
	Van den Pol- van Dasselaar et al.	Not yet in file	

	1997		
	Wild et al. 2001	Not yet in file	
13	*CH_4; Grassland, shallow-drained, nutrient-rich, temperate (should be n=16) – TO BE COMPLETED AT LATER DATE AS FENS ARE RELATIVELY SCARCE*		
	Augustin 2003	Not obtained within deadline	
	Droesler et al. 2013	Impossible to figure out which of the sites are deep – vs shallow-drained (water table only given as low, medium, high) and/or nutrient-poor versus rich (no indication of vegetation composition or peat type (bog/fen)	
	Jacobs et al. 2003	Not yet in file	
	Van den Pol-van Dasselaar et al. 1997	Not yet in file	
14	*CH_4; Peatland managed for extraction, boreal& temperate (should be n=15)*		
14	Hyvonen et al. 2009	1 site (cutover) × 4 yrs, the other site is used for canary grass crop (not included)	Possibly
14	Nykanen et al. 1996	Average value for 3 cutover sites	Possibly
14	Strack and Zuback 2013	1 site, separate summer/winter data, added together	Possibly
14	Sundh et al. 2000	8 sites, summer fluxes only, converted to annual by addition of 15%	Possibly
14	Tuittila et al. 2000	1 extracted site × 1 yr, (rewetted site not included)	Possibly
14	Waddington and Day 2007	1 site, 4 years, summer data only, 15 % added	Possibly
19	*N_2O, Forest Land, drained, temperate (should be n=13)*		
N/A	Sikstrom et al. 2009	In Swedish, non-peer reviewed, could not be traced within deadline	N/A
19	Von Arnold et al. 2005a	2 forestry sites × 2 years	Possibly, different management though
19	Von Arnold et al. 2005b	3 forestry sites × 3-4 years	Possibly, different management though
19	Weslien et al. 2009	1 site (3 year average) – exceptionally high value	Possibly, different management though
19	Yamulki et al. 2013	2 forestry sites × 1 year	Yes
20	*N_2O; Cropland, drained, boreal & temperate (should be n=36)*		
ND	Augustin et a 1998	No cropland data?	ND
20	Droesler et al. 2013	7 sites, 1-2 years	Possibly

ND	Elsgaard et al. 2012	No cropland data?	ND
20	Flessa et al. 1998	2 arable sites	Possibly
20	Kasimir-Klemedtsson et al. 2009	1 site × 3 dates (summer/winter), 15% added	Possibly
ND	Maljanen et al. 2003a	No N_2O data	ND
20	Maljanen et al. 2003b	4 sites, but only shallow organic layer	No, not deep enough to be peat
20	Maljanen et al. 2004	4 datasets	No, both sites on shallow peat (30/70cm) site 2 has mineral soil added
20	Maljanen et al. 2007	7 datasets (2 entries removed as they refererred to earlier Maljanen 2003/04 papers as data source)	Possibly
20	Petersen et al. 2012	3 sites × 1 yr	Possibly
20	Regina et al. 2004	10 datasets from 2 sites with 2-4 crops/fallow	Possibly
20	Taft et al. 2013	2 sites	Yes
21	*N_2O; Grassland, drained, nutrient-poor, temperate (should be n=7)*		
	Droesler et al. 2013	Impossible to figure out which of the sites are deep – vs shallow-drained (water table only given as low, medium, high) and/or nutrient-poor versus rich (no indication of vegetation composition or peat type (bog/fen)	
	Kasimir-Klemedtsson et al. 2009	1 site, 3 dates (summer/winter)	
22	*N_2O; Grassland, deep-drained, nutrient-rich, temperate (should be n=47) – TO BE COMPLETED AT LATER DATE AS FENS ARE RELATIVELY SCARCE*		
	Augustin and Merbach 1998	Not yet in file	
	Augustin et al. 1996	Not yet in file	
	Augustin et al. 1998	Not yet in file	
	Droesler et al. 2013	Not yet in file	
	Flessa et al. 1997	Not yet in file	
	Flessa et al. 1998	Not yet in file	
	Jacobs et al. 2003	Not yet in file	
	Kroon et al. 2010	Not yet in file	
	Langeveld et al. 1997	Not yet in file	
	Meyer et al. 2001	Not yet in file	
	Nykanen et al. 1995	Not yet in file	
	Petersen et al. 2012	Not yet in file	
	Teh et al. 2011	Not yet in file	
	Van Beek et al.	Not yet in file	

	2010			
	Velthof et al. 1996	Not yet in file		
	Wild et al. 2001	Not yet in file		
23	*N_2O; Grassland, shallow-drained, nutrient-rich, temperate (should be n=13) – TO BE COMPLETED AT LATER DATE AS FENS ARE RELATIVELY SCARCE*			
	Droesler et al. 2013	Impossible to figure out which of the sites are deep – vs shallow-drained (water table only given as low, medium, high) and/or nutrient-poor versus rich (no indication of vegetation composition or peat type (bog/fen)		
	Jacobs et al. 2003	Not yet in file		
24	*N_2O; Peatland managed for extraction, boreal& temperate (should be n=4)*			
24	Hyvonen et al. 2009	1 site, 4 years (canary grass site not included)		Possibly
24	Nykanen et al. 1996	1 average value for 3 cutover sites		Possibly
24	Regina et al. 1996	1 cutover site out of a large synthesis of peatland fluxes		Possibly
25/26	*CO_2, rewetted soils, temperate, nutrient-poor/nutrient-rich (should be n=43/n=15)*			
	Shurpali et al. 1995	1 bog site , NEE	25	Unlikely
	Lafleur et al. 2001	1 natural bog, NEE	25	Unlikely
	Wickland 2001	1 site (natural fen) × 3 yrs NEE	26	Unlikely
	Aurela et al. 2002	1 site (natural fen), 1 yr (NEE)	26	Possibly
	Schulze et al. 2002	1 site (natural bog, surrounded by P.sylvestris forest), 2 NEE-type values, 1 by EC (lower) and one by peat accumulation method (50% higher)	25	Possibly
	Petrone et al. 2003	1 site, rewetted cutover bog, 2 years NEE (summer data only), 15 % added	25	Unlikely
	Roehm and Roulet 2003	1 site, natural bog, 1 years NEE data	25	Unlikely
	Billett et al. 2004	1 site (slightly drained bog) x 2 yrs NEE	25	Yes
	Droesler et al. 2013	2 sites (nutrient-rich?) × 5 yrs; 7 sites assumed nutrient-poor × 1-2 yrs (degraded heather moorland; rewetted heather moorland; rewetted sphagnum lawn, rewetted peat cutting; damp/dry heather moor; natural bog), all data NEE	25/26	Possibly
ND	Nagata et al. 2005	Not included (japan peatlands)	ND	No
	Bortoluzzi et al. 2006	3 microsites in 1 restored area, 2 yrs data (NEE). Reported values are min-max; converted to mean by (min+max/2)	25	Possibly
	Hendriks et al. 2007	1 site x 3 yrs (NEE), rewetted fen, semi-natural grassland vegetation	26	Possibly

	Jacobs et al. 2007	2 sites that could be classed as rewetted,both N-enriched (Horstermeer & Fochtelooerveen), × 4 yrs NEE	26	Possibly
	Lund et al. 2007	1 site (natural bog) × 1 yr NEE	25	Possibly
	Riutta et al. 2007	1 site (fen), crude NEE from summer NEP and winter R_t	26	Fen
	Roulet et al. 2007	1 site (natural bog) × 6 year average (1 value) NEE	25	Unlikely
	Wilson et al. 2007	3 microsites in 1 reflooded cutover fen × 2 yrs NEE (fen)	26	Yes
	Augustin and Chojnicki 2008	Have not managed to obtain this reference within the deadline	ND	ND
	Cagampan and Waddington 2008	1 bog site with 2 experimental areas (natural, restored) and 2 microsites (dry/wet); NEE values for summer only	25	Unlikely
	Golovatskaya and Dyukarev 2009	1 site with 2 bog and 1 fen element, NEE values extrapolated from NECB – aqueous estimate – CH4	25/26	Unlikely
	Kurbatova et al. 2009	1 natural bog site (afforested) × NEE values	25	Unlikely
	Drewer et al. 2010	1 natural bog (UK) × 3 yrs; 1 fen × 2 yrs NEE	25/26	Yes
	Waddington et al. 2010	Restored bog 1-3 yrs post restoration (NEE)	25	Unlikely
	Adkinson et al. 2011	Not yet in file (JY)	ND	ND
	Augustin et al. pers comm in Couwenberg et al. 2011	Pers comm, data not retrieved within deadline	ND	ND
	Koehler et al. 2011	1 natural bog × 6 yrs NEE	25	Yes
	Christensen et al. 2012	1 natural bog × 8 yrs NEE	25	Possibly
	Urbanova et al. 2012	Laboratory study, not included	ND	ND
	Strack and Zuback 2013	1 natural and 1 restored bog site × 1 yr NEE	25	Unlikely
	Droesler 2005	13 microsites (restored, abandoned, degraded bog areas in same site) × 1 yrs NEE	25	Some possibly
	Herbst et al. 2013	1 site (fen) × 3 yrs NEE	26	Fen
	Wilson et al. 2013	3 rewetted microsites (fourth microsite is bare) in 1 bog × 3 yrs NEE	25	Yes
additional	Von Arnold et al. 2005	Additional site not used in IPCC	26	Possibly
29/30	*CH_4, rewetted soils, temperate, nutrient-poor/nutrient-rich (should be n=42/n=37)*			
	Augustin and Merbach 1998	Not retrieved within deadline	ND	ND
	Augustin et al. 2003	Not retrieved within deadline	ND	ND
	Augustin et al. 1996	Not retrieved within deadline	ND	ND

	Augustin et al, pers comm in Couwenberg et al. 2011	Data not yet added (have reference)	ND	ND
	Bortoluzzi et al. 2006	3 microsites in 1 restored area, 2 yrs data (NEE). Reported values are min-max; converted to mean by (min+max/2)	29	Possibly
	Cleary et al. 2005	Canadian wide estimates using reference values from other studies (no primary data) not included	ND	ND
	Crill in Bartlett	Not retrieved within deadline	ND	ND
	Dise and Gorham 1993	2 microsites in naturally forested bog	29	Unlikely
	Droesler 2005	13 microsites (restored, abandoned, degraded bog areas in same site) × 1 yrs	29	Some, possibly
	Droesler et al. 2013	2 sites (nutrient-rich?) × 5 yrs; 7 sites assumed nutrient-poor × 1-2 yrs (degraded heather moorland; rewetted heather moorland; rewetted sphagnum lawn, rewetted peat cutting; damp/dry heather moor; natural bog),	29/30	Some, possibly
	Flessa et al. 1997	Not retrieved within deadline	ND	ND
	Glatzel et al. 2011	Not retrieved within deadline	ND	ND
	Harriss et al. 1982	Not retrieved within deadline	ND	ND
	Hendriks et al. 2007	2 microsites, rewetted former fen peatland (now seminatural grassland) × 2 yrs	30	Fen
	Jungkunst and Fiedler 2007	Large review, not yet fully digested and checked for double-counting	ND	ND
	Koehler et al. 2011	1 natural bog × 6 yrs	29	Yes
	Nagata et al. 2005	Not in file (Japanese site)	ND	ND
	Nilsson et al. 2008	1 minerogenic site × 2 yrs	30	Unlikely
	Roulet et al. 2007	1 natural bog site, 6 yr average	29	Unlikely
	Scottish Executive 2007	No primary data, not included	ND	ND
	Shannon and White 1994	Not retrieved within deadline	ND	ND
	Sommer et al. 2003	Compound dataset including wetlands but also other sites	ND	ND
	Tauchnitz et al. 2008	1 site (slope mire) × 1 yr (Highly aerobic and thus net methane sink)	30	unlikely like Scottish counterparts
	Von Arnold 2004	Large thesis, not yet fully digested	ND	ND
	Waddington and Price 2000	Not yet available to us	ND	ND
	Wickland, 2001	1 natural fen × 3 years	30	Unlikely
	Wild et al. 2001	Not yet in file (unassigned, constructed wetlands though – not relevant)	ND	ND
	Wilson et al, 2009	3 microsites in 1 reflooded cutover fen × 2 yrs	30	Yes
	Wilson et al. 2013	3 rewetted microsites (fourth microsite is bare) in 1 bog x 3 yrs NEE	29	Yes

	Beetz et al. 2013	2 microsites, 1 natural bog, 1 rewetted area × 2 yrs	29	Possibly
additional	Christensen et al. 2012	Additional to IPCC	29	Possibly
additional	Von Arnold et al. 2005b	Additional to IPCC	30	Possibly
additional	Aurela et al. 2002	Additional to IPCC, summer fluxes only, 15% added	30	Possibly
additional	Herbst et al. 2013	Additional to IPCC	30	Possibly
additional	Drewer et al. 2011	Additional to IPCC	29	Possibly
additional	Waddington and Day, 2007	Additional to IPCC, summer fluxes only, 15% added	29	Possibly

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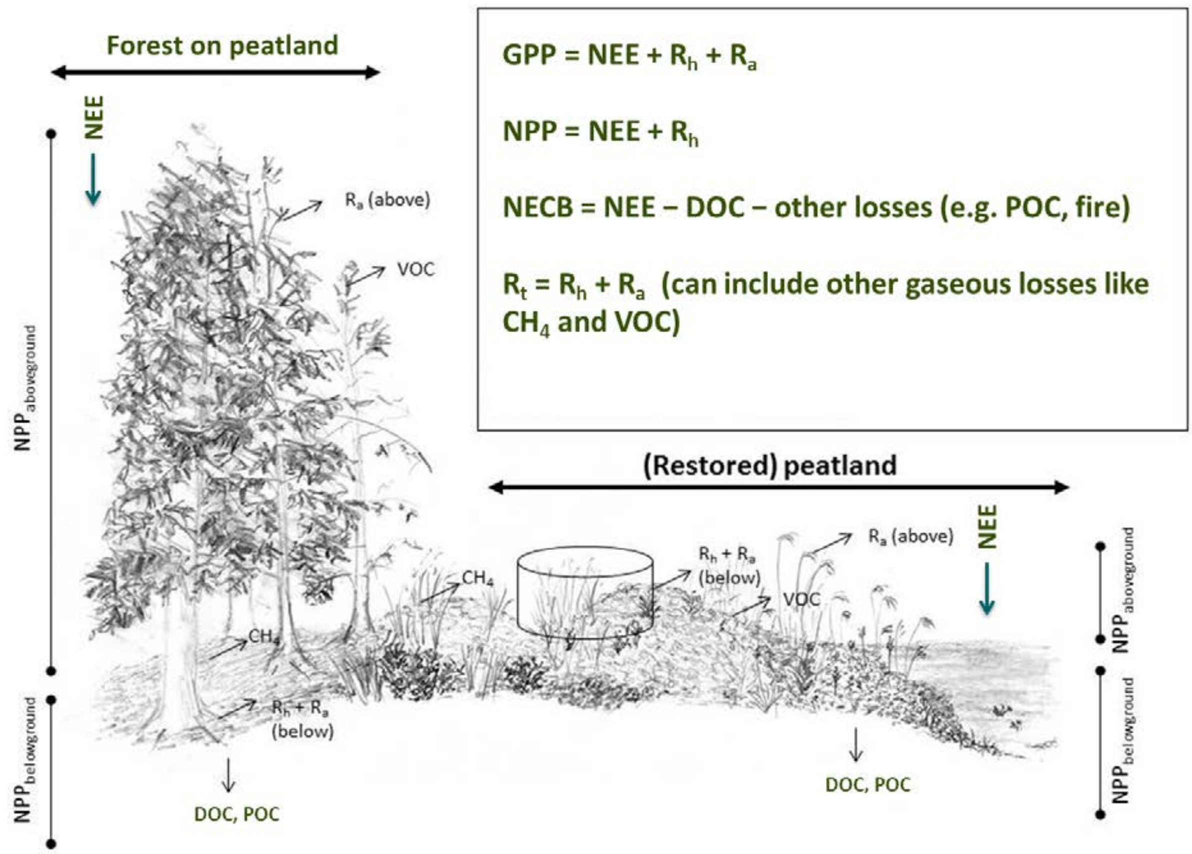

Figure 1 Carbon fluxes in forested or restored peatland

GPP – Gross Primary Production
NPP – Net Primary Production
NEE – Net Ecosystem Exchange
NECB – Net Ecosystem Carbon Balance
R_t – Total Respiration
R_h – Heterotrophic Respiration
R_a – Autotrophic Respiration
DOC – Dissolved Organic Carbon
POC – Particulate Organic Carbon
VOC – Volatile Organic Carbon

Note: Both NPP and R_a have aboveground (shoot) and belowground (root) components. It can be seen that transparent chambers capture NEE in the peatland but only Rh and belowground Ra where no understorey vegetation exists in the forest ecosystem.

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