Department for Business, Energy & Industrial Strategy

Mapping greenhouse gas emissions & removals for the land use, land-use change & forestry sector

A report of the National Atmospheric Emissions Inventory 1990-2020

Prepared by the UK Centre for Ecology & Hydrology for the Department for Business, Energy & Industrial Strategy (BEIS)

June 2022

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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 (e.g. nitrogen fertilisation of forest soils, drainage and rewetting of organic soils), are run for each of the four countries of the UK to report emissions and removals of greenhouse gases (CO_2, CH_4 and N_2O). 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 2020 inventory year (published in 2022).

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.

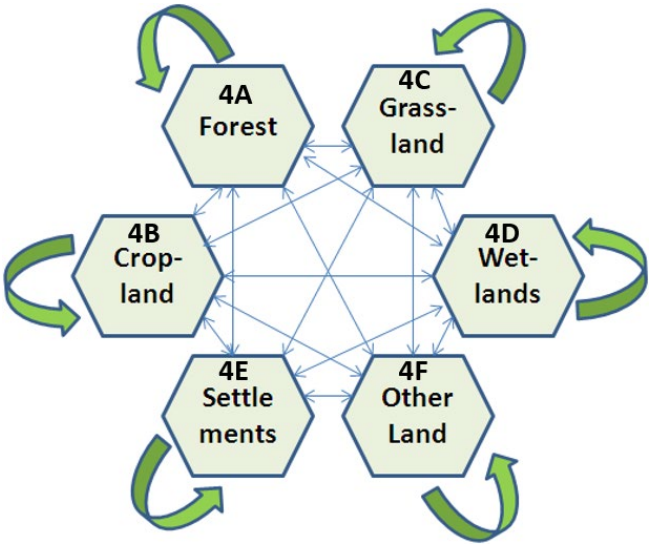
Categories

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 1990-2020 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 peat[1]), 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 included in LULUCF reporting under Wetlands. Emissions of CO_2, CH_4, and N_2O 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’.

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



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.

[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 along with other relevant non-CO_2 gases (i.e. CH_4 and N_2O) covered for the first time this year 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 CO_2e) for 2020 as reported in the 1990-2020 Inventory (excluding emissions from the UK's Overseas Territories and Crown Dependencies). This year additional gages, CH_4 and N_2O, have been added to the CO_2 emissions and removals reported in the LA report, given in units of Gg of carbon dioxide equivalent (CO_2e). 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. 2022).

Table 1: The UK CO_2e emissions and removals in Sector 4 (Land Use, Land-Use change and Forestry) for 2020 sorted in order of magnitude.

LULUCF Category	Parameter	Gases	Gg CO_2e	Group
4A	Forest (mineral soil and all biomass)	Carbon	-18,686.11	Forest Land
4B	Cropland (mineral soil)	Carbon	9,013.80	Emissions from soils due to land-use change on mineral soils
4C	Grassland (mineral soil)	Carbon	-8,635.39	Emissions from soils due to land-use change on mineral soils
4B	Cropland (drainage of organic soil)	Carbon, CH_4	5,945.86	Emissions from soils due to drainage, rewetting, and management of organic soils

LULUCF Category	Parameter	Gases	Gg CO_2e	Group
4C	Grassland (drainage of organic soil)	Carbon, CH_4, N_2O	5,820.30	Emissions from soils due to drainage, rewetting, and management of organic soils
4E	Settlement (mineral soil)	Carbon	3,275.31	Emissions from soils due to land-use change on mineral soils
4C	Grassland (undrained organic soil)	Carbon, CH_4, N_2O	2,415.67	Emissions from soils due to drainage, rewetting, and management of organic soils
4D	Wetlands (peat extraction)	Carbon, CH_4, N_2O	2,182.16	Emissions from soils due to drainage, rewetting, and management of organic soils
4G	Harvested Wood Products	Carbon	-2,128.72	NA
4A	Forest (drainage of organic soil)	Carbon, CH_4, N_2O	1,347.06	Emissions from soils due to drainage, rewetting, and management of organic soils
4E	Land converted to Settlement (deforestation to Settlement)	Carbon, CH_4, N_2O	605.89	Minor emissions
4C	Land converted to Grassland (deforestation to Grassland)	Carbon, CH_4, N_2O	531.16	Minor emissions
4B	Land converted to Cropland (soil mineralisation)	N_2O	396.71	Emissions from soils due to land-use change on mineral soils
4C	Land converted to Grassland (non-forest biomass)	Carbon	381.45	Minor emissions
4B	Land converted to Cropland (non-forest biomass)	Carbon	-283.10	Minor emissions

LULUCF Category	Parameter	Gases	Gg CO_2e	Group
4E	Land converted to Settlements (soil mineralisation)	N_2O	278.87	Emissions from soils due to land-use change on mineral soils
4D	Land converted to Wetland (deforestation to Wetland)	Carbon, CH_4, N_2O	264.87	Minor emissions
4D	Wetlands (rewetted organic soil)	Carbon, CH_4, N_2O	241.72	Emissions from soils due to drainage, rewetting, and management of organic soils
4	Indirect N2O Emissions from Managed Soils	N_2O	171.75	Minor emissions
4A	Forest (wildfires)	Carbon, CH_4, N_2O	152.33	Forest Land
4C	Grassland (rewetted organic soil)	Carbon, CH_4, N_2O	145.44	Emissions from soils due to drainage, rewetting, and management of organic soils
4A	Land converted to Forest (soil mineralisation)	N_2O	68.95	Forest Land
4C	Grassland remaining Grassland (grassland management biomass)	Carbon	54.87676	Minor emissions
4E	Land converted to Settlements (non-forest biomass)	Carbon	40.13	Minor emissions
4A	Forest (drainage of mineral soil)	N_2O	33.87	Forest Land
4E	Settlement (drainage of organic soil)	Carbon, CH_4, N_2O	29.13	Emissions from soils due to drainage, rewetting, and management of organic soils
4C	Land converted to Grassland (soil mineralisation)	N_2O	17.51	Emissions from soils due to land-use change on mineral soils

LULUCF Category	Parameter	Gases	Gg CO_2e	Group
4B	Cropland remaining Cropland (cropland management soils)	Carbon	-16.63	Minor emissions
4D	Wetlands (near-natural organic soil)	Carbon, CH_4	-14.33	Emissions from soils due to drainage, rewetting, and management of organic soils
4C	Grassland (wildfires)	CH_4, N_2O	12.24	Minor emissions
4B	Cropland remaining Cropland (cropland management biomass)	Carbon	-4.32	Minor emissions
4A	Forest (fertilisation)	N_2O	0.80	Forest Land
4B	Cropland (wildfires)	CH_4, N_2O	0.05	Minor emissions
4B	Land converted to Cropland (deforestation to Cropland)	Carbon, CH_4, N_2O	0.00	Minor emissions
4D	Land converted to Wetlands (grassland to flooded land)	Carbon	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 CO_2 net emissions. While CH_4 emissions are fairly stable over time, they dominate LULUCF overall net emissions by gas in CO_2 equivalents from 2000 onwards (Brown et al. 2021). Estimates in the 2020 inventory for the different GHGs are -2,994 Gg CO_2 for carbon dioxide, 4,875 Gg CO_2e for methane (or 195 Gg CH_4), and 1,778 Gg CO_2e for nitrous oxide (or 5.97 Gg N_2O) across the UK in 2020). This is due to CH_4 emissions from drained and rewetted organic soils. Emissions of greenhouse gases are produced by undrained modified, rewetted and near natural peatlands (note that CH_4 emissions from near-natural bogs are cancelled out by CO_2 uptake in CO_2-equivalent terms), drainage ditches on peatlands, biomass burning during wildfires or the conversion of Forest Land to Cropland, Grassland or Settlements. Direct and indirect emissions of N_2O are also produced from nitrogen fertilisation of new forests and soil mineralisation following land-use change. Emissions of non-CO_2 gases from agricultural land (e.g. due to fertilisation) are reported in the Agriculture sector of the Greenhouse Gas Inventory.

Coverage

The methods used for disaggregating each activity from Devolved Administration to Local Authority scale are described below. The level of spatial detail available differs between activities. For all activities there is currently no spatial activity data available for the Isle of Scilly, hence all LULUCF emissions and removals are estimated as zero for this LA.

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 CO_2 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 2020 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 or 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).

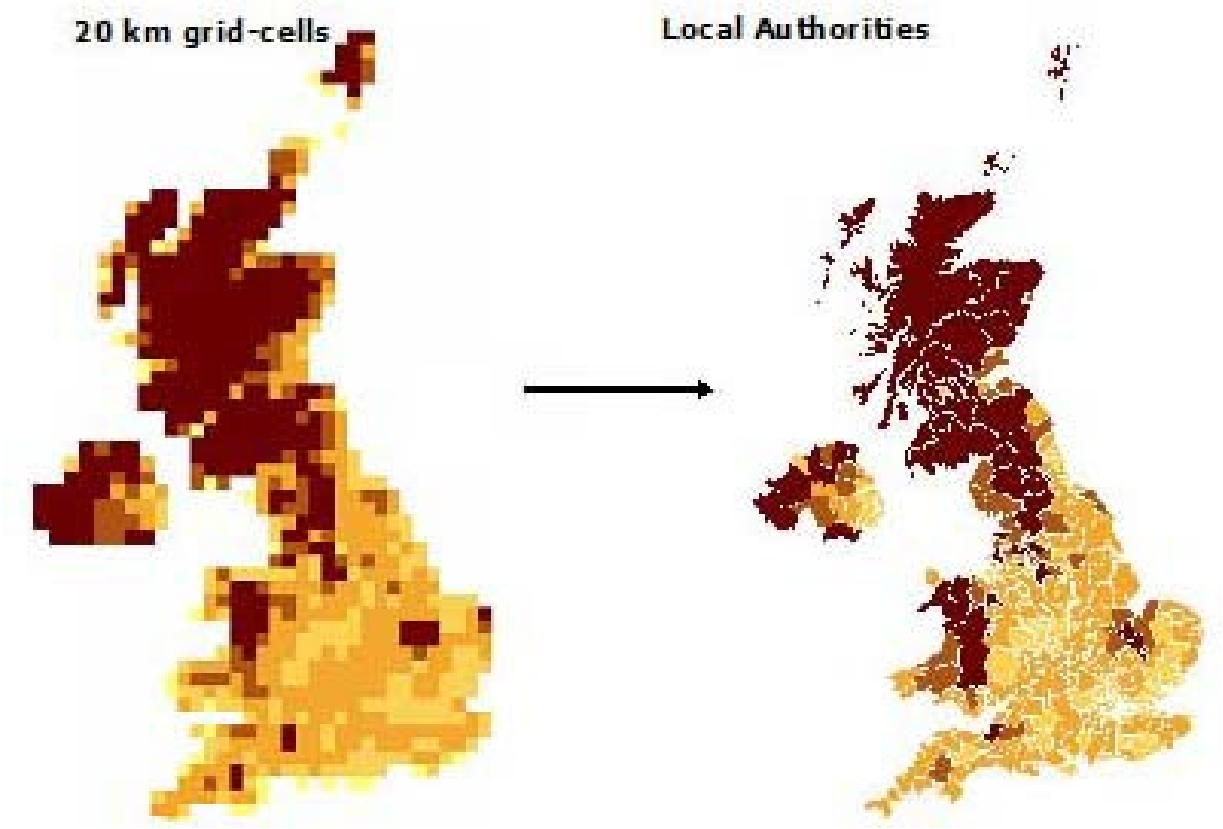
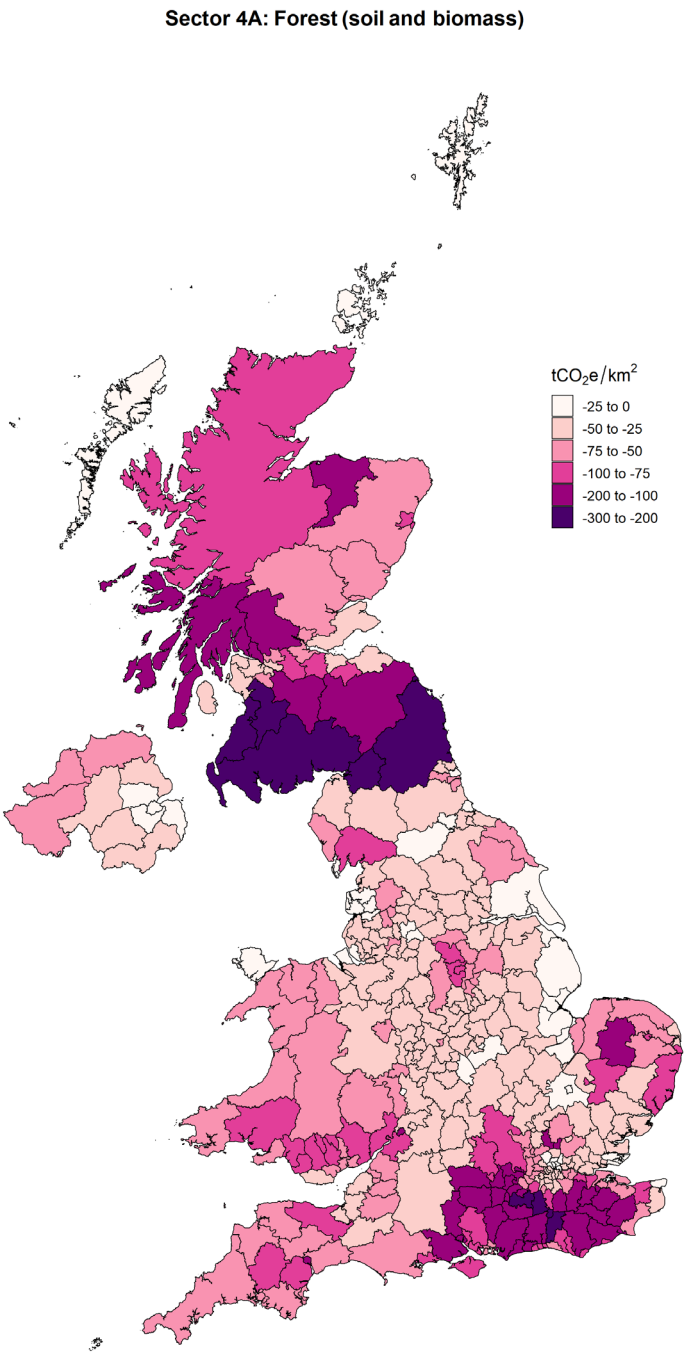


Figure 3 shows the distribution of carbon removals due to forest land per local authority area expressed as tonnes of carbon dioxide per square kilometre (tCO_2 per km^2). Maps of total CO_2 emissions/removals per LA can be misleading due to the wide range of areas across authorities – maps tend to be dominated by the Highland region of Scotland. The distribution of forest carbon removals is directly linked to the location of forests (Forestry Commission, 2020), 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 2020 per local authority area expressed as tCO_2 per km^2.



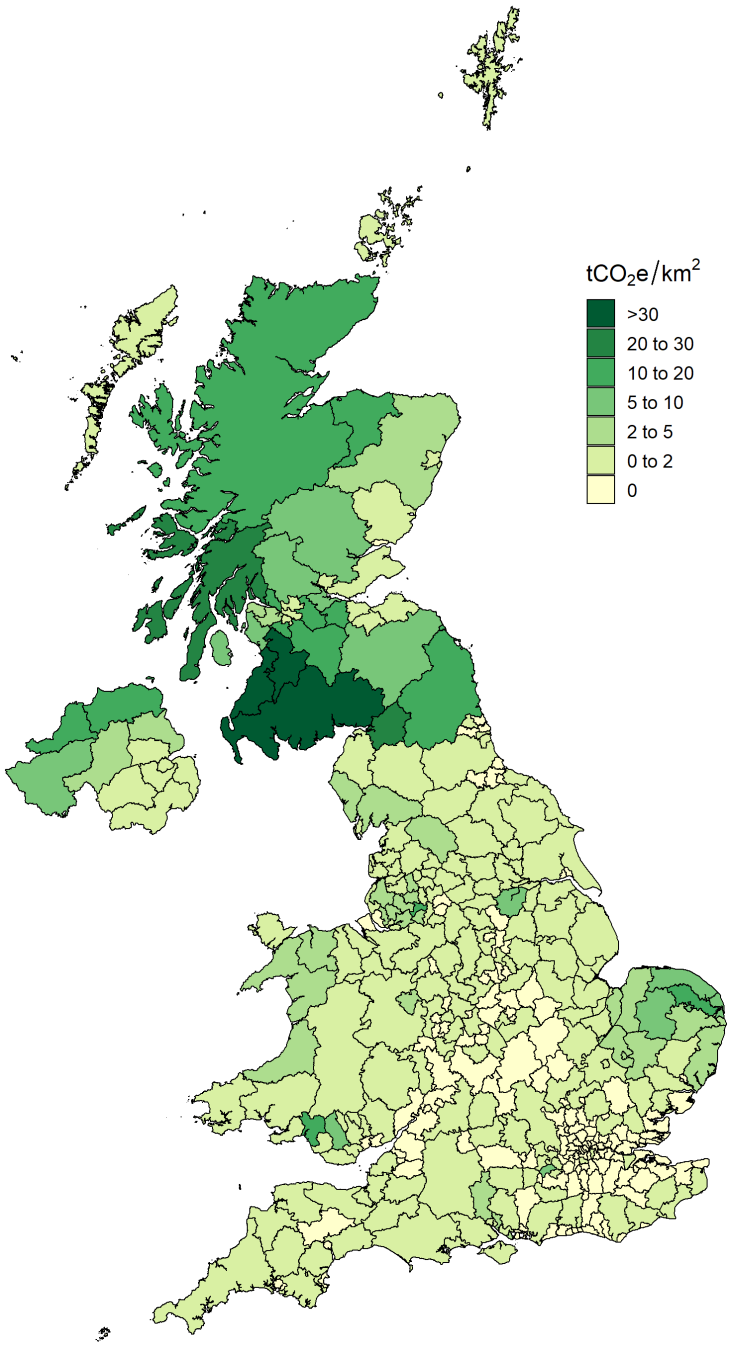
Drainage

Organic Soil

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. CO_2 emissions from indirect fluvial export of particulate organic carbon (POC) and dissolved organic carbon (DOC), and emissions of direct CH_4, CH_4 from ditches, and N_2O emissions 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 Emissions from soils due to drainage, rewetting and management 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 (from POC and DOC), methane and nitrous oxide emissions due to drainage of organic soils under Forests per local authority area (tCO_2e/km^2) in 2020.

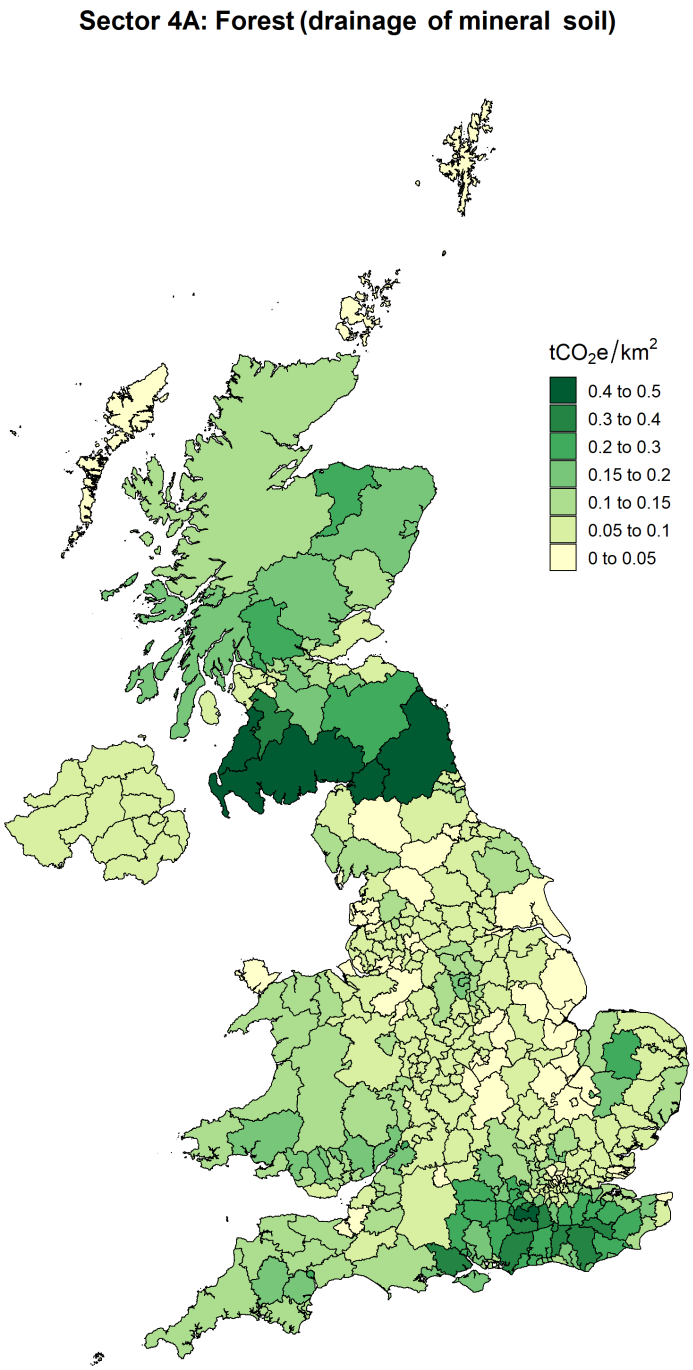


Mineral Soil

Forests planted on mineral or organo-mineral soils which have slow natural drainage and are prone to waterlogging are assumed to be artificially drained and N_2O emissions are reported

for this drainage. These emissions are disaggregated to LA scale using the same methodology as for forest soil and biomass (Figure 5).

Figure 5: Nitrous oxide emissions due to drainage of mineral soils under Forests per local authority area (tCO_2e/km^2) in 2020.

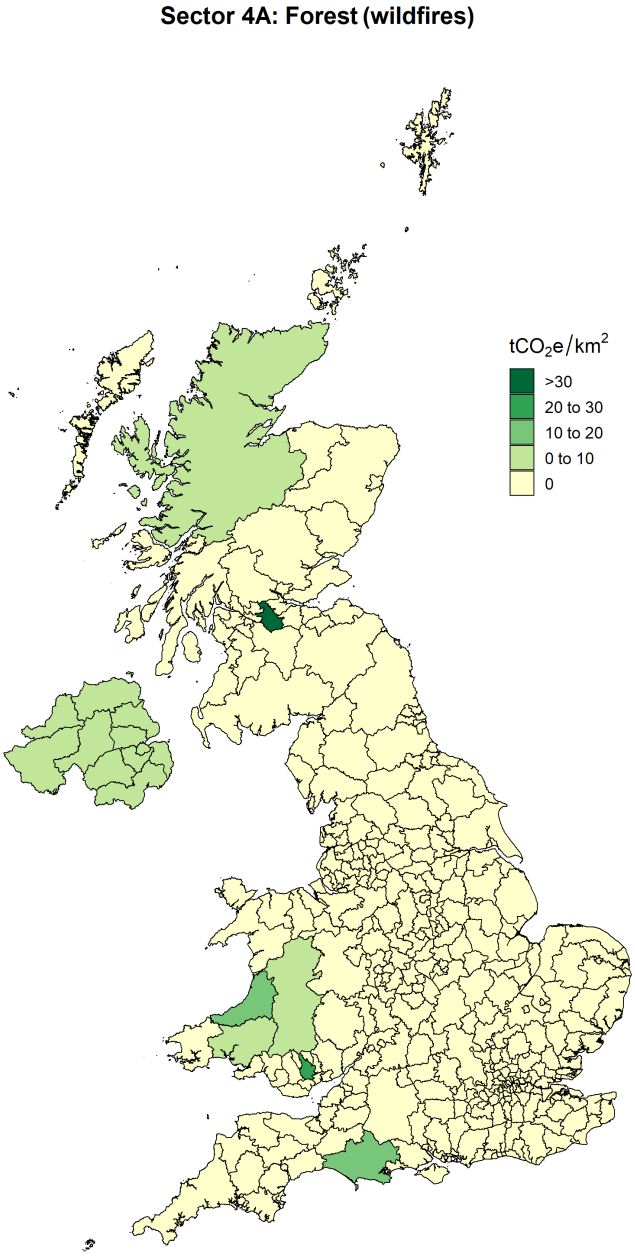


Forest Wildfires

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 occurred in each country in 2020 as shown in Figure 6.

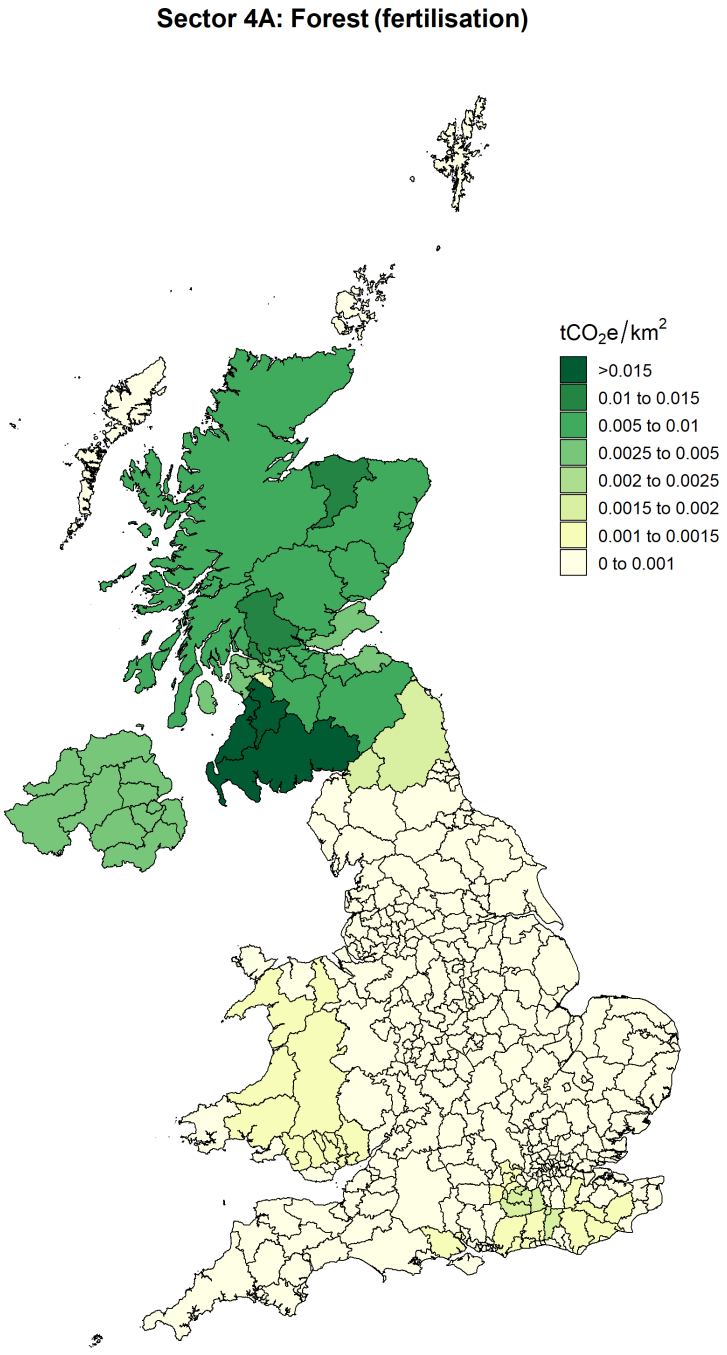
Figure 6: Emissions of carbon dioxide, methane and nitrous oxide due to forest wildfires per local authority area (tCO_2e/km^2) in 2020.



Forest Fertilisation

Fertilisation, leading to emissions of N_2O, occurs on the first rotation of forests planted on nutrient poor soils and is applied in the years of planting and again three years later. These emissions are disaggregated to LA scale using the same methodology as used for forest soil and biomass. Forest fertilisation is highest in Scotland in 2020, particularly in the South West, followed by Northern Ireland (Figure 7).

Figure 7: Emissions/removals of nitrous oxide arising from Forest fertilisation per local authority area (tCO_2e/km^2) in 2020



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 of carbon from soils to the atmosphere as CO_2.

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 to a dynamic model of carbon stock change. In the 1990-2020 inventory a major improvement was made to the land use change matrices which are now derived annually using a Bayesian data assimilation approach combining data from Earth Observation, land cover surveys and agricultural land statistics (Brown et al 2022, Annex section A 3.4.2).

To disaggregate the devolved administration (England, Scotland, Wales and Northern Ireland) level soil carbon stock change time series of land-use change, 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).[2] This information is used to split the soil carbon stock change for each land transition to give estimates per local authority (see Figure 8). 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. 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 8). N_2O from soil mineralisation from land use change are presented for the first time in this report this year (Figure 9).

[2] This is the same methodology as was used to disaggregate the 1990-2019 (and previous) LULUCF inventory to LA scale. More work is required before the land-use change activity data update used in the 1990-2020 inventory (Brown et at, Annex section A3.4.2.1) can be utilised for disaggregation to LA scale.

Figure 8: Carbon dioxide emissions from mineral soil due to land-use change per local authority area (tCO_2/km^2) in 2020. This covers the conversion of all land types to (a) Cropland (b) Grassland and (c) Settlements

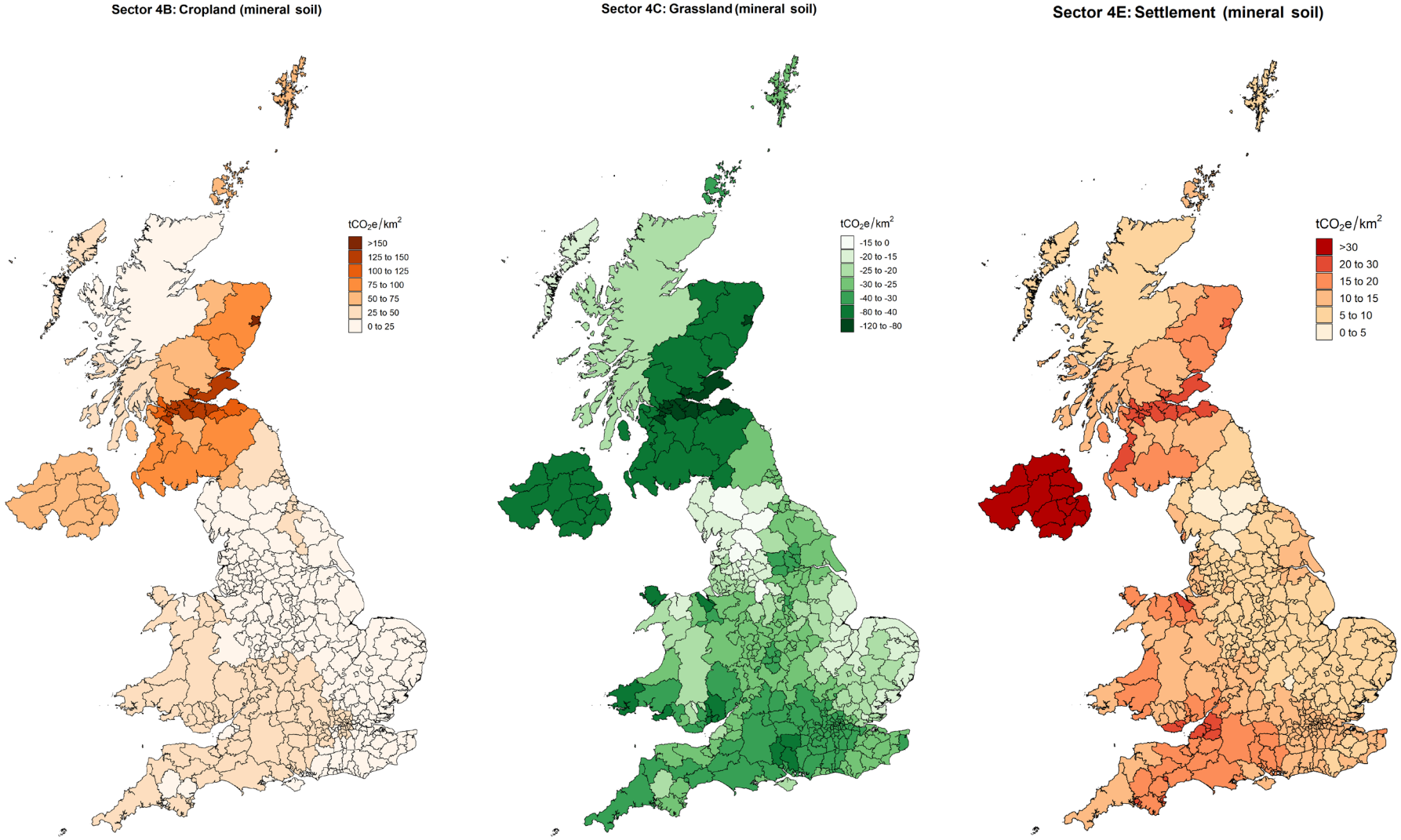
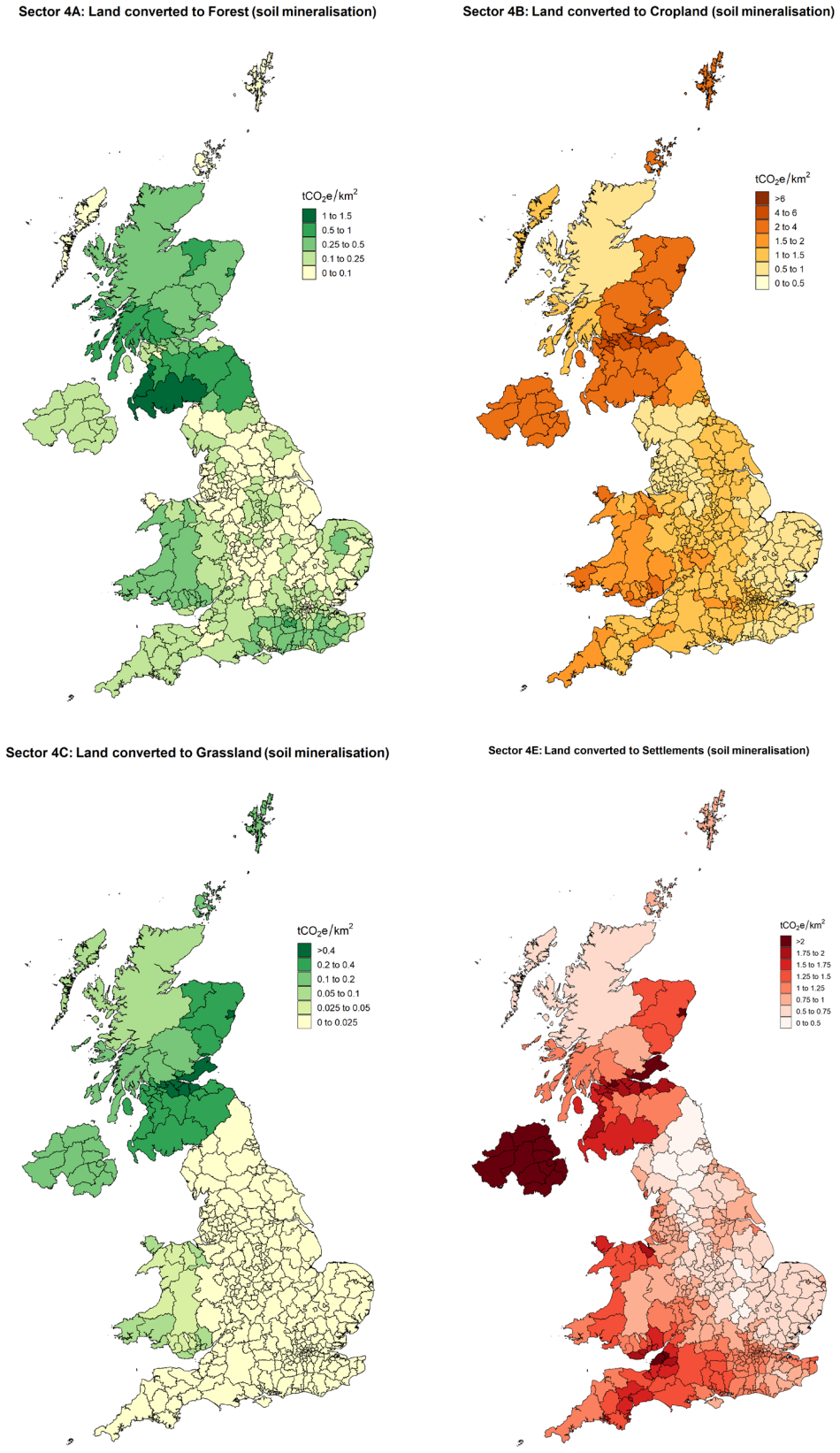


Figure 9: Nitrous oxide emissions from soil mineralisation resulting from land use change to Forest, Cropland, Grassland and Settlement per local authority area tCO_2e/km^2) in 2020.



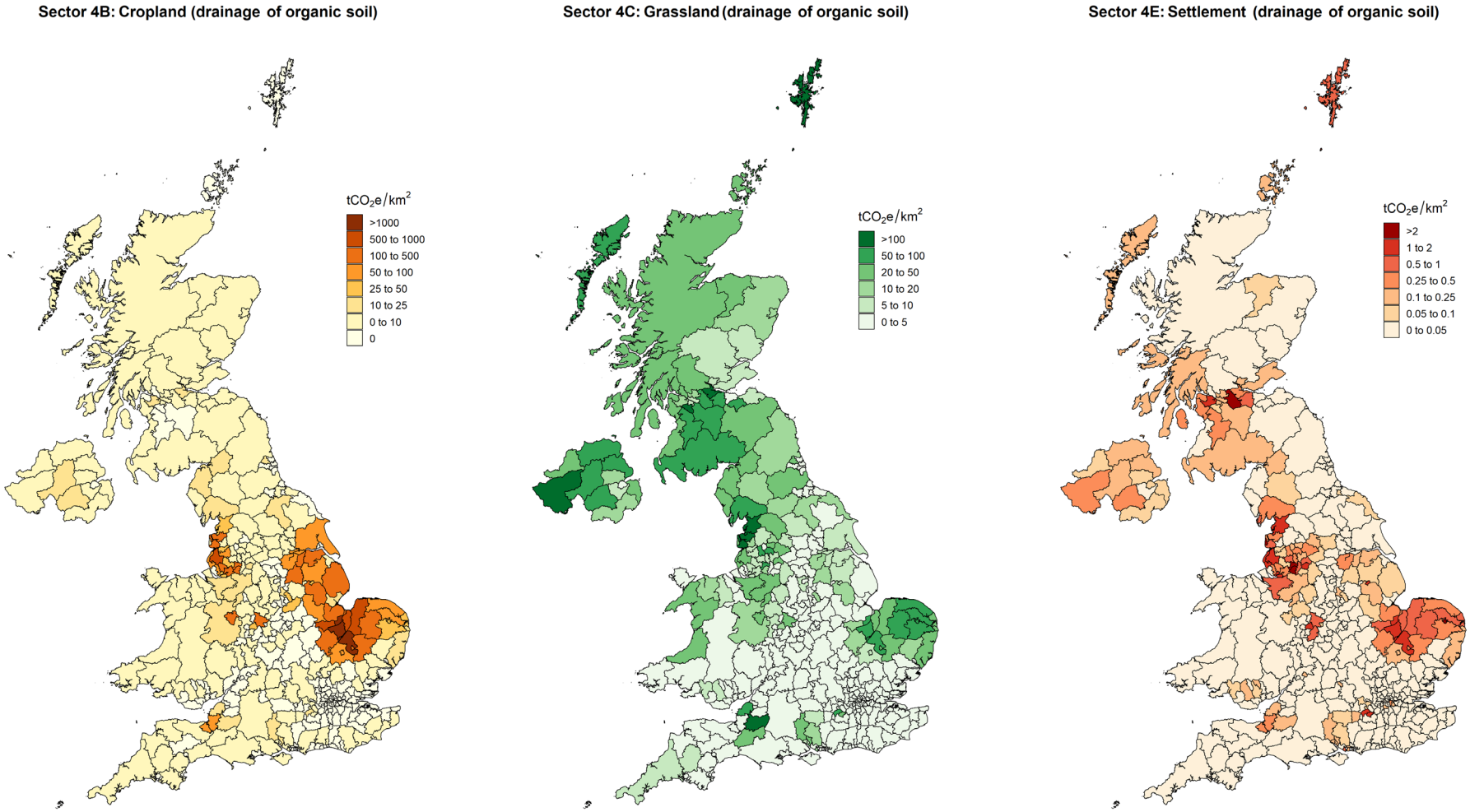
Emissions from soils due to drainage, rewetting and management of organic soils: forest, cropland, grassland, wetland, settlement

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 CO_2, as well as emit significant amounts of N_2O associated with organic matter decomposition. In a natural state, peatlands are important long-term sinks for carbon, which is counterbalanced by similar emissions of methane in CO_2 equivalent terms, making near-natural peatland close to carbon neutral (see section on undrained organic soils below). The method for estimating drained (and undrained) 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 10 shows the estimated distribution of emissions (tCO_2e/km^2). Emissions from drained organic soils under Cropland are largely concentrated in the East and North Midlands of England and are associated with wasted peat (organic soils that were previously deep peat, and now mapped as retaining less than 40 cm of 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 10. Emissions from Settlement on organic soils mostly occur in lowland regions where population density is higher.

Figure 10: Carbon dioxide, methane and nitrous oxide emissions due to drainage of organic soils under Cropland and Grassland (intensive, extensive, modified bog), and Settlement per local authority area (tCO_2/km^2) in 2020.

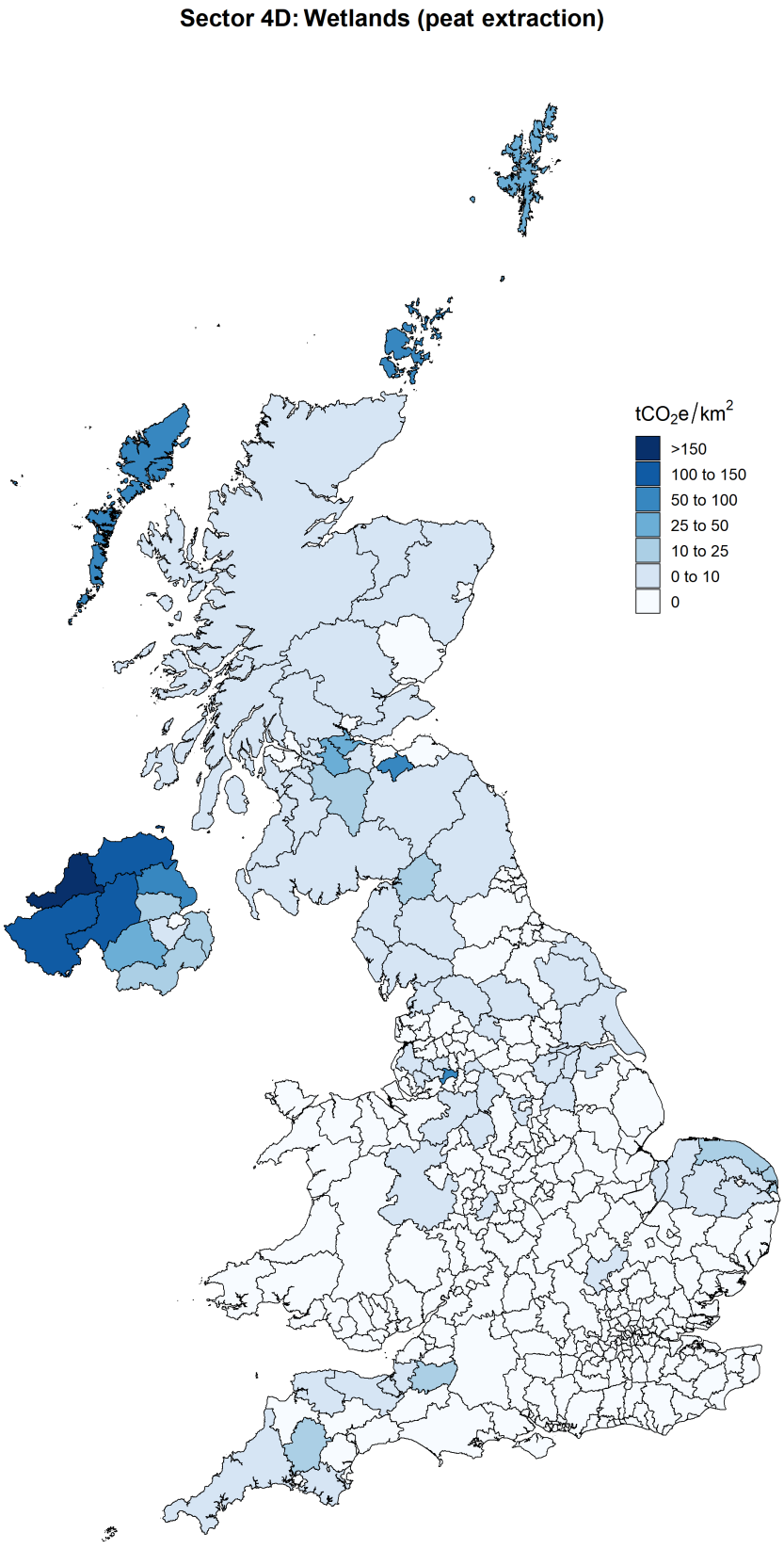


Peat Extraction

On-site CO_2, CH_4 and N_2O emissions and off-site CO_2 emissions from peat extraction are calculated for the LULUCF inventory based on data published in the *Mineral Extraction in Great Britain Business Monitor PA1007 and Growing Media Association report* (GMA 2021) 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 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 11).

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 11: Carbon dioxide, methane and nitrous oxide emissions from active and historical extraction of peat for horticultural and domestic use per local authority area (tCO_2e/km^2) in 2020. This is part of the Wetlands category.

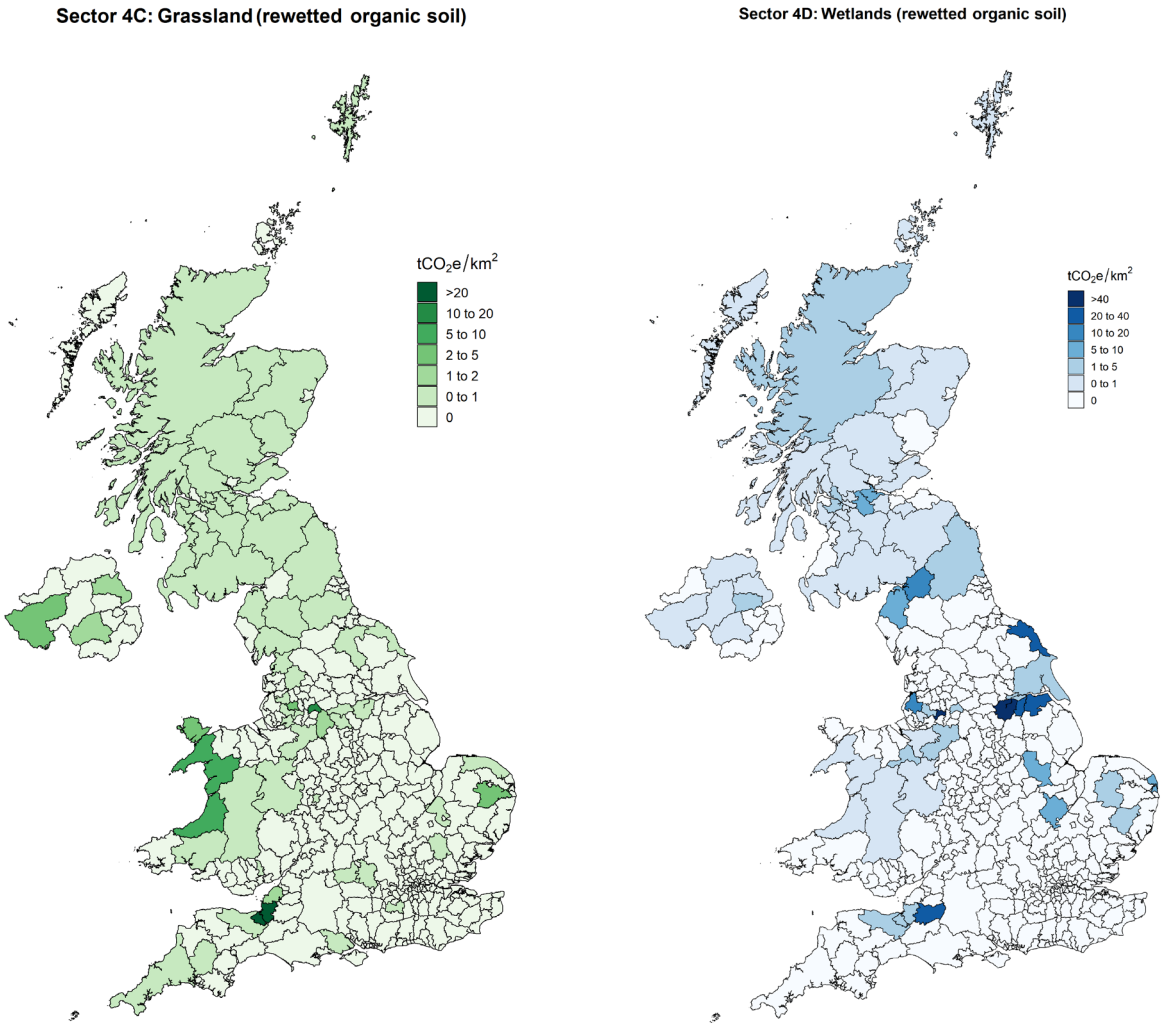


Rewetting

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. 2022). 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 2020 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 12 as those exhibiting either a net sink or source of CO_2e 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. 2022), 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 10 and 11 above.

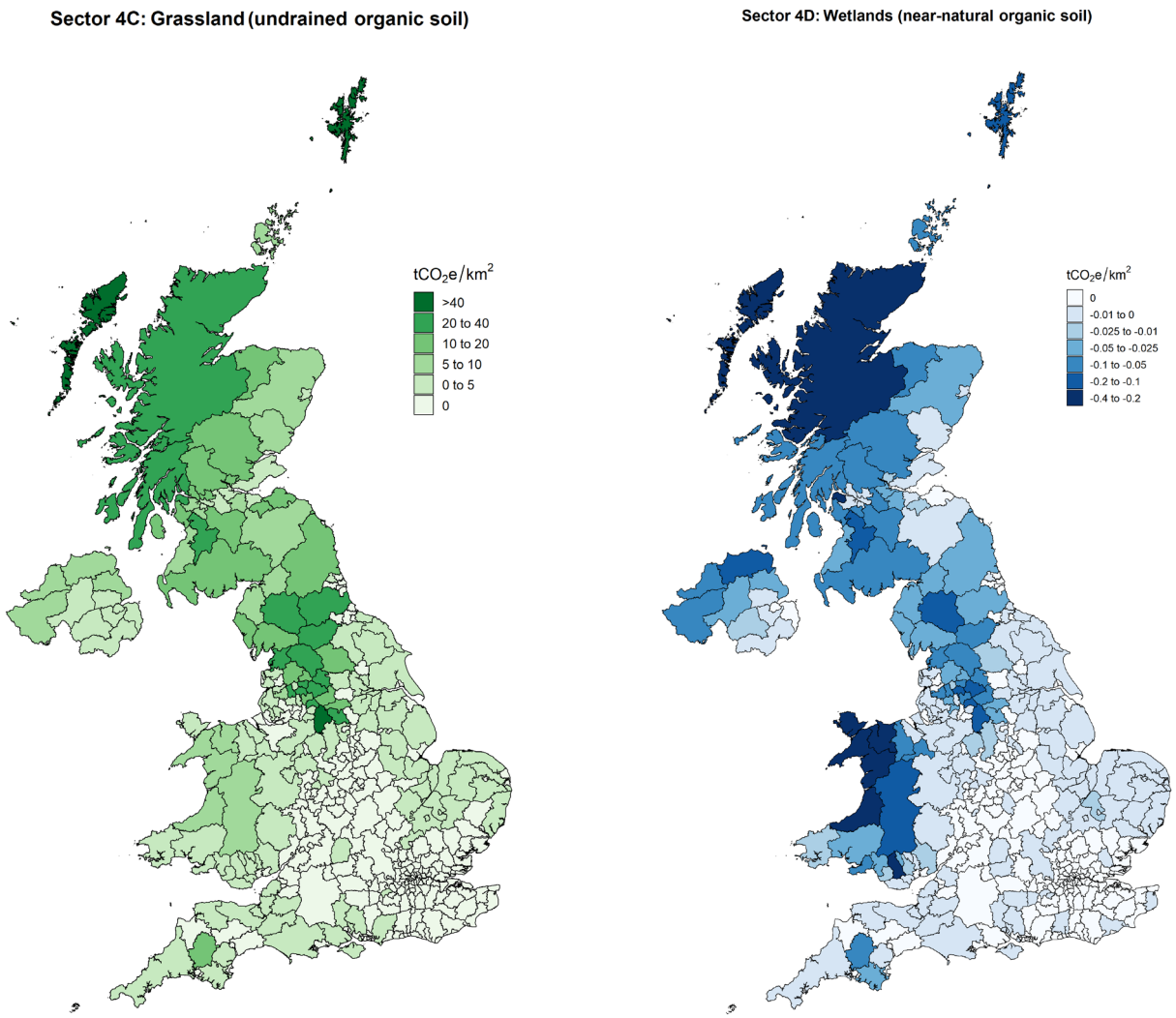
Figure 12: Net carbon dioxide, methane and nitrous oxide emissions from rewetted organic soils per local authority area (tCO_2e/km^2) in 2020. This is part of the Grassland and Wetlands categories.



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 carbon sequestration and are reported under Wetlands (Figure 13). Emissions of CH_4 and removals of CO_2 (N_2O emissions from undrained soils are assumed to be negligible) 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 13).

Figure 13: Net carbon dioxide and methane emissions and removals from undrained semi-natural and near natural peatlands per local authority area (tCO_2e/km^2) in 2020, which are part of the Grassland and Wetlands categories, respectively.



Estimates of various minor emissions

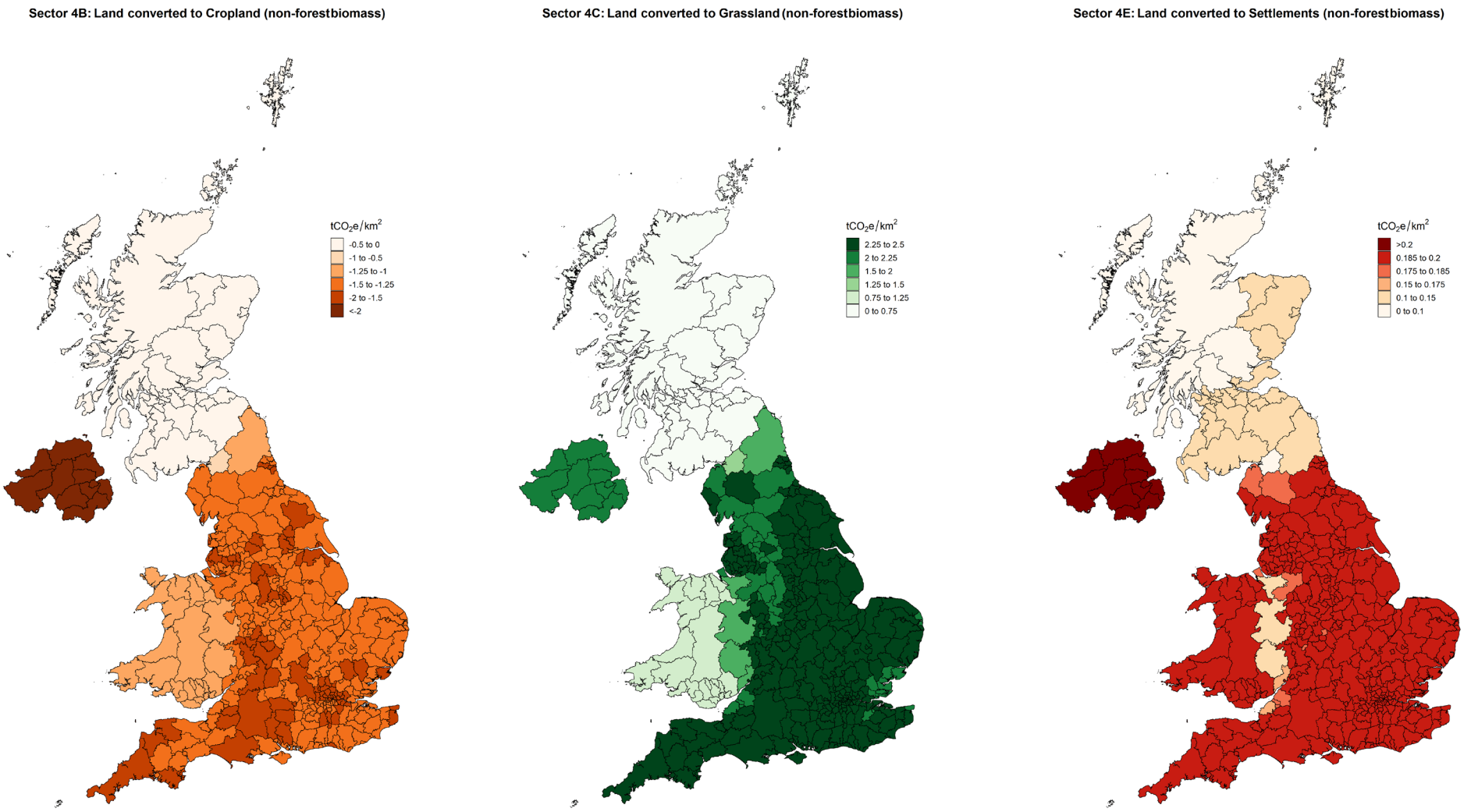
Non-Forest Biomass

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 14).

Figure 14: 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 2020, expressed as carbon dioxide emissions or removals per local authority area (tCO_2/km^2).



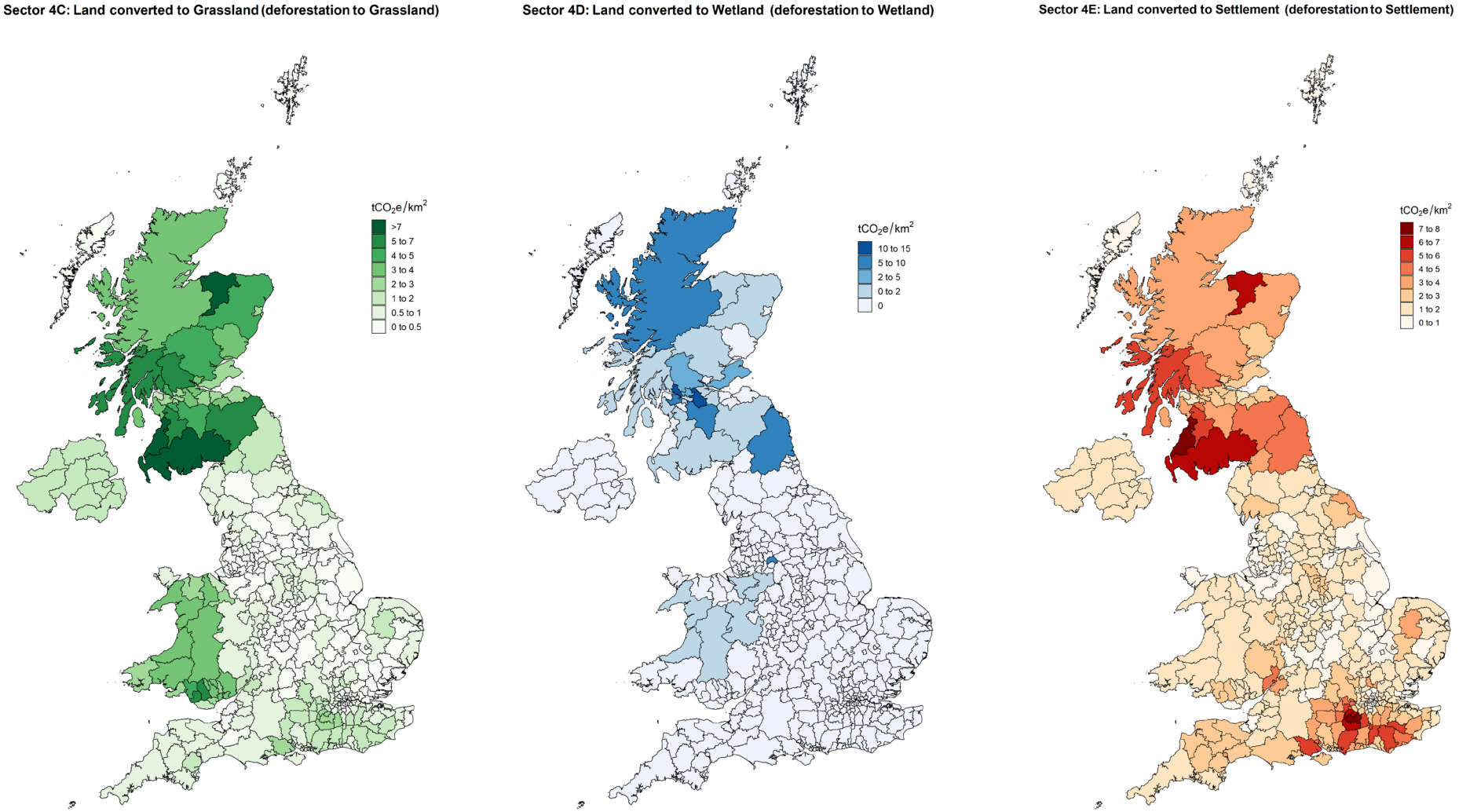
Deforestation

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 15, this does not show Deforestation to Cropland as this was zero in 2020).

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.

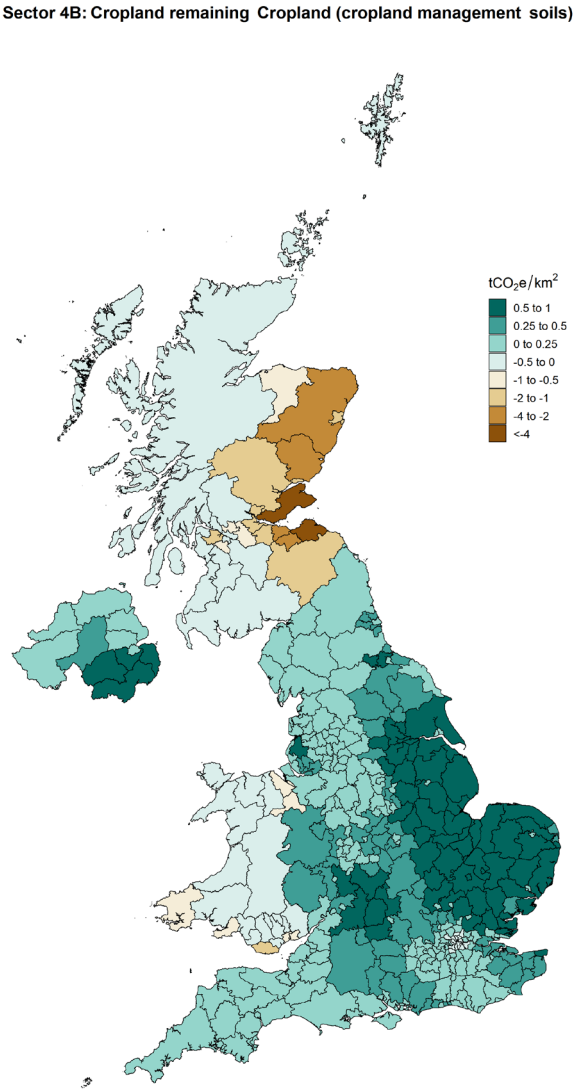
Figure 15: Emissions of carbon dioxide, methane and nitrous oxide from deforestation to Grassland, Wetlands, or Settlements per local authority area (tCO_2e/km^2) in 2020.



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, 2020; Welsh Government, 2020; Scottish Government, 2020; 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, 2021 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 16.

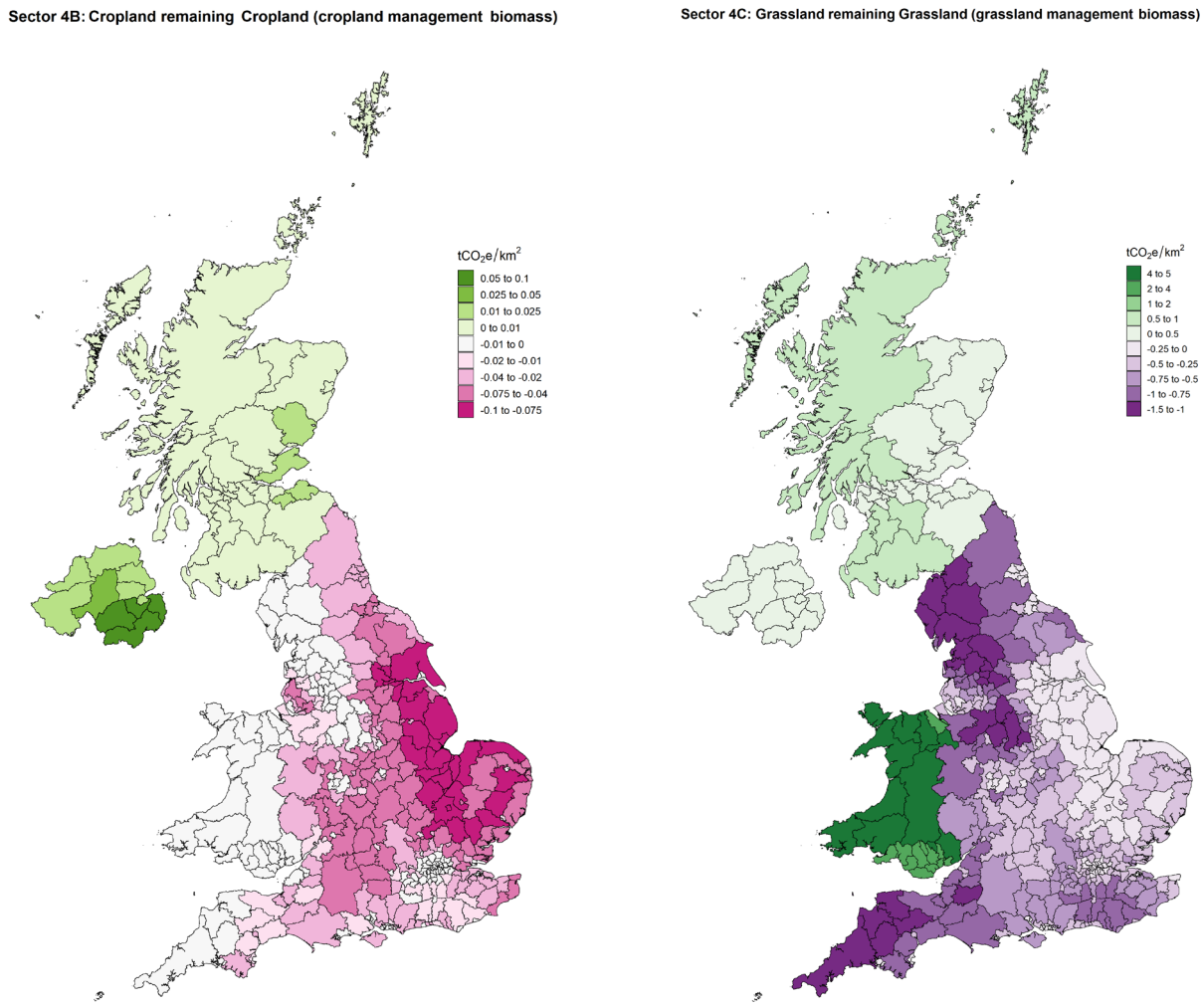
Figure 16: Emissions / removals of carbon dioxide from Cropland Management soil activities per local authority area (tCO_2/km^2) in 2020.



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, 2020; Welsh Government, 2020; Scottish Government, 2020; DAERA, 2021). 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 17.

Figure 17: Emissions / removals of carbon dioxide from Cropland and Grassland Management biomass activities per local authority area (tCO_2/km^2) in 2020.

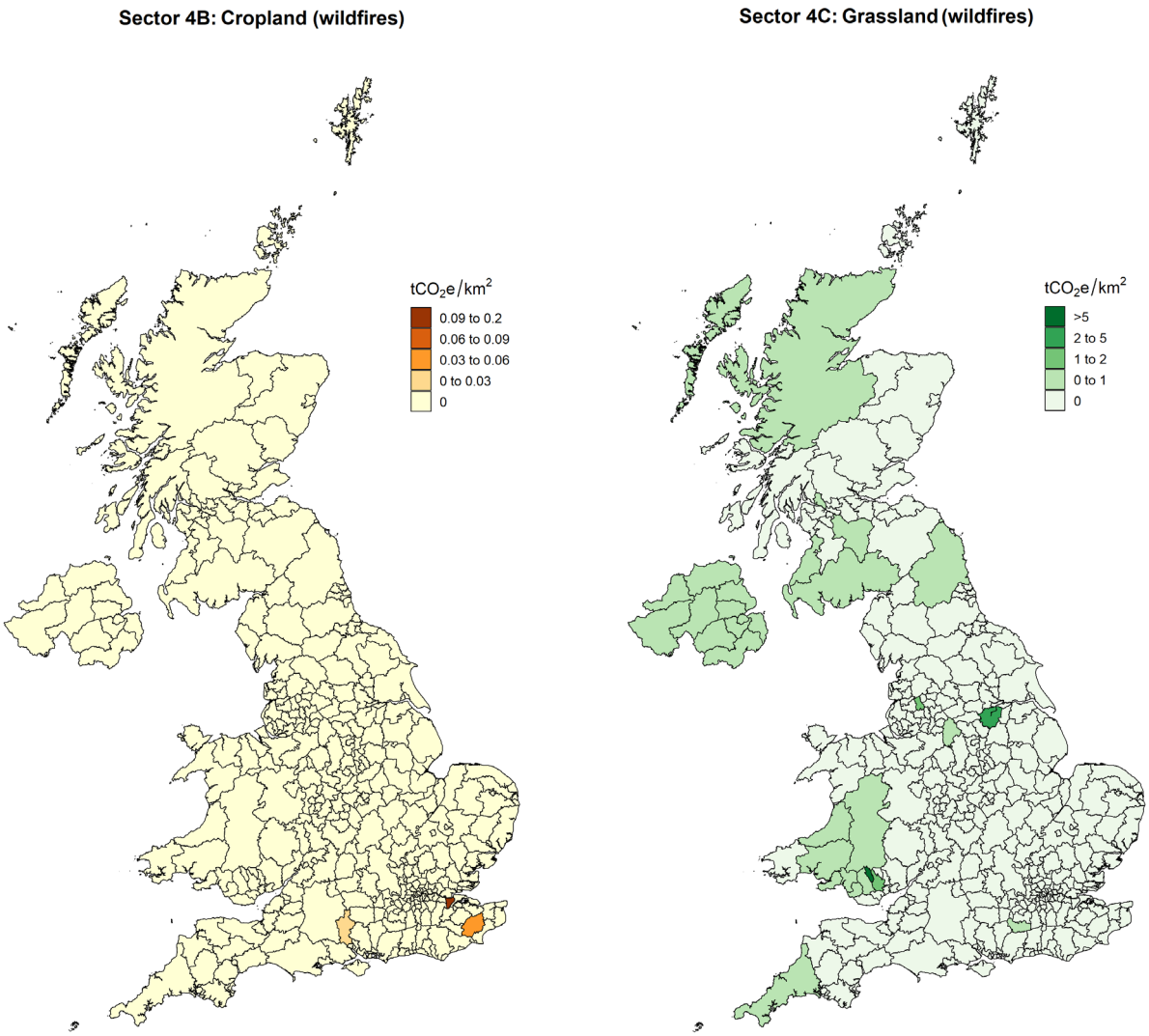


Non-Forest Wildfires

Information on areas of wildfires on cropland and grassland in Great Britain and in Northern Ireland are available from the Fire Service Incident Response System (IRS). As is the case with forest

wildfires, the non-forest wildfire dataset is spatially explicit, available at individual grid referenced fire level for Great Britain and as a national total for Northern Ireland. Hence, in Great Britain wildfires on cropland and grassland 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 crop or grassland in each LA. Data for non-Forest wildfires in England from 2015-2017 were not supplied with coordinates. For these incidents emissions were assigned proportionally between the LAs within the fire service boundary in which the incident occurred. Wildfires on cropland only occurred in England in 2020, whereas wildfires on grassland occurred in each country in 2020 (Figure 18).

Figure 18: Emissions of methane and nitrous oxide from non-forest wildfires per local authority area (tCO_2e/km^2) in 2020.

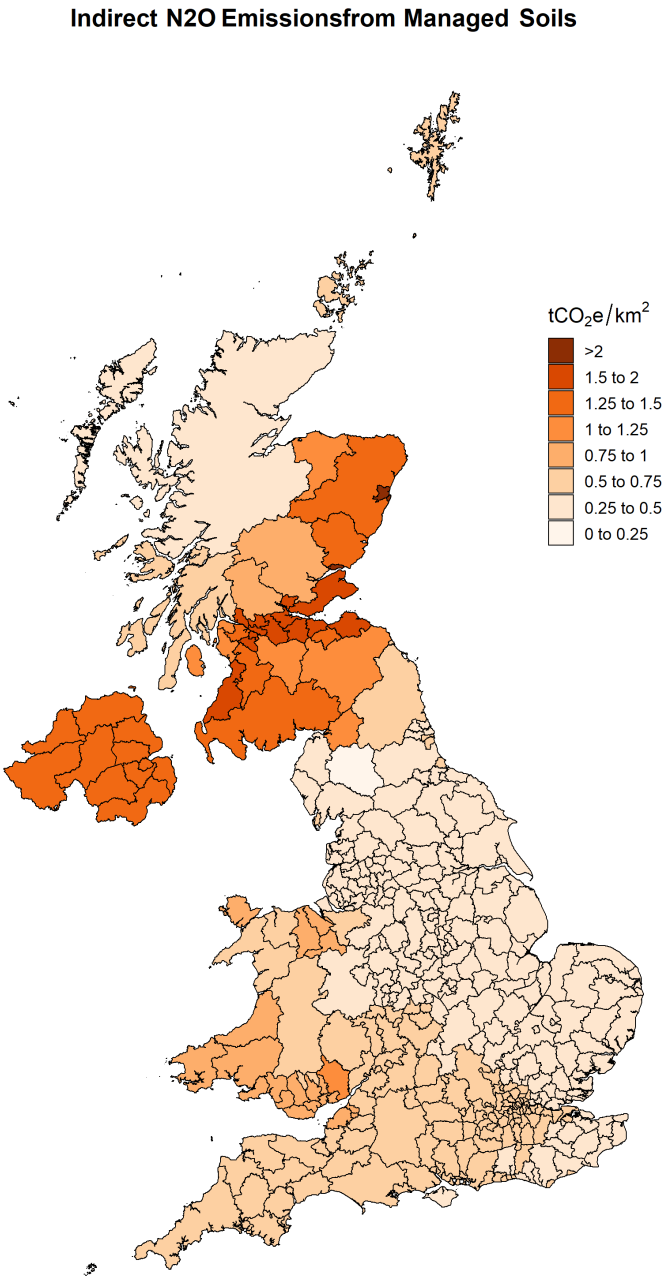


Indirect N_2O

Indirect emissions of N_2O from atmospheric deposition and leaching are reported collectively for all LULUCF sectors (as set out in inventory reporting rules). Indirect N_2O from atmospheric deposition arises from forest fertilisation, hence these emissions have been disaggregated with the same methodology as used for forest fertilisation. Indirect emissions from leaching arise from both forest fertilisation and N_2O mineralisation as a result of land use change. These direct N_2O emissions for

each LA were combined and converted to a ratio which was used to disaggregate the indirect N_2O from leaching. Finally the two sources of indirect N_2O are summed to give a total for each LA.

Figure 19: Indirect nitrous oxide emissions from managed soil per local authority area (tCO_2e/km^2) in 2020.



LULUCF Totals

The total greenhouse gas emissions and removals for the UK land use, land-use change and forestry sector (excluding harvested wood products which cannot be mapped) are shown in Figure 20. Maps of emissions and removals of individual gases, CO_2, CH_4, and N_2O are shown in Figures 21-23.

Figure 20: Emissions or removals of GHGs from land use, land-use change and forestry per local authority area (tCO_2e/km^2) in 2020.

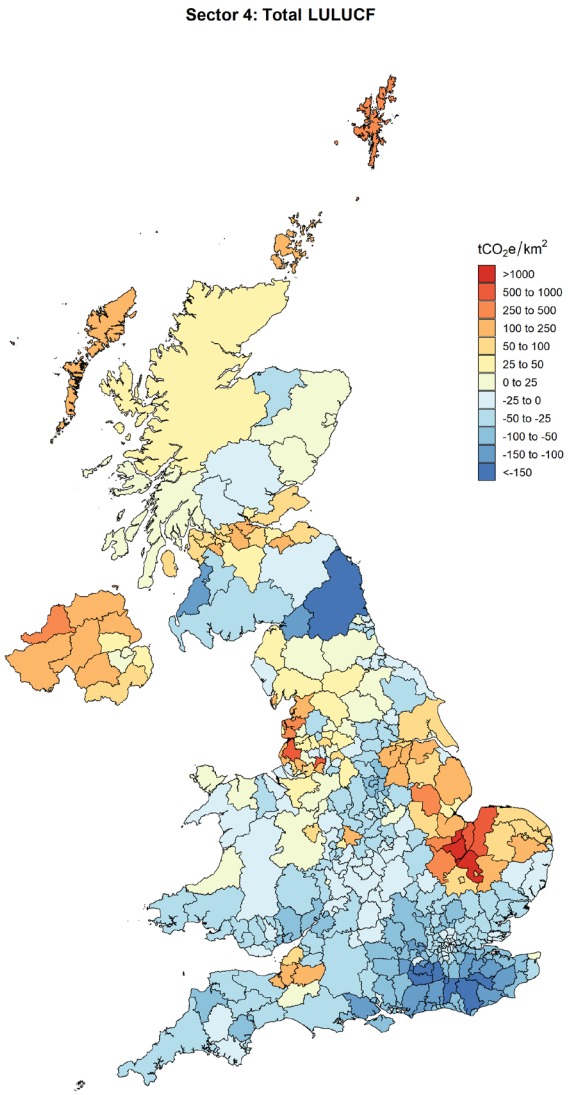


Figure 21: Emissions or removals of carbon dioxide from land use, land-use change and forestry per local authority area (tCO_2e/km^2) in 2020.

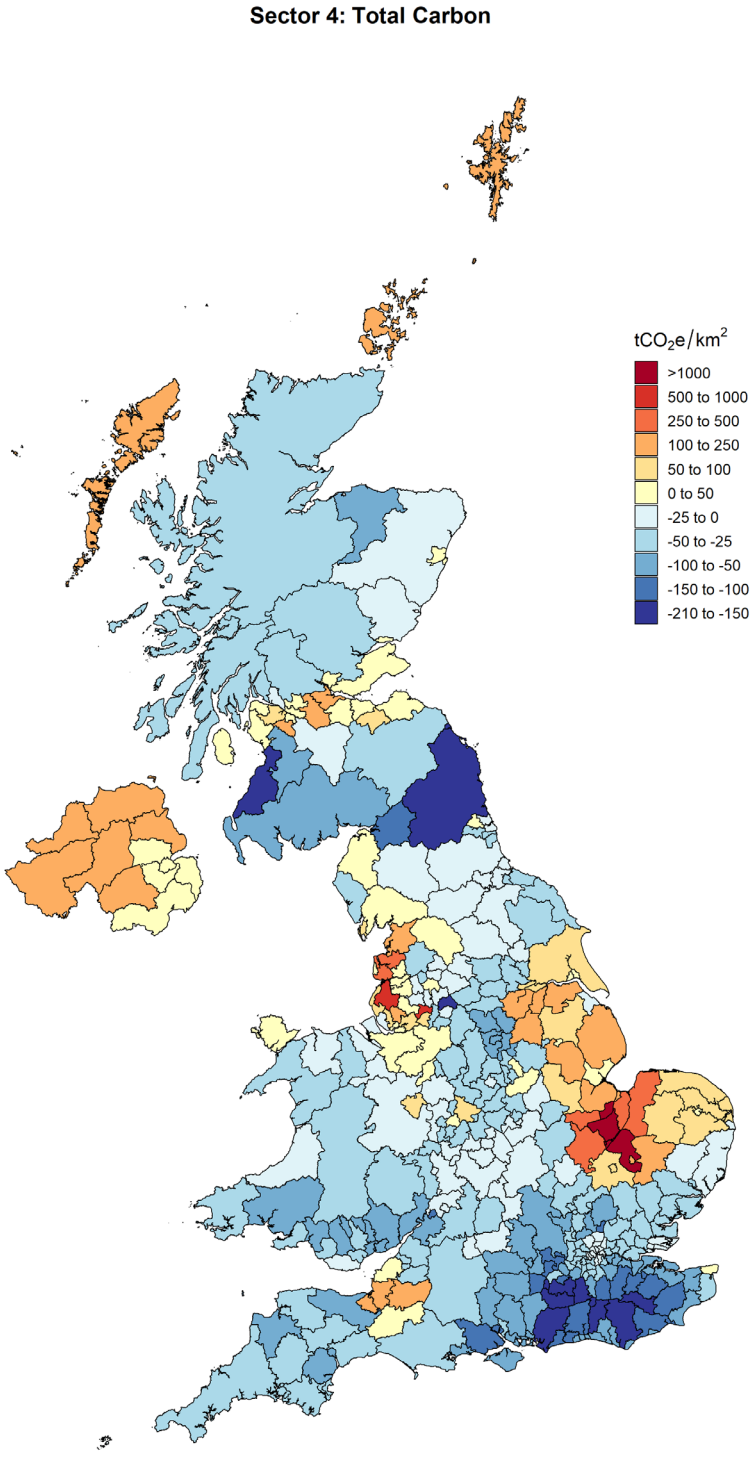


Figure 22: Emissions or removals of methane from land use, land-use change and forestry per local authority area (tCO_2e/km^2) in 2020.

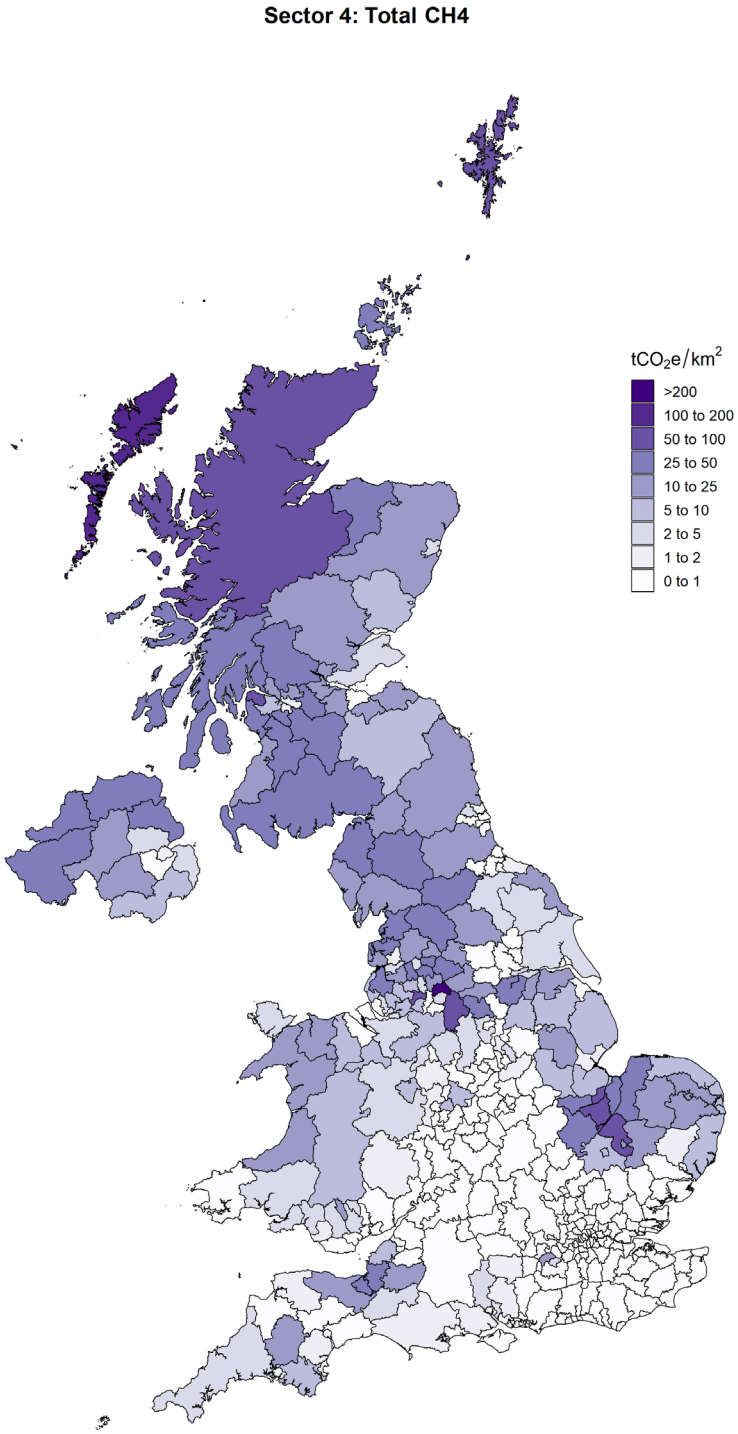
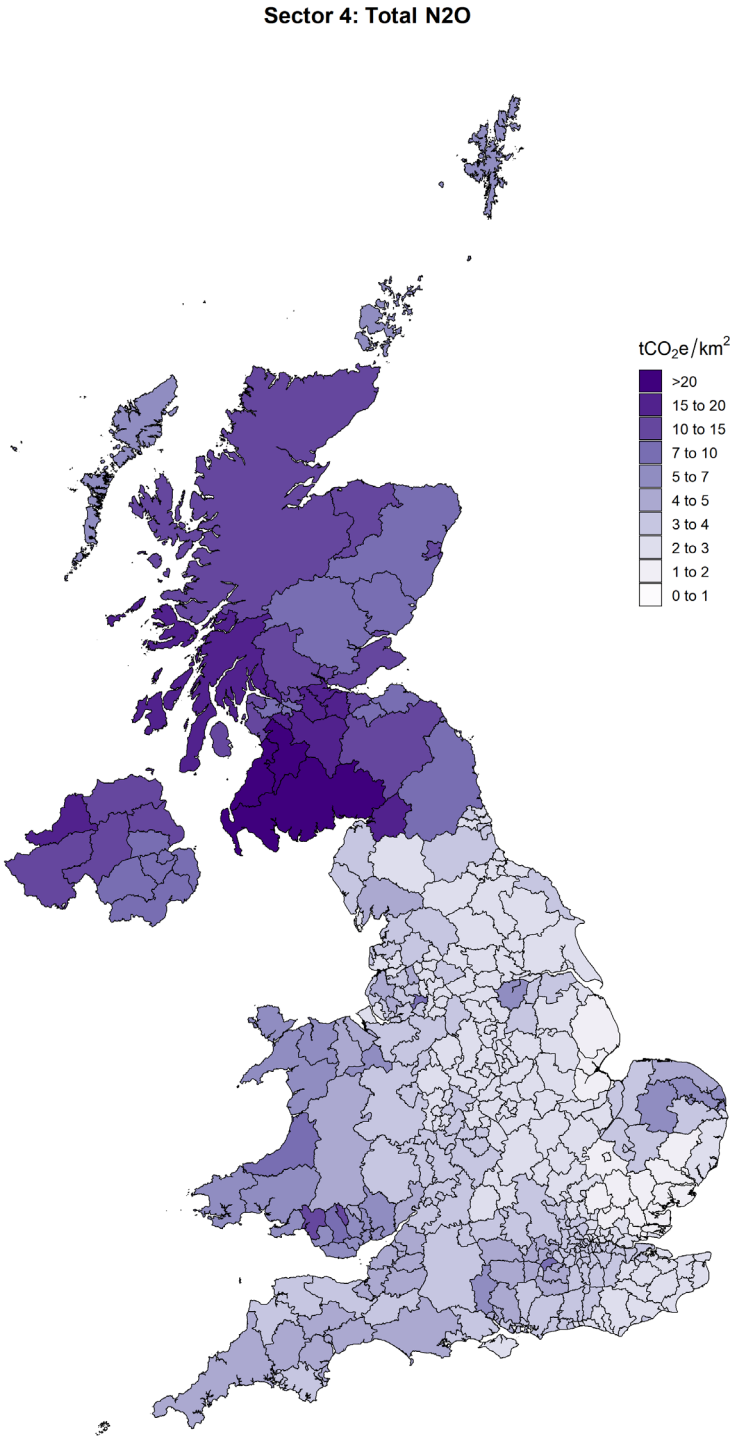


Figure 23: Emissions or removals of nitrous oxide from land use, land-use change and forestry per local authority area (tCO_2e/km^2) in 2020.



Uncertainties

The uncertainties in calculating the LULUCF inventory are described in an annex of the National Inventory Report (see Table A 3.4.32 in Brown et al. 2022) and range from 12-197% for CO_2, 36-95% for CH_4 and 34-240% in 2020 depending on the LULUCF sector activity. Additional uncertainty is associated with disaggregating the dataset to LA scale. 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 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
Minor estimates:		
Non-Forest Biomass	Countryside Surveys	Moderate
Deforestation	As for Forest Land	High

Category	Source data used for disaggregation	Uncertainty
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. More detailed descriptions of the changes can be found in the UK National Inventory Report and annexes (Brown et al. 2022).

Table 3: Details of the major changes to carbon emissions / removals between the 2019 and 2020 LULUCF inventories.

Description of Change	Reason for Change	Categories Affected (all Carbon only)	1990-2019 Inventory 2019 UK Value ($GgCO_2e$)	1990-2020 Inventory 2019 UK Value ($GgCO_2e$)	1990-2020 Inventory 2020 UK Value ($GgCO_2e$)
Updated forest planting statistics and a new approach was applied for adjusting reported forest areas to stocked forest (areas within the forest which actually have trees as opposed to integral open spaces, e.g. ponds, roads etc.). Northern Ireland data is now based on an approach similar to the other DAs (with public and private sector species/yield class/age class forest area inventories). A minor change was made to the Forest Research CARBINE forest accounting model to fix assumed water saturation when drainage is included during afforestation.	Inclusion of new data and improving consistency of forest reporting across the DAs. Improving the drainage assumptions in the CARBINE model.	4A Forest (soils and biomass), Forest (drainage of organic soil)	-17,430.32	-18,205.69	-18,028.84

Description of Change	Reason for Change	Categories Affected (all Carbon only)	1990-2019 Inventory 2019 UK Value ($GgCO_2e$)	1990-2020 Inventory 2019 UK Value ($GgCO_2e$)	1990-2020 Inventory 2020 UK Value ($GgCO_2e$)
An update to the land use change activity data, based on a BEIS funded land use tracking project. The new approach assimilates a wider range of land use and land-use change data sources to produce an annual time series, rather than the previous approach that used decadal rates of change based on the Countryside Survey. The new activity data impacts the mineral soil and non-forest biomass carbon stock change as a result of land use change.	Temporal and spatial improvements to the Land Use Change activity data.	4B Cropland (mineral soil), 4B Land converted to Cropland (non-forest biomass), 4C Grassland (mineral soil, 4C Land converted to Grassland (non-forest biomass), 4E Settlement (mineral soil), 4E Land converted to Settlement (non-forest biomass)	4,554.06	3,744.26	3792.20

Description of Change	Reason for Change	Categories Affected (all Carbon only)	1990-2019 Inventory 2019 UK Value ($GgCO_2e$)	1990-2020 Inventory 2019 UK Value ($GgCO_2e$)	1990-2020 Inventory 2020 UK Value ($GgCO_2e$)
Updated activity data on the volumes of peat sold from Growing Media Association (GMA 2021) affecting off-site peat emissions. Revision to one peat extraction site in Northern Ireland using information on operational status and site activity from Growing Media Association.	Continuous inventory improvement due to additional activity data availability	4D Wetlands (peat extraction),	2,237.30	2,079.05	2,046.58
Revisions to the activity data for forest planting (the split between planting on mineral and organic soils) have reduced the area of cropland and grassland on drained organic soils and hence the greenhouse gas emissions from these land types.	Updated forest activity data.	4B Cropland (drainage of organic soil), 4C Grassland (drainage of organic soil),	10,518.24	10,433.88	10,401.90
		LULUCF Total[3]	**-1025.39**	**-2687.69**	**-2994.19**

[2] This is the total of carbon emissions / removals for all LA categories both recalculated and unchanged (excludes Harvested Wood Products as this is not disaggregated to LA scale).

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