



Department for
Business, Energy
& Industrial Strategy



Mapping Carbon Emissions & Removals for the Land Use, Land-Use Change & Forestry Sector

A report of the National Atmospheric
Emissions Inventory 2019

This document has been prepared by the UK Centre for Ecology & Hydrology
on behalf of the Department for Business, Energy & Industrial Strategy (BEIS)

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Land Use, Land-Use Change and Forestry in the National Inventory

The Department for Business, Energy and Industrial Strategy (BEIS) takes the lead in the UK in preparing the annual Inventory of Greenhouse Gas Emissions for the United Nations Framework Convention on Climate Change (UNFCCC). BEIS contract Ricardo Energy & Environment (REE) to compile the overall greenhouse gas emissions inventory and they in turn subcontract the UK Centre for Ecology and Hydrology (UKCEH) and Forest Research (FR) to prepare the data relating to Land Use, Land-Use Change and Forestry (LULUCF) in the UK.

This report is prepared in order to describe the method used to spatially disaggregate the emissions and removals in the LULUCF sector to enable the compilation of LULUCF estimates for Local Authorities as part of BEIS's assistance to Local Authorities in tracking progress on decarbonisation.

The LULUCF data reported to the annual inventory is prepared in accordance with the reporting requirements of the UNFCCC. In addition, the UK is required to provide reports to the UNFCCC on progress towards its Kyoto Protocol (KP) target following KP reporting requirements. These are substantially different in approach. The data provided in this report are taken from the UNFCCC reporting data set and are consistent with current UK Carbon Budgets approaches.

These estimates are made using dynamic models of changes in stored carbon, driven by land use change data. For forestry, the CARBINE model (developed and run by FR) deals with plant carbon, dead organic matter, soil carbon and harvested wood products and is driven by the area of land newly afforested each year, management practices and harvesting. Changes in soil carbon are driven by estimated time series of land use transitions between grassland, cropland, forest land and settlement land uses. These models, and those for other LULUCF activities, are run for each of the four countries of the UK. Until the 1990-2004 inventory (submitted in 2006) no data were reported in map format at a scale below the devolved administrations (England, Scotland, Wales and Northern Ireland); here we report results from methods to provide estimates of LULUCF emissions and removals at the scale of local authority (LA) within the UK for the 2019 inventory year (published in 2021).

The LULUCF Sector differs from other sectors in the Greenhouse Gas Inventory in that it contains both sources and sinks of greenhouse gases. The sources, or emissions *to the atmosphere*, are given as positive values; the sinks, or removals *from the atmosphere*, are given as negative values.

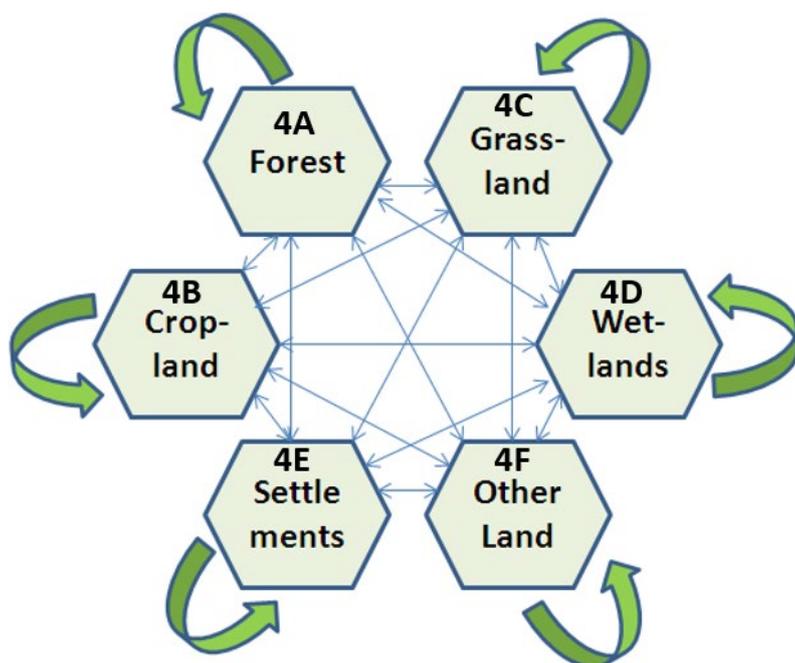
Categories

The IPCC Guidelines for National Greenhouse for National Greenhouse Gas Inventories (IPCC 2006, IPCC 2014) describes a uniform structure for reporting emissions and removals of greenhouse gases. This format for reporting can be seen as "land based"; all land in the country must be identified as having remained in one of six classes since a previous survey, or as having changed to a different (identified) class in that period. The six land classes are A: Forest Land, B: Cropland, C: Grassland, D: Wetlands, E: Settlements and F: Other land. There is a seventh category for the pool of harvested wood products, category G.

The IPCC (2006) guidelines for LULUCF accommodate differences in national land-use classification systems. Emissions from the drainage and rewetting of peatlands, included for the first time in the 1990-2019 LULUCF inventory (Brown et al. 2021), are reported under all LULUCF land use categories. These are compiled following guidance for estimating emissions from inland organic soils set out in chapters 2 and 3 of the 2013 IPCC Wetlands Supplement, and employing the Tier 2 methodological approach for implementation described in the BEIS-funded wetlands report (Evans et al. 2017), with additional updates summarised in section A.3.4 of the National Inventory Report Annexes (Brown et al. 2021). Emissions from drained and rewetted organic soils have been allocated to their local authorities in the UK using the peat condition mapping outputs from Evans et al. (2017). The majority of peatland area is reported in the Grassland category, which includes semi-natural bog categories, extensive and intensive grassland, and rewetted bog or fen from semi-natural bog and intensive and extensive grassland. Emissions from active peat extraction (onsite, and off-site for horticultural peat¹), as well as organic soils affected by historical peat extraction are reported under Wetlands. Naturally occurring emissions and removals from pristine areas of bog and fen, and rewetted bog or fen from Forest Land, Cropland, peat extraction, and pre-1990 rewetted fen are now included in LULUCF reporting under Wetlands. Emissions of CO₂ from drained organic soils under Forest, Cropland and Settlement are reported in those respective categories. The Other land category is predominantly made up of bare rock and scree and no emissions or removals are reported. In addition, it is assumed that there are very few, if any, transitions of land to a type that is classified as 'Other'.

The UK land-use change matrix can be simplified to that shown in Figure 1, including Forest Land (A), Cropland (B), Grassland (C), Wetlands (D), and Settlements (E). For each land use and land-use transition, the change in stocks of carbon in living biomass (above and below ground), dead biomass and soil organic matter should be reported. In Figure 1, each arrow represents the possible change for an area of land between two time points.

Figure 1: UK Sector 4 land-use transitions showing categories for carbon stock change. See text for details.



¹ While emissions from the combustion of peat used as fuel are reported in the energy sector of the country of consumption.

Different activities are associated with each land use or land-use change. For example, ‘afforestation’ refers to all land-use change to Forest Land, ‘drainage’ activity can relate to Forest Land, Cropland, Grassland, Wetlands, and Settlement. ‘Peat extraction’ affects Wetlands. The change in carbon stocks of living biomass, dead biomass and soil organic matter must be reported for each activity together with other relevant non-CO₂ gases (i.e. CH₄ and N₂O, not covered in this report).

Further subdivision of the classes by ecosystem, administrative region or time of occurrence of change is also encouraged in the IPCC Good Practice Guidance. For the UK, the data are currently subdivided into England, Scotland, Wales and Northern Ireland where possible. Subdivision into smaller units, such as 20 km × 20 km regions, is appropriate for modelling purposes and the development of estimates at local authority scale as described in this report.

Activities

The activities reported within LULUCF are listed in Table 1. The main category designations are listed with the activity description and the UK total emissions/removals (Gg CO₂) for 2019 as reported in the 1990-2019 Inventory (excluding emissions from the UK’s Overseas Territories and Crown Dependencies). Since 2020 the units in the LA report have been changed from Gg of carbon to Gg of carbon dioxide (CO₂) for consistency with the National Inventory Report. In this year’s LA report additional categories are included for reporting emissions and removals from Wetland Drainage and Rewetting of organic soils following implementation of the 2013 Wetlands Supplement (IPCC 2014) in the 1990-2019 inventory. The activities are sorted in order of magnitude and divided into four groups; afforestation, emissions from soils due to land-use change, emissions from organic soils due to drainage and rewetting and minor emissions. Full details are given in the National Inventory Report (Brown et al. 2021).

Table 1: The UK CO₂ emissions and removals in Sector 4 (Land Use, Land-Use change and Forestry) for 2019 sorted in order of magnitude.

Category	Activity	2019 UK total Gg CO ₂ emission (+) or removal (-)	Group
4A – Forest (soils and biomass)	Land converted to Forest land and land remaining Forest Land (not including emissions from wildfires)	-18,090.81	Forest Land
4C – Grassland (on mineral soil)	Land converted to Grassland and land remaining Grassland	-10,493.42	Emissions from soils due to land-use change on mineral soils
4B – Cropland (on mineral soil)	Land converted to Cropland and land remaining Cropland	9,786.04	Emissions from soils due to land-use change on mineral soils
4B– Cropland (drainage of organic soil)	Cropland remaining Cropland (drainage of organic soils)	5,698.20	Emissions from soils due to drainage, rewetting, and management of organic soils

Category	Activity	2019 UK total Gg CO ₂ emission (+) or removal (-)	Group
4E – Settlement (on mineral soil)	Land converted to Settlement and land remaining Settlement	4,962.94	Emissions from soils due to land-use change on mineral soils
4C – Grassland (drainage of organic soil)	Grassland remaining Grassland (drainage of organic soils)	4,820.03	Emissions from soils due to drainage, rewetting, and management of organic soils
4D – Wetlands (peat extraction)	Wetlands remaining Wetlands (peat extraction)	2,237.30	Emissions from soils due to drainage, rewetting, and management of organic soils
4G*	Harvested Wood Products	-2222.56	NA
4D – Wetlands (near-natural)	Wetlands remaining Wetlands (near-natural organic soil) – new category	-1,820.60	Emissions from soils due to drainage, rewetting, and management of organic soils
4C – Grassland (undrained organic soil)	Grassland (undrained organic soil) - new category	1,219.69	Emissions from soils due to drainage, rewetting, and management of organic soils
4D – Wetlands (deforestation to Wetlands)	Land converted to Wetlands (deforestation) - new category	875.85	Minor emissions
4A – Forest (drainage of organic soil)	Forest (drainage of organic soil) - new category	660.49	Forest Land
4C – Grassland (non forest biomass)	Non-Forest land converted to Grassland (change in non-forest living biomass)	519.32	Minor emissions
4E – Settlement (deforestation to settlement)	Forest Land converted to Settlement (deforestation to settlement – not including soil changes)	387.53	Minor emissions
4C – Grassland	Forest Land converted to Grassland (deforestation to grassland – not including soil changes)	335.11	Minor emissions

Category	Activity	2019 UK total Gg CO₂ emission (+) or removal (-)	Group
(deforestation to Grassland)			
4A – Forest (wildfires)	Forest Wildfires	293.87	Forest Land
4B – Cropland (non-forest biomass)	Non-Forest land converted to Cropland (change in non-forest living biomass)	-288.57	Minor emissions
4D – Wetlands (rewetted organic soil)	Wetlands (rewetted organic soil) - new category	115.53	Emissions from soils due to drainage, rewetting, and management of organic soils
4C – Grassland (rewetted organic soil)	Grassland (rewetted organic soil) - new category	-103.31	Minor emissions
4E – Settlement (non-forest biomass)	Non-Forest land converted to Settlements (change in non-forest living biomass)	67.75	Minor emissions
4B – Cropland (cropland management soils)	Cropland remaining Cropland (cropland soil management practices)	-57.92	Minor emissions
4C – Grassland (grassland management biomass)	Grassland remaining Grassland (grassland biomass management practices)	54.88	Minor emissions
4E – Settlement (drainage of organic soil)	Settlement (drainage of organic soil) - new category	12.88	Emissions from soils due to drainage, rewetting, and management of organic soils
4B – Cropland (cropland management biomass)	Cropland remaining Cropland (cropland biomass management practices)	4.40	Minor emissions
4B - Cropland (deforestation to Cropland)	Forest Land converted to Cropland (deforestation to crop – not including soil changes)	0.00	Minor emissions

Category	Activity	2019 UK total Gg CO ₂ emission (+) or removal (-)	Group
4D – Wetlands (Grassland to flooded land)	Land converted to Wetlands (grassland to flooded land) - new category, used to be with peat extraction	0.00	Minor emissions

* Sector 4G (Harvested Wood Products) is not included in the LA estimates because of insufficient data for distributing the emissions and removals.

Each of the activities are described below. Changes in net emissions from the LULUCF Sector over time are dominated by the decrease in CO₂ net emissions. While CH₄ emissions are fairly stable over time, they dominate LULUCF overall net emissions by gas in CO₂ equivalents from 2000 onwards (Brown et al. 2021). This is due to a major update to CH₄ and N₂O emissions from drained and rewetted organic soils resulting from the implementation of the Wetlands Supplement. Emissions and removals from all gases will be reported in the Local Authority dataset based on the 1990-2020 inventory. Emissions of other greenhouse gases are produced by undrained modified, rewetted and near natural peatlands (note that CH₄ emissions from near-natural bogs are cancelled out by CO₂ uptake in CO₂-equivalent terms), drainage ditches on peatlands, biomass burning during wildfires or the conversion of Forest Land to Cropland, Grassland or Settlements (CH₄ and N₂O). Direct and indirect emissions of N₂O are also produced from nitrogen fertilisation of new forests and soil mineralisation following land-use change. Estimates of N₂O and CH₄ emissions from these sources are included in the 2019 inventory (196 Gg CH₄ or 4,897Gg CO₂e (Carbon dioxide equivalents) for methane and 6.96 Gg N₂O or 2,074 Gg CO₂e for nitrous oxide across the UK in 2019). Other emissions of these non-CO₂ gases from agricultural land (e.g. due to fertilisation) are reported in the Agriculture sector of the Greenhouse Gas Inventory. Only emissions and removals of CO₂ are included in this report.

Forest Land

Soil and Biomass

For the National Inventory, the carbon uptake by forests planted in the UK is calculated by a carbon accounting model, CARBINE, as gains and losses in pools of carbon in standing trees, litter and soil in conifer and broadleaf forests and in harvested wood products. Forests accumulate carbon (by removing CO₂ from the atmosphere) in their biomass and soils as they grow, but timber harvesting, planting activities and drainage disturb this accumulation and result in loss of carbon via emissions of carbon dioxide, and other greenhouse gases to the atmosphere. The net carbon stock change at any one time depends on the balance between these different activities. Forestry management cycles operate over long time scales (40+ years) so the rate of carbon dioxide removal *now* is driven by the rate of forest planting in previous decades. Three parameters are required for the model; a) areas of new forest planted in each year in the past, b) areas deforested each year and c) management/harvesting pattern.

The national estimates use the combined area of new private and state planting from 1920 to 2019 and estimated planting areas for pre-1920 for England, Scotland, Wales and Northern Ireland sub-divided into conifers and broadleaves. For mapping at LA scale, the results from the CARBINE model for England, Scotland, Wales and Northern Ireland were disaggregated to 20 km × 20 km grid squares across the UK using country level historic average estimates of planting data reformatted to this scale. The disaggregated data were then combined to provide estimates of forests on mineral soils per local authority. This is achieved by taking the 20 km grid square data and disaggregating further to every 1 km square in the UK. Up to 400 1 km grid squares make up one cell in the 20km resolution map, however in coastal regions where cells fall in the sea the flux is apportioned to the land-based 1km data points enclosed within the 20km cell. These smaller units can then be combined according to the LA boundaries based on the SW corner of each cell (see Figure 2). For mapping of forests on organic soils, country level emissions were adjusted in proportion to the area of forest on organic soil in each LA. The results for forests on each soil type were summed to give total forest carbon stock change per LA.

Figure 2: Model output is generated for 852 20 × 20 km squares across the UK, which is further disaggregated to 245,655 1 × 1 km land-based squares (not shown). Data are combined to provide estimates for each local authority (data for illustration only).

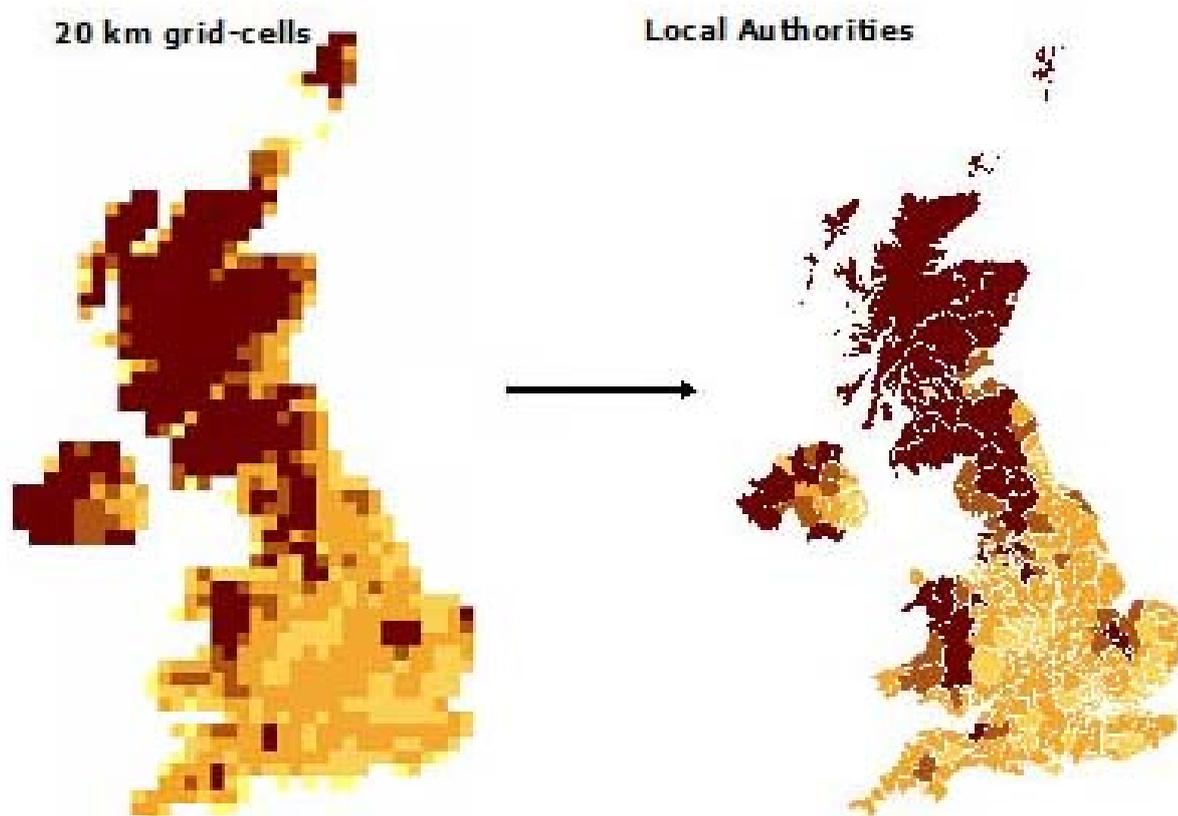
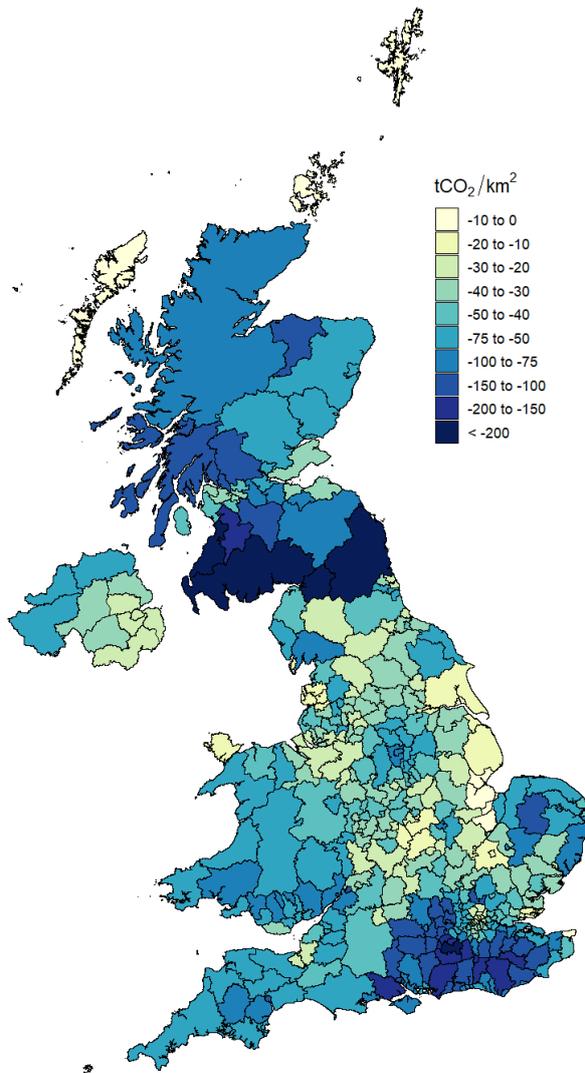


Figure 3 shows the distribution of carbon removals due to forest land per local authority area expressed as tonnes of carbon dioxide per square kilometre (tCO₂ per km²). Maps of total CO₂ emissions/removals per LA can be misleading due to the wide range of areas across authorities – maps tend to be dominated by the Highland region of Scotland. The distribution of forest carbon removals is directly linked to the location of forests (Forestry Commission, 2019),

for example close to half of the forest land in England is in the north, which is clearly visible from the large sink in that area.

Figure 3: Distribution of forest carbon dioxide removals from the atmosphere in 2019 per local authority area expressed as tCO₂ per km².

Sector 4A: (Forest Land, soil and biomass)

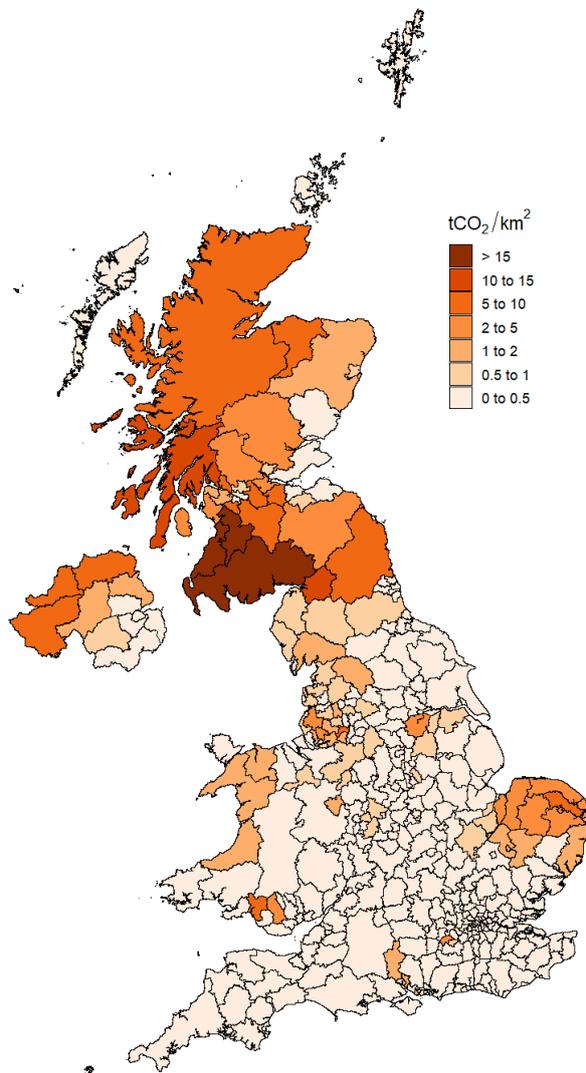


Indirect Drainage

Direct soil carbon stock change due to drainage of forest soils is included in the CARBINE modelling and hence in the data behind Figure 3. Emissions from indirect fluvial export (POC & DOC) as a result of forest drainage of organic soils are disaggregated to LA scale using the same method as for organic soil drainage of other land uses (see the Drainage section). The distribution of emissions from drained organic soils under Forest is focused in Scotland where peat extent and the location of forests are both high (Figure 4).

Figure 4: Indirect carbon dioxide emissions due to drainage of organic soils under Forests per local authority area (tCO₂/km²) in 2019.

Sector 4A (Forest, drainage of organic soils)

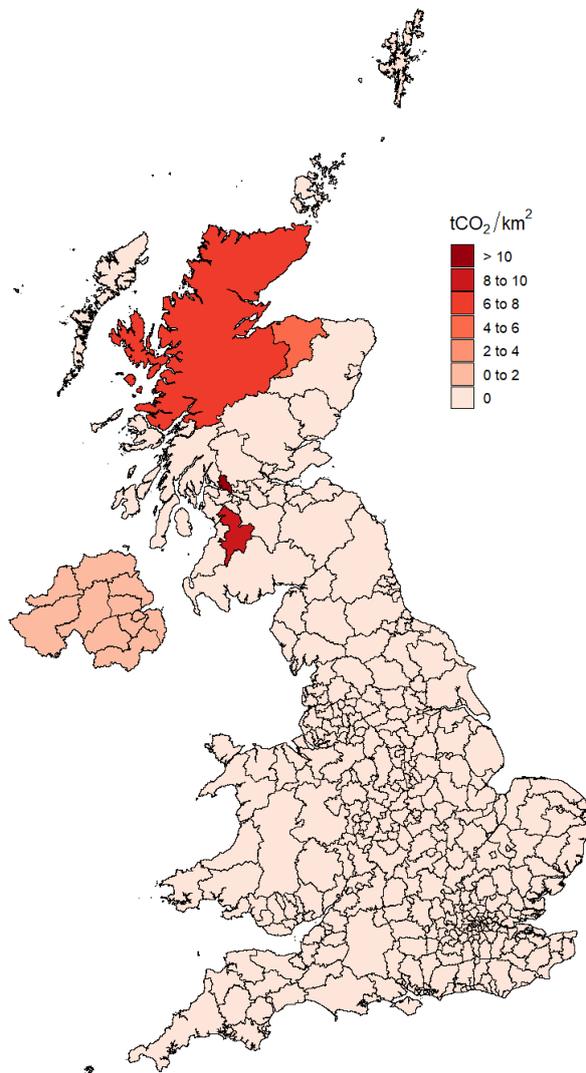


Forest Wildfires

Information on areas of wildfires on forest land in Great Britain and in Northern Ireland is available from the Fire Service Incident Response System (IRS). This dataset is available at individual grid referenced fire level for Great Britain and as a national total for Northern Ireland. Hence, in Great Britain fires can be assigned to the LA in which they occurred, and in Northern Ireland the emissions are assigned to LAs in proportion to the total area of forest land in each LA. Forest wildfires only occurred in Scotland and Northern Ireland in 2019 as shown in Figure 5.

Figure 5: Emissions of carbon dioxide due to forest wildfires per local authority area (tCO₂/km²) in 2019.

Sector 4A (Forest Land, Wildfires)



Emissions from mineral soils due to land-use change: cropland, grassland, settlements

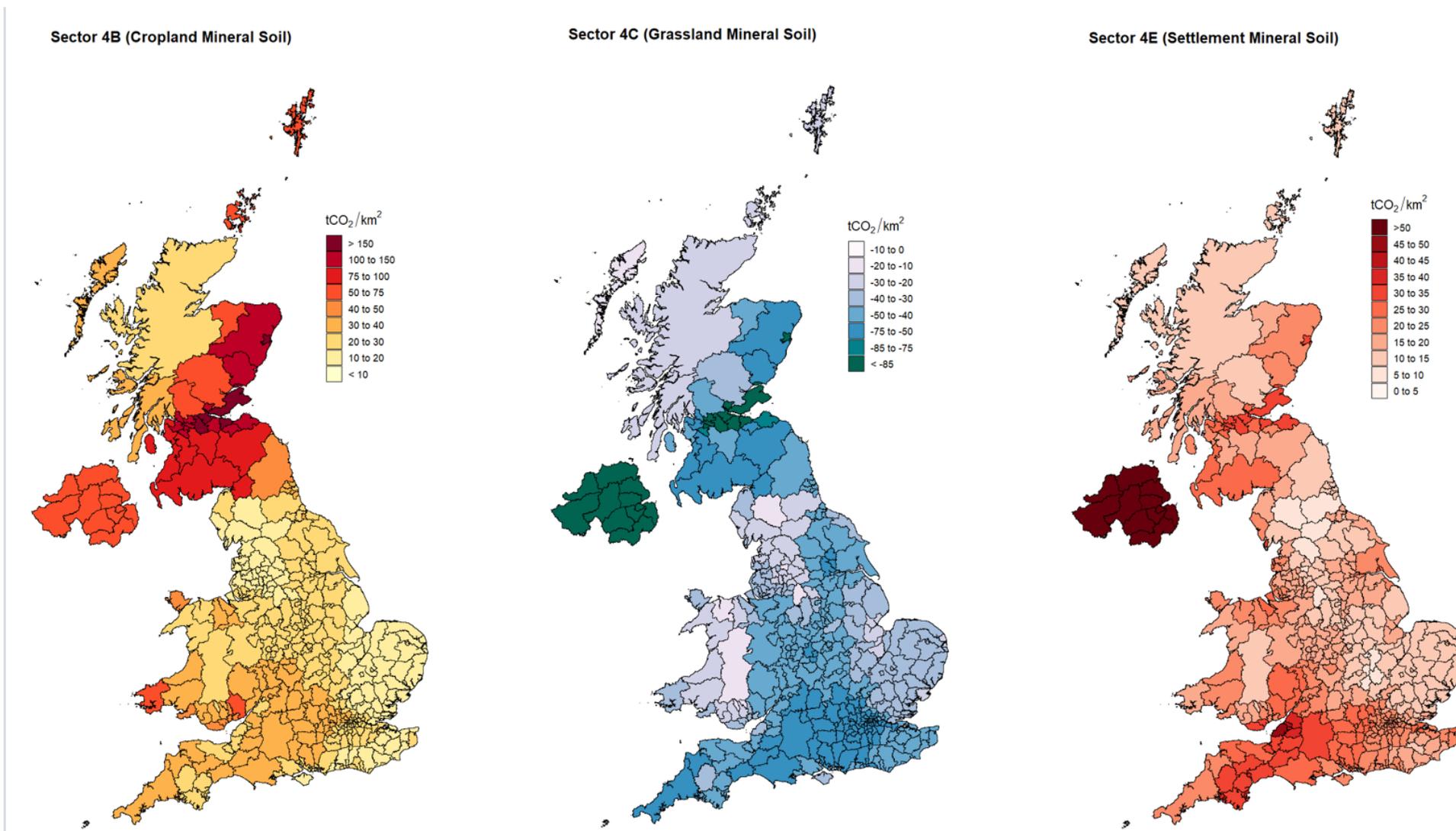
Changes from one land use type to another will result in a change in soil carbon stocks over time. The change in vegetation cover and management will affect the amount of carbon that goes into the soil from biomass decomposition. This is represented by emissions or removals which continue for decades after the change in land use until equilibrium carbon stocks characteristic of the new land use are reached. Also, any initial disturbance of the soil is represented by a release carbon from soils to the atmosphere as CO₂.

For the LULUCF inventory, the method for assessing changes in soil carbon stock due to land-use change on mineral soil links a matrix of area changes at country level coming mainly from land surveys to a dynamic model of carbon stock change. For Great Britain, matrices from the Monitoring Landscape Change data from 1947 & 1980 (MLC, 1986) and the Countryside Surveys (CS) of 1984, 1990, 1998 and 2007 are used. The rates assumed after 2007 are obtained by extrapolating rates of change observed pre-2007.

In Northern Ireland, for 1990 to 1998 and 1998 to 2007, a matrix for the whole of Northern Ireland was available from the Northern Ireland Countryside Survey (Cooper, McCann and Rogers 2009). The only data available pre-1990 for Northern Ireland are land-use areas from the Agricultural Census and the Forest Service (Cruickshank and Tomlinson 2000). Matrices of land-use change were then estimated for 1970-80 and 1980-90 using area data. The basis of the method devised assumed that the relationship between the matrix of land-use transitions for 1990-1998 and the area data for 1990 is the same as the relationship between the matrix and area data for each of two earlier periods – 1970-79 and 1980-89. The matrices developed by this approach were used to extrapolate areas of land-use transition back to 1950 to match the start year in the rest of the UK.

Time series of land-use change in 20 × 20 km grid-cells (to match those used for the afforestation fluxes) have been developed using the Countryside Surveys covering periods 1984 to 1990, 1990 to 1998 and 1998 to 2007 (Mobbs and Milne 2005). The land-use change matrices for the 20 × 20 km grid-cells are scaled to match those used in estimates of emissions and removals for the devolved administration areas in the United Kingdom. These matrices are then used for each grid-cell as input to the soil carbon model. The data are then combined to give estimates per local authority (see Figure 6). The pattern of emissions and removals across the UK for each land-use type is dependent on the ratio of land-use change in each LA in relation to the total for that devolved administration (England, Scotland, Wales and Northern Ireland). For example, the majority of land-use change to both Cropland and Grassland in Scotland occurs in the south and east of the country. For Northern Ireland there is no spatial information available so the values for each LA are the same.

Figure 6: Carbon dioxide emissions from mineral soil due to land-use change per local authority area (tCO₂/km²) in 2019. This covers the conversion of all land types to (a) Cropland (b) Grassland and (c) Settlements.



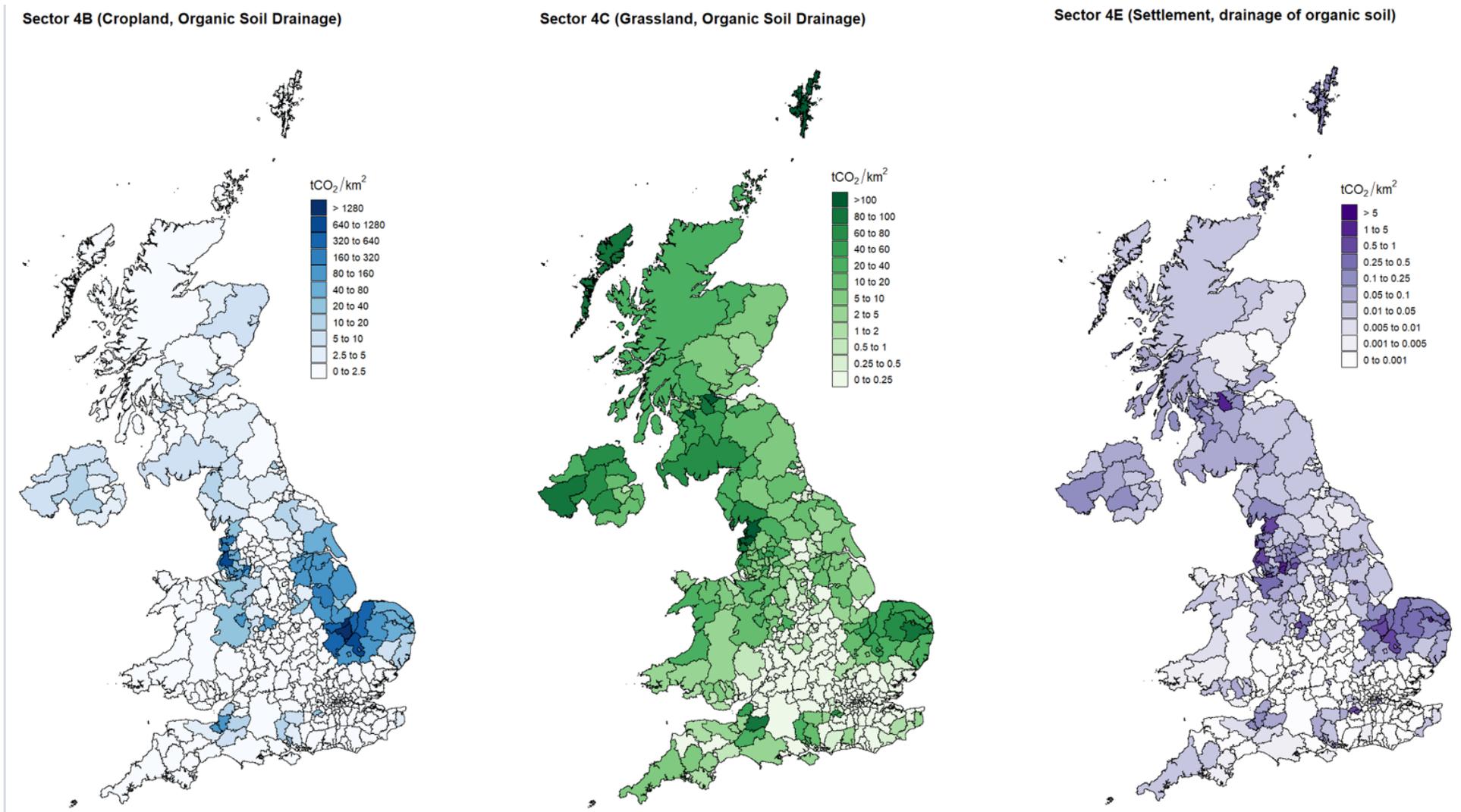
Emissions from soils due to drainage, rewetting and management of organic soils: forest, cropland, grassland, wetland, settlement

Drainage

The majority of peatlands in the UK were drained many decades ago for agricultural purposes and continue to lose carbon from the soil as CO₂. The method for estimating drained areas at both the UK and LA scale is to extract areas of peatland condition from unified maps of organic soil extent and maps of land use using the outputs from Evans et al. (2017) and applying a number of assumptions to semi-natural bog categories to derive final areas (detailed in Table 3.3 in Evans et al. 2017). Emissions resulting from drainage of organic soils in each country were then adjusted in proportion to the area of organic soil condition category in each LA.

Figure 7 shows the estimated distribution of emissions (tCO₂/km²). Emissions from drained organic soils under Cropland are largely concentrated in the East and North Midlands of England associated with wasted peat. Emissions from drained organic soils under Grassland are driven by different proportions of peatland condition categories reported together in the Grassland sector. Like Cropland, intensive and extensive grasslands have high GHG emissions per unit area, and LAs with emissions from these grasslands are distinguishable in dark green in Figure 7. Emissions from Settlement on organic soils mostly occur in lowland regions where population density is higher.

Figure 7: Carbon dioxide emissions due to drainage of organic soils under Cropland and Grassland (intensive, extensive, modified bog), and Settlement per local authority area (tCO₂/km²) in 2019.



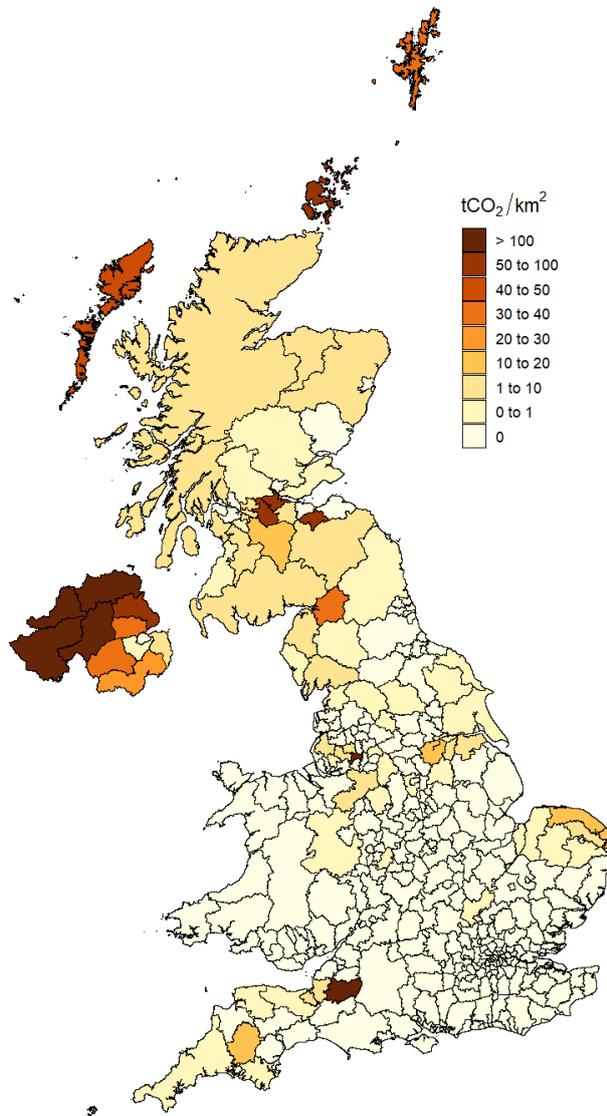
Peat Extraction

On- and off-site carbon emissions from peat extraction are calculated for the LULUCF inventory based on data published in the *Mineral Extraction in Great Britain Business Monitor PA1007* which gives data on volumes of peat sold, the BGS *Directory of Mines and Quarries (DMQ)* and BritPits database, and peat condition mapping outputs from Evans et al. (2017) which gives the location of peat extraction sites, and the UKCEH Google Earth dataset which provides information on the area and activity of peat extraction sites. The publication of the peat volumes sold has been discontinued from 2014, so for 2015 onwards the 2005-2014 average value is used. The DMQ and BritPits data give the location of origin of active peat extraction, and mapping outputs from the BEIS-funded Wetlands Supplement project (Evans et al. 2017) also provide areas of historical domestic and industrial extraction, we have assumed that the carbon emission applies to this combined area (see Figure 8).

In LAs with peat extraction, the total emissions resulting from peat extraction in each country were adjusted in proportion to the area of peat extraction per LA so that the total equals the submitted national emission. Local authorities with no peatland extraction activities have zero emissions from peat extraction. Emissions from peat extraction are reported in category 4D (Wetlands).

Figure 8: Carbon dioxide emissions from active and historical extraction of peat for horticultural and domestic use per local authority area (tCO₂/km²) in 2019. This is part of the Wetlands category.

Sector 4D1 (Wetland, Peat Extraction)



Rewetting

Rewetted peatlands are reported under Grassland and Wetland categories (see LULUCF category description in the Categories section). Rewetting has largely occurred from 2000 onwards, and is increasing in practice as regions attempt to restore natural functioning of peatlands and long-term sinks for carbon. For disaggregation of the country level rewetted areas database collated in Evans et al. (2017), point data associated with the rewetted areas were superimposed on the LA maps. Where GPS locations were not available, geographical information was obtained using project names and notes to assign each project area to its LA. Evans et al. (2017) reported spatial datasets of peatland restoration from 2000 to 2013, thus an average rate of restoration was applied to the respective LA between 2000 to 2013 (See Section A3.4.6.1 in Brown et al. 2021). Due to limited temporal and spatial data on restoration, this annual rate has been extrapolated to the latest inventory year for England, Wales, and

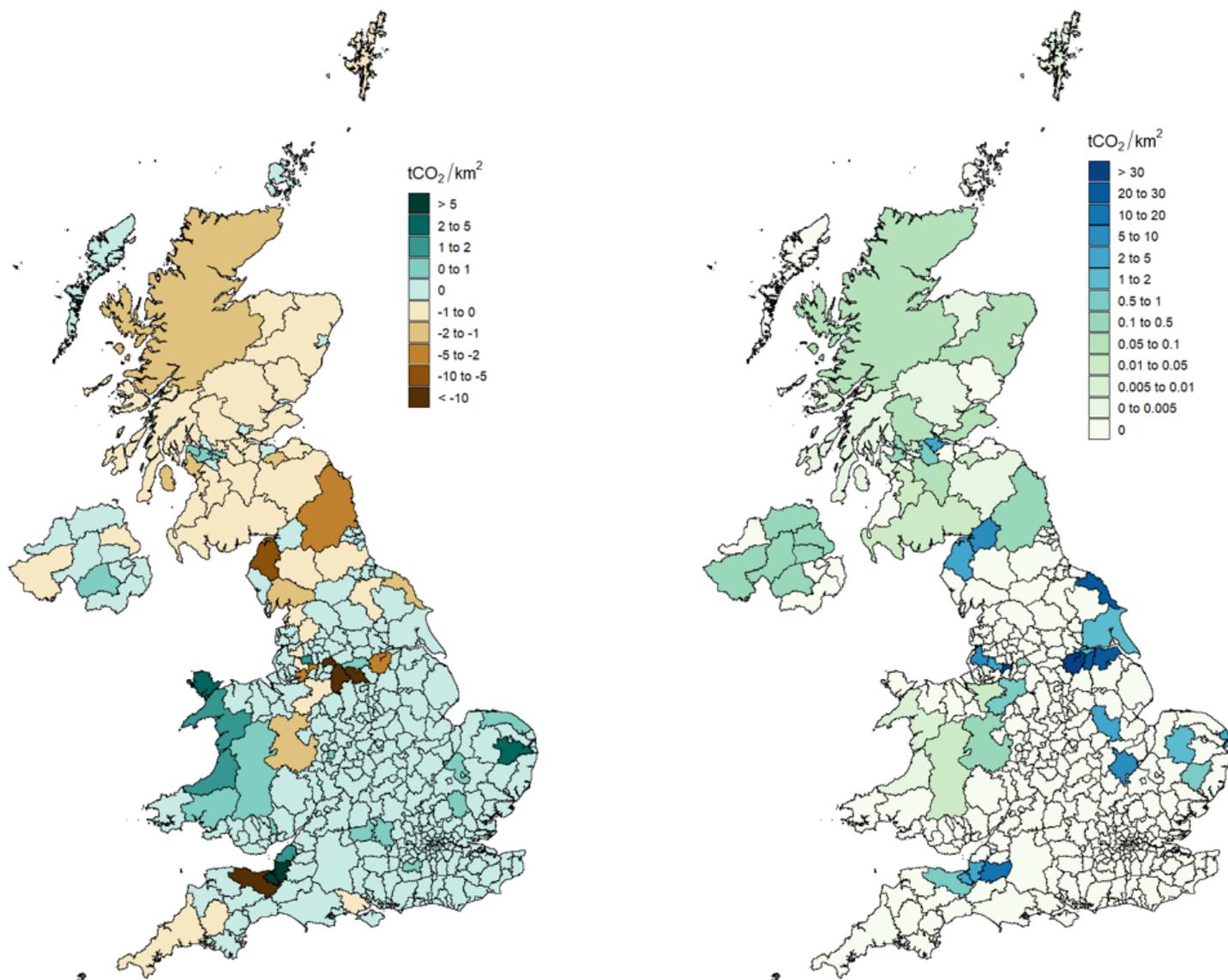
Northern Ireland in the LAs where restoration activities were reported pre 2013. Reporting of peatland rewetting areas in the inventory will be updated as spatial and temporal data from recent restorations are made available. For Scotland, GPS locations were provided for sites by Peatland Action, NatureScot, with annual data from 2000 to 2019 that allowed rewetting activities to be allocated to the LA in the year that they occurred. Rewetting of peat extraction sites was provided by the UKCEH Google Earth dataset and site-specific enquiries to land managers, and is reported under Wetlands along with Forest and Cropland to bog/fen restoration. Where spatial data were not available prior to 2000 for rewetted peatlands remaining rewetted peatlands, these areas were applied proportionally to LAs with historical peat extraction. LAs with lands that have undergone peatland restoration (rewetting) are shown in Figure 9 as those exhibiting either a sink or source of CO₂ emissions. Separate emissions factors are applied to rewetted peatlands depending on the starting condition of the restored lands (see Section A3.4.6.3 of the NIR, Brown et al. 2021), with rewetted semi-natural habitats reported under Grassland having the lowest emission factors.

Avoided soil emissions due to the conversion of drained organic soils to rewetted peatlands were accounted for by deducting the area of drained land from the relevant land use category in the LA and year in which the restoration activities occurred. These savings are incorporated into the emissions presented in Figures 7 and 8 above.

Figure 9: Carbon dioxide emissions and removals from rewetted organic soils per local authority area (tCO₂/km²) in 2019. This is part of the Grassland and Wetlands categories.

Sector 4C (Grassland, rewetted organic soil)

Sector 4D (Wetlands, rewetted organic soil)



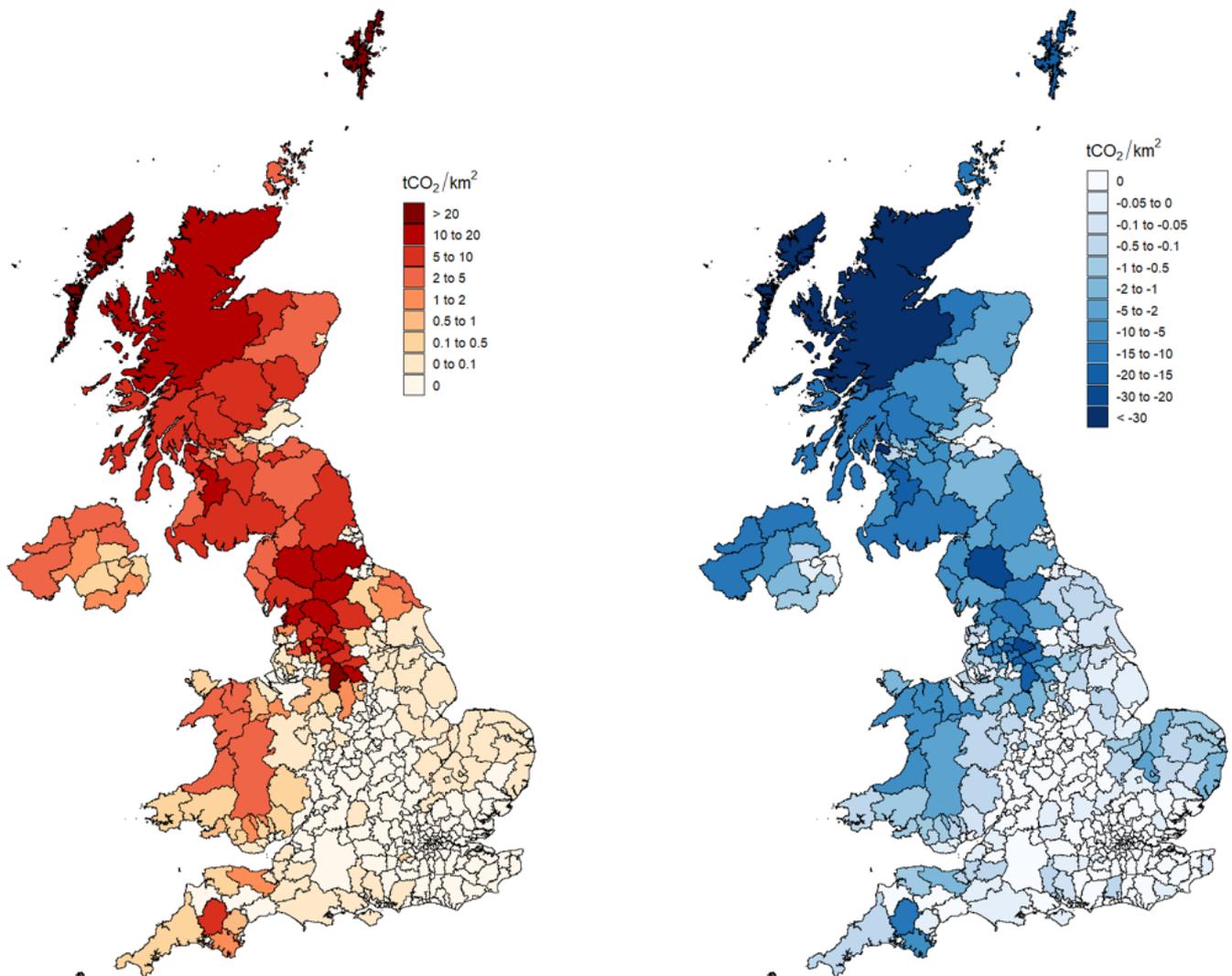
Emissions from undrained organic soils: grassland, wetland

Large areas of UK peatlands are undrained, predominantly semi-natural heather- and grass-dominated bog that are modified by grazing and burning-management practices, reported under Grassland, and near-natural bog or fen which have suitable conditions for C sequestration and are reported under Wetlands (Figure 10). The emissions and removals from undrained peatlands were disaggregated to the LA level using the same methodology as for emissions from soils due to drainage (see the Drainage section). The emissions and removals from these peatland habitats are distributed similarly across the UK, with patterns of highest emissions (for Grasslands) and removals (for Wetlands) in the Highlands and Islands of Scotland, the Pennines in Northern England, North West and Mid Wales, and North and West Northern Ireland (Figure 10).

Figure 10: Carbon dioxide emissions and removals from undrained semi-natural and near natural peatlands per local authority area (tCO₂/km²) in 2019, which are part of the Grassland and Wetlands categories, respectively.

Sector 4C (Grassland, undrained organic soil)

Sector 4D (Wetlands, near-natural organic soil)



Estimates of various minor emissions

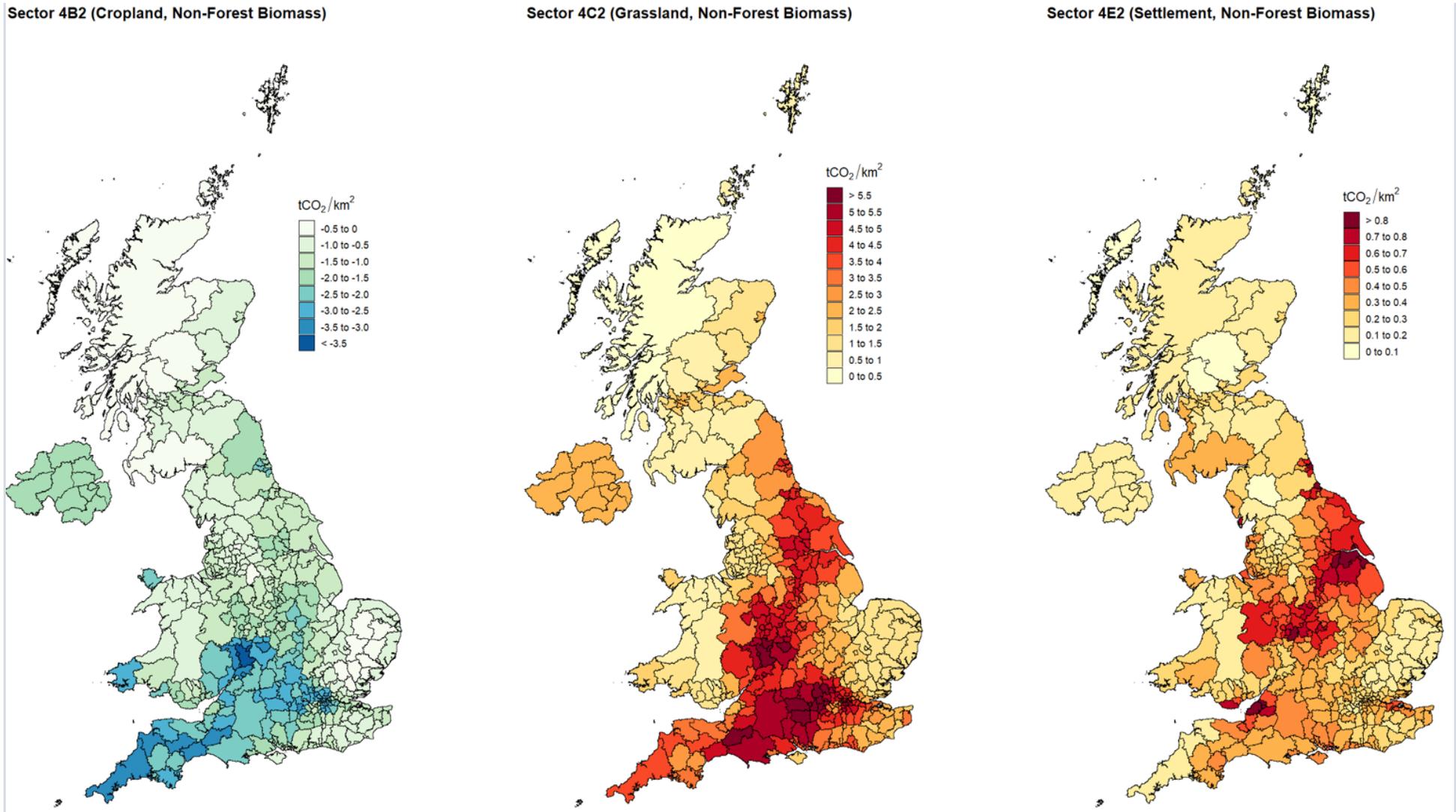
Non-Forest Biomass

The different land-use types have different biomass carbon densities per area at equilibrium. Change from one land use type to another can result in an increase or decrease in biomass carbon density per area. This category describes the annual change in the carbon stock in vegetation biomass due to all land-use change to Grassland, Cropland or Settlements, excluding forests and woodland.

For the LULUCF inventory, estimates of emissions and removals for this category are made using the Countryside Survey Land-Use Change matrix approach. Changes in carbon stocks in

biomass due to land-use change are based on the same area matrices used for estimating changes in carbon stocks in soils. The biomass carbon density per area for Wetlands and Settlement were assigned by expert judgement based on the work of Milne and Brown (1997). Average biomass densities per area for Cropland and Grassland used in the non-forest biomass LUC model are the same as those used in the cropland and grassland management calculations, based on a UK-relevant literature review in Moxley et al. (2014). Five basic land uses were assigned initial biomass carbon densities per area, then the relative occurrence of these land uses in the four countries of the UK were used to calculate mean biomass carbon densities per area for each of the IPCC types, Cropland, Grassland and Settlements. The mean biomass carbon densities per area for each land type were then weighted by the relative proportions of change occurring between land types in the same way as the calculations for changes in soil carbon densities per area. Changes between these equilibrium biomass carbon densities per area were assumed to happen in a single year. This matrix approach was extended and applied to each 20 km × 20 km grid square across the UK, and the results combined to give estimates for each local authority (see Figure 11).

Figure 11: Changes in living biomass following land-use change from Grassland and Settlements to Cropland (4B2), from Cropland, Settlements and Wetlands to Grassland (4C2) and Cropland, Grassland and Wetlands to Settlements (4E2) in 2019, expressed as emissions or removals per local authority area (tCO₂/km²).



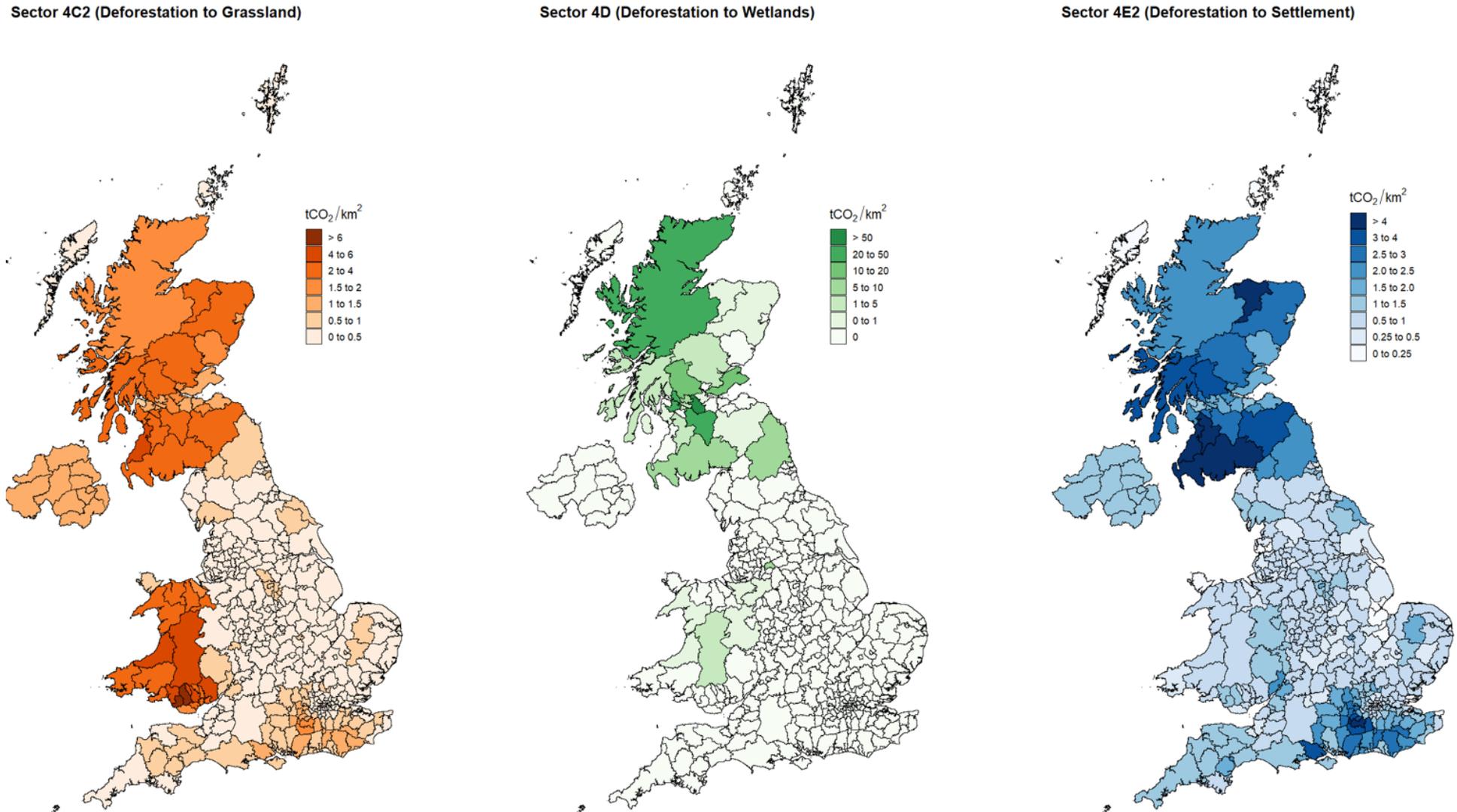
Deforestation

Emissions due to deforestation are disaggregated into deforestation to Cropland (reported in 4B, and only occurring in England and Scotland up to 2006 and 2005 respectively), Grassland (4C), Wetlands 4D, and Settlements (4E). This includes emissions from loss of living biomass and decay of dead organic matter, but excludes emissions from soils as these are presented separately, see the Emissions from mineral soils due to land-use change and Emissions from soils due to drainage, rewetting and management of organic soils sections.

The area of land deforested on mineral soils in each Local Authority is not currently available so we assume that the area deforested is proportional to the total area of forest in each LA. We also assume that the relative conversion of forest to either Cropland, Grassland or Settlement is the same for each LA (see Figure 12, this does not show Deforestation to Cropland as this was zero in 2019).

Deforestation on organic soil areas are known through rewetting projects and the methodology for splitting deforestation to Wetlands is the same as described in the Rewetting section.

Figure 12: Emissions of carbon dioxide from deforestation to Grassland, Wetlands, or Settlements per local authority area (tCO₂/km²) in 2019.

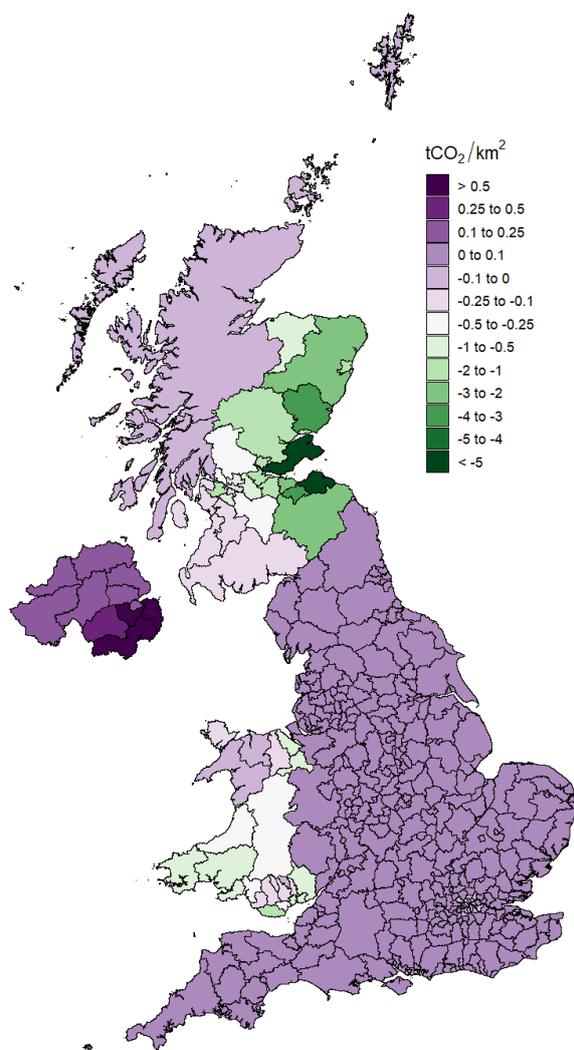


Cropland Management Soil

Cropland management activities including inputs of fertiliser, manure and crop residues have an impact on soil carbon stocks. Data on the areas under the main crop types are obtained from the annual June Agricultural Censuses carried out by each UK administration (Defra, 2020a; Welsh Government, 2019; Scottish Government, 2019; DAERA, 2020). Data on the areas of Cropland receiving inputs of manure, fertiliser and crop residues are obtained from the annual British Survey of Fertiliser Practice (Defra, 2020b and previous editions). The emissions were disaggregated to the LA level using the same methodology as for Cropland mineral soil emissions due to land use change (see the Emissions from mineral soils due to land-use change section). The resulting assignment by LA is shown in Figure 13.

Figure 13: Emissions / removals of carbon dioxide from Cropland Management soil activities per local authority area (tCO₂/km²) in 2019.

Sector 4B (Cropland Management Soils)



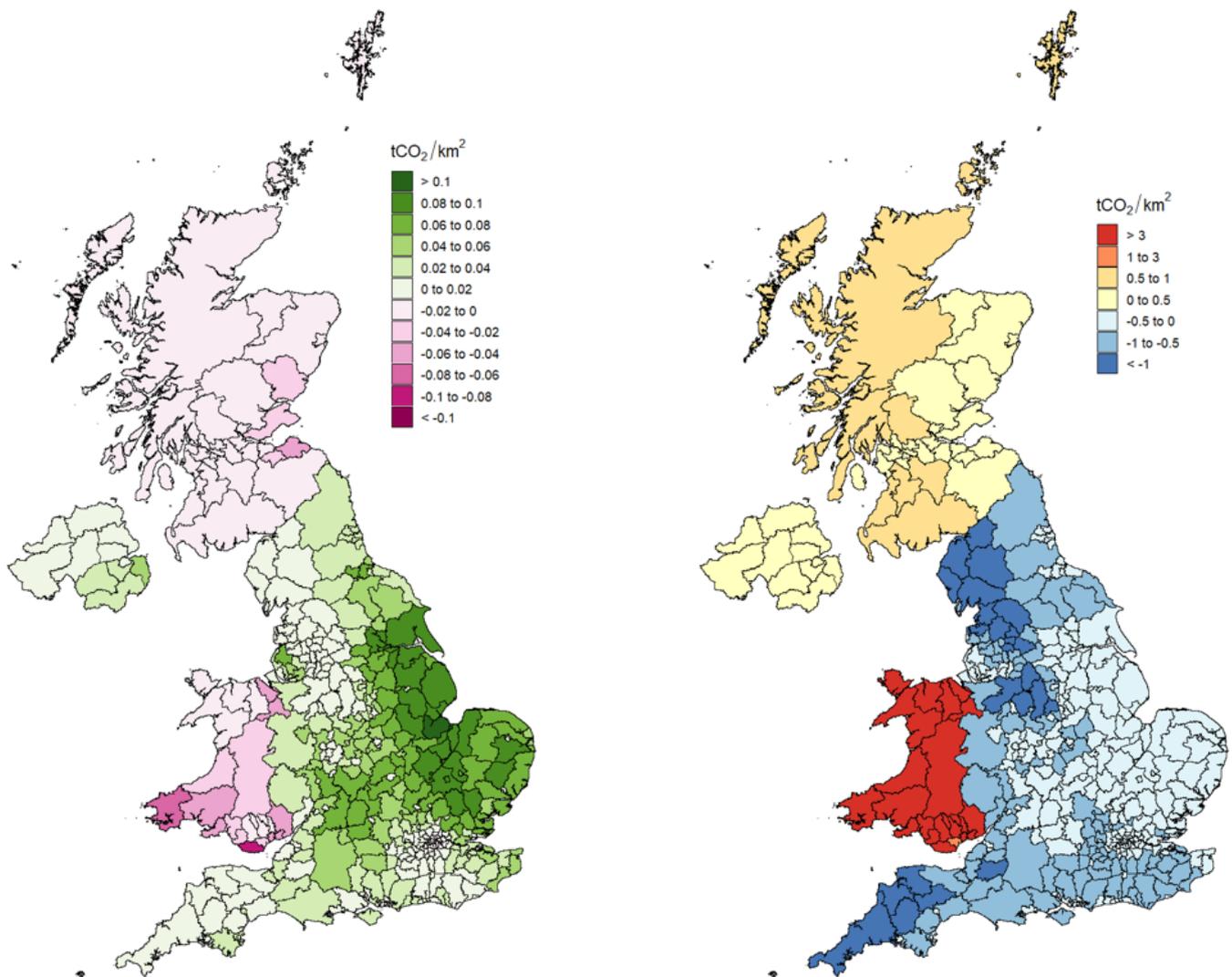
Cropland and Grassland Management Biomass

Changes in biomass carbon stocks arising from Cropland and Grassland management activities are reported in the inventory. These include change between annual crops, orchards, short rotation coppice, set aside and fallow for Cropland and change between shrubby and non-shrubby grassland types and hedge creation and removal for Grassland. Data on the areas under the main crop types are obtained from the annual June Agricultural Censuses carried out by each UK administration (Defra, 2020a; Welsh Government, 2019; Scottish Government, 2019; DAERA, 2020). Data on areas of grassland types are derived from the Countryside Surveys of 1990, 1998 and 2007. Information on emission factors were derived from a literature review described in Moxley et al. (2014). The emissions and removals were disaggregated to the LA level using the same methodology as for Cropland and Grassland non-forest biomass emissions. The resulting assignment by LA is shown in Figure 14.

Figure 14: Emissions / removals of carbon dioxide from Cropland and Grassland Management biomass activities per local authority area (tCO₂/km²) in 2019.

Sector 4B (Cropland Management Biomass)

Sector 4C (Grassland Management Biomass)

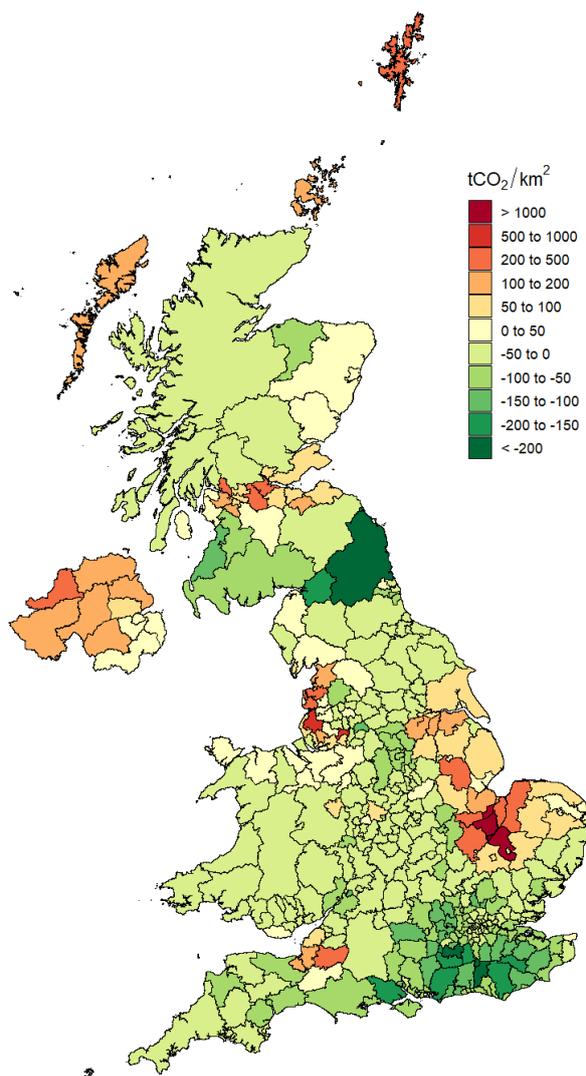


LULUCF Totals

The total emissions of carbon dioxide for the UK land use, land-use change and forestry sector (excluding harvested wood products which cannot be mapped) are shown in Figure 15.

Figure 15: Emissions or removals of carbon dioxide from land use, land-use change and forestry per local authority area (tCO₂/km²) in 2019.

Sector 4: Total LULUCF



Uncertainties

The uncertainties in calculating the LULUCF inventory are described in an annex of the National Inventory Report (see Table A 3.4.33 in Brown et al. 2021) and range from 12-80% for CO₂ in 2019 depending on the LULUCF sector activity. Additional uncertainty is associated with disaggregating the dataset to LA scale. A full uncertainty analysis of this procedure has not been carried out, however, it is estimated that the uncertainty in the disaggregation process

is in the range of 20-30 % on decadal timescales, though probably higher for annual estimates. There is low uncertainty in the LA mapping of carbon emissions associated with wildfire occurrence and emissions from organic soils due to fine-scale spatial input data. Moderate uncertainty in the disaggregation process is attributed to emissions from soils due the land-use change, soils due to drainage, and the minor categories where similar input scales and methodology were employed. There is higher uncertainty in the LA mapping of deforestation due to a lack of deforestation data below DA level; hence, a proxy using forested area and total deforestation is applied. Similarly, the yearly evolution of the forest sink at LA level is assumed to follow the country level estimates relatively closely, but without explicit representation of forest management operations (including clear-fell operations) this introduces high uncertainty associated with the forest sink reported at LA scale for specific years.

Table 2: Summary of source data and estimated uncertainty associated with the disaggregation of emissions to the local authority level.

Category	Source data used for disaggregation	Uncertainty
Forest Land	UK forestry and planting data from the National Inventory of Woodland and Trees	Moderate for decadal average, high for annual average
Emissions from soils due to land-use change - Cropland, Grassland, Settlements	Extrapolation from Countryside Surveys	Moderate
Emissions from soils due to drainage and rewetting of organic soils – Forest, Cropland, Grassland, Wetland, Settlement	BEIS organic soil condition maps of the UK	Low
Peat Extraction	BGS BritPits database co-ordinates, and BEIS organic soil condition maps of the UK	Low
<i>Minor estimates:</i>		
Non-Forest Biomass	Countryside Surveys	Moderate
Deforestation	As for Forest Land	High
Wildfires	Fire and rescue service Incident Recording System	Low
Cropland Management Soil	Countryside Surveys	Moderate
Cropland and Grassland Management Biomass	Countryside Surveys	Moderate

Recalculations

The National Inventory is often updated to include improved, or new, datasets and modelling techniques. In the 2019 inventory there were major changes and improvements associated with implementation of the 2013 IPCC Wetlands Supplement (Table 3). More detailed descriptions of the changes can be found in the UK National Inventory Report and annexes (Brown et al. 2021).

Table 3: Details of all changes between the 2018 and 2019 LULUCF inventories.

Description of Change	Reason for Change	Categories Affected	1990-2018 Inventory	1990-2019 Inventory	1990-2019 Inventory
			2018 UK Value (GgCO ₂)	2018 UK Value (GgCO ₂)	2019 UK Value (GgCO ₂)
<p>Revisions were made to the Forest Research CARBINE model inputs due to major changes to forest planting on organic soils (approx. doubling of organic soil area under forest) based on mapping outputs from the BEIS-funded WS project (Evans et al. 2017).</p> <p>Additional emissions are reported for fluvial export of CO₂ from particulate organic matter (POC) and dissolved organic matter (DOC) in drainage ditches on organic soils.</p> <p>Updated statistics on forest planting were also included as routine inventory improvement.</p>	<p>Implementation of emissions from wetland drainage and rewetting using the 2013 IPCC Supplement to the 2006 IPCC guidelines.</p> <p>Inclusion of planting data from the Forestry Statistics 2020 publication.</p>	4A Forest (soils and biomass)	-18,360.22	-17,623.95	-17,430.32

Description of Change	Reason for Change	Categories Affected	1990-2018 Inventory 2018 UK Value (GgCO ₂)	1990-2019 Inventory 2018 UK Value (GgCO ₂)	1990-2019 Inventory 2019 UK Value (GgCO ₂)
Updated use of the Fire Service Incident Response Data to calendar years instead of financial years	Change made for consistency with other categories and accuracy of wildfire emissions reporting.	4A Forest (wildfires)	29.65	221.56	293.87
<p>Major update to the area of cropland on organic soils (increase of ca. 2-fold), based on mapping outputs from the BEIS-funded WS project.</p> <p>New tier 2 direct CO₂ EFs for Cropland on drained organic soils. New tier 1 and 2 EFs for indirect (fluvial export in drainage ditches) POC and DOC from organic soils.</p> <p>Adjustments to the agricultural census data for areas of different crops. Small changes in the areas can cause significant changes in the Cropland management biomass estimates if they shift the</p>	<p>Implementation of emissions from wetland drainage and rewetting using the 2013 IPCC Supplement to the 2006 IPCC guidelines.</p> <p>Updates to agricultural census data due to error correction and improvements.</p>	4B Cropland (on mineral soil), 4B Cropland (drainage of organic soil), 4B Cropland (cropland management soils), 4B Cropland (cropland management biomass)	11,046.93	15,177.56	15,142.15

Description of Change	Reason for Change	Categories Affected	1990-2018 Inventory 2018 UK Value (GgCO ₂)	1990-2019 Inventory 2018 UK Value (GgCO ₂)	1990-2019 Inventory 2019 UK Value (GgCO ₂)
proportion of crop types with different biomass densities.					
<p>Major update to the area of grasslands on organic soils (ca. 7.4-fold increase), based on mapping outputs from the BEIS-funded WS project. While areas of grassland on organic soils have increased in many LAs, the improved maps of organic soils result in some LAs now having no grassland on drained organic soil.</p> <p>New tier 2 EFs applied to sub-categories of grassland condition (intensive and non-intensive) on organic soils. Changes in this category includes drainage of wetland soils for conversion to grassland, and rewetting of grassland due to restoration activities. Wetlands converted to Grassland no longer reported as restored peat extraction sites are now reported under Wetlands.</p>	Implementation of emissions from wetland drainage and rewetting using the 2013 IPCC Supplement to the 2006 IPCC guidelines.	4C Grassland (on mineral soil), 4C Grassland (drainage of organic soil), 4C Grassland (undrained organic soil), 4C Grassland (rewetted organic soil), 4C Grassland (deforestation to Grassland)	-8,976.33	-3,440.41	-3,647.70

Description of Change	Reason for Change	Categories Affected	1990-2018 Inventory 2018 UK Value (GgCO ₂)	1990-2019 Inventory 2018 UK Value (GgCO ₂)	1990-2019 Inventory 2019 UK Value (GgCO ₂)
Estimates of deforestation on organic soils have been updated with the information from the WS reporting.					
<p>Information on peat extraction sites was revisited when compiling this inventory and revisions were made for Wales (only one site in Wales (Wrexham) which is now a nature reserve) and Northern Ireland (identification of additional extraction sites over the time series). The majority of the change is due to the additional sites identified in Northern Ireland.</p> <p>Major changes have occurred to the wetlands areas (ca. 261-fold increase), which includes increased areas for peat extraction, which now accounts for significant areas of inactive domestic (fuel) extraction in Scotland and Northern Ireland LAs, rewetted fen, and near natural peatlands, based on mapping outputs from the BEIS-funded Wetlands Supplement</p>	<p>Major changes: Implementation of emissions from wetland drainage and rewetting using the 2013 IPCC Supplement to the 2006 IPCC guidelines.</p> <p>Minor changes: Continuous inventory improvement due to additional activity data availability. Updating the biomass value improves consistency within LULUCF as this value is already used for and use change and management calculations.</p>	4D Wetlands (peat extraction), 4D Wetlands (near-natural), 4D Wetlands (deforestation to Wetlands), 4D Wetlands (rewetted organic soil)	334.99	1,051.38	1,408.08

Description of Change	Reason for Change	Categories Affected	1990-2018 Inventory 2018 UK Value (GgCO ₂)	1990-2019 Inventory 2018 UK Value (GgCO ₂)	1990-2019 Inventory 2019 UK Value (GgCO ₂)
<p>project. New tier 1 and 2 EFs for these categories.</p> <p>Estimates of deforestation on organic soils have been updated with the information from the WS reporting which results in Forest to Wetlands areas and emissions being reported for the first time.</p> <p>Minor changes: Conversion of grassland to flooded land (reservoir creation) is reported at T1 which means that only the carbon stock change from loss of biomass is reported. The biomass carbon stock value was updated this year to use the UK specific value for shrubby grassland instead of the IPCC default value. At the same time an error with area unit conversions in the model was corrected.</p>					
<p>Addition of settlement areas on organic soils based on mapping outputs and new Tier 2 EFs from</p>	<p>Implementation of emissions from wetland drainage and</p>	<p>4E Settlement (on mineral soil), 4E Settlement</p>	<p>6,554.86</p>	<p>5,426.05</p>	<p>5,431.10</p>

Description of Change	Reason for Change	Categories Affected	1990-2018 Inventory 2018 UK Value (GgCO ₂)	1990-2019 Inventory 2018 UK Value (GgCO ₂)	1990-2019 Inventory 2019 UK Value (GgCO ₂)
<p>the BEIS-funded Wetlands Supplement project.</p> <p>Emissions from Settlements on organic soils were previously reported under mineral soils, hence the reduction in emissions when these are properly accounted for</p> <p>Estimates of deforestation on organic soils have been updated with the information from the WS reporting.</p>	<p>rewetting using the 2013 IPCC Supplement to the 2006 IPCC guidelines.</p>	<p>(deforestation to settlement), 4E Settlement (drainage of organic soil)</p>			

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