National Atmospheric Emissions Inventory

Projections of Emissions and Removals from the LULUCF Sector to 2050/2100

(consistent with the 1990-2017 inventory)

Prepared by the UK Centre for Ecology & Hydrology (UKCEH) and Forest Research for the Department for Business, Energy and Industrial Strategy (BEIS) as part of the UK National Atmospheric Emissions Inventory

UK Centre for Ecology & Hydrology

Department for Business, Energy & Industrial Strategy

Forest Research

Reference: ERG 1103 | Issue Number 1 | Date October 2020

Customer:

Department for Business, Energy & Industrial Strategy (BEIS)

Customer reference:

ERG1103

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Acknowledgment:

To the various individuals who contributed to the definition of the specifications of the scenarios, among others Mark Broadmeadow whose contribution has been instrumental.

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October 2020

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Summary for Policy Makers

The Climate Change Act, passed in 2008, committed the United Kingdom of Great Britain and Northern Ireland (UK) to reducing greenhouse gas (GHG) emissions by at least 80% by 2050 when compared with 1990 levels. In 2019, the UK passed a law which further tightened the target by requiring the UK to bring all GHG emissions to net zero by 2050.It also established a system of legally-binding carbon budgets which limit the net amount of GHG that can be emitted in successive five-year periods. Emissions and removals from Land Use, Land-Use Change and Forestry (LULUCF) are an integral component of those legislated targets. Projections of these emissions, based on a range of policy assumptions, are included in the the Energy and Emissions Projections (EEP)[1] which this year have been extended to 2040. These are one way we monitor progress towards the UK's legislated targets. Considering the inertia and long term impact in the land-use sector, this report covers changes in land use as a result of different policy assumptions until 2050 and covers their longer-term impact until 2100. The full projections data are available on the national atmospheric emissions inventory (NAEI) website[2].

LULUCF activities can result in net annual emissions or removals of GHG, and changes in carbon stocks in the pools associated with LULUCF. The results presented here are based on the reporting conventions of the United Nations Framework Convention on Climate Change (UNFCCC). They do not represent potential future reported or accounted emissions and removals under the Kyoto Protocol.

This report provides projections at the UK and country level, with separate estimates for Scotland, England, Wales and Northern Ireland, which are summed to give the UK totals.

LULUCF is divided into six land use types: Forest Land (4A), Cropland (4B), Grassland (4C), Wetlands (4D), Settlements (4E), and Other Land (4F). Carbon stock changes of Harvested Wood Products are reported in an additional category, Harvested Wood Products (4G). The code refers to the inventory category of LULUCF in the common reporting format for GHG inventories submitted to the UNFCCC. There is a separate inventory sector for Agriculture covering most emissions of methane (CH_4) and nitrous oxide (N_2O) from agricultural activities, which are not covered in this report.

The emissions resulting from five future scenarios (*Baseline 1, Baseline 2, Central, Low* and *Stretch*) have been described. The *Baseline* scenarios are based on climate change-related and forestry policies extant in July 2009. The other scenarios take account of current land use policies for which funding was secured by May 2019 (Central scenario) or policy aspirations (low scenario) or even more ambitious climate mitigation measures (Stretch scenario).

The main results are:

- At a UK level, the LULUCF sector is a net sink from 1991 onwards and is projected to remain so under the Low and Stretch scenarios although declining from ~2018 to 2050. Under the *Baseline 1* and *Baseline 2* scenarios the sector is predicted to become a net source between 2037 and 2041 and remain so until 2050. Under the Central scenario, the transition from a net sink to a net source is delayed until 2044. The maximum sink size is in the *Stretch* scenario for 2018 of 11.5Mt carbon dioxide equivalent (CO_2e). By 2050 the UK source in the *Central* scenario is predicted to be 0.3Mt CO_2e
- At a country level, Wales remains a small net sink under all scenarios (in the range 0.2Mt CO_2e to 1.2 CO_2e over the period 2018-2050 under all scenarios).
- England is a net sink under the *Low* and *Stretch* scenarios reflecting policy ambition beyond those in place in May 2019, but will later become a net source under *Baseline 1* (2038), Baseline 2 (2040) and *Central* scenarios (2041). By 2050 the emissions in the LULUCF sector are estimated

[1] https://www.gov.uk/government/collections/energy-and-emissions-projections
[2] https://naei.beis.gov.uk/reports/reports?report_id=1013

to be 2.5 Mt CO_{2e} in *Baseline 1*, 2.2 CO_2e in *Baseline 2* and 2.0 CO_2e in the *Central* scenario.

- Scotland is a net sink of decreasing magnitude over the 2020s and 2030s under all scenarios. In the *Baseline 1*, it becomes a small source from 2037 onwards. In the *Baseline 2,* it becomes a small source between 2042 and 2045.In all other scenarios it remains a sink throughout time.
- Northern Ireland is a small net source of between 0.0 and 0.7 MtCO_2e under the *Baseline 1*, *Baseline 2*,*Central* and *Low* scenarios, but becomes a small net sink of between 0 and 0.2 MtCO_2e during the 2040s under the *Stretch* scenario.
- The LULUCF sector in the UK and in each of the countries is dominated by CO_2 emissions and removals, although N_2O emissions also make a significant contribution.
- The changes in the Forest Land, Cropland, Grassland and Settlement categories determine the trend in the UK and each country.
- The main changes in the projections since the 1990-2016 projections are:
  - Forestry: Higher harvesting intensity assumed and lower forest sink. This is largely driven by improvements in the GHG inventory itself – more details are provided in Chapter 6 of the National Inventory Report (Brown *et al*. 2019) .
  - *Baseline 1* and *Baseline 2* scenarios use 2010 as the first projected year.
  - Baseline 2 – the effect of policies not aiming at reducing GHG emissions are considered similar to the *Central* scenario.
  - 2051-2100 estimates: land-use change is projected until 2050 but ongoing emissions / removals resulting from these changes are now projected out to 2100. This is predominantly relevant for forest carbon stock change and soil carbon stock change from land use transitions.

Contents

1 Introduction

Projections of UK greenhouse gas (GHG) emissions and removals from Land Use, Land-Use Change and Forestry (LULUCF) activities in the period to 2050 are described in this report. Projections are made for carbon stock changes and carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) emissions arising from LULUCF activities reported in the latest UK GHG Inventory, for the period 1990-2017 (Brown *et al*., 2019).

The LULUCF projections address a number of policy needs including:

- Alignment with international commitments for biennial reporting of projections with and without policy measures, and with additional measures;
- The projections feed into the annually updated Energy and Emissions Projections (EEP) published by the Department for Business, Energy and Industrial Strategy (BEIS) which help to track progress towards Government climate targets;
- The exploration of potential low carbon development strategies; and
- The requirement to monitor progress towards targets under the Climate Change (Scotland) Act, the Environment (Wales) Act. It is also used for the annual projection of GHG in Northern Ireland[3].

There have been some changes to the forest management elements of the projection scenarios this year, but except for land use change to forest or settlement, land management elements are largely unchanged from the previous projections (based on the 1990-2016 inventory). Three policy scenarios (*Central*, *Low* and *Stretch*) have been constructed along with two *Baseline* scenarios which continue existing trends pre-2010 with no new policy interventions.

- *Baseline 1* scenario: Underpins the option to submit a technical correction to the Forest Management Reference Level for the Second Commitment Period of the Kyoto Protocol. It is based on climate change-related and forestry policies extant in July 2009. The projections continue 2000-2009 average activity rates out to 2050 and the first projected year is 2010.
- *Baseline 2* scenario: This is the EEP "baseline" scenario. It is based on climate change-related and forestry policies extant in July 2009 as in *Baseline 1* for the duration of the original policy and the first projected year is 2010. Forest planting rates drop to a low level after 2015 to project the impact of no further grant-aided planting beyond that which was contained in existing policy in 2009 under the programme of the Common Agricultural Policy. Other activities not driven by policies with a specific time limit are considered similar to the *Central* scenario.
- *Central* scenario: Based on current policies and the duration of agreed funding (as extant in June 2019) continuing at the same rate into the future. Categories for which there is no direct policy we can project, a ten year average (2008-2017) is used. For afforestation, planting rates are maintained for the remainder of the current Rural Development Programme (RDP) to 2021, after which planting rates decline to those in *Baseline 2*. This is the EEP "reference" scenario.
- *Low* scenario: Climate change mitigation policy aspirations for England and each of the Devolved Administrations (DAs)[4] are projected forward beyond 2021.
- *Stretch* scenario: This assumes an ambitious climate change mitigation programme exceeding current policy aspirations and existing public funding.

The assumptions underlying the scenarios were developed by the Department for Business, Energy and Industrial Strategy (BEIS) with input from the Forestry Commission, the Department for Environment, Food and Rural Affairs (Defra), the Devolved Administrations (DAs) and LULUCF experts. The scenarios are designed to explore the magnitude of the changes in net emissions that could potentially be produced by LULUCF activities in the future, taking into account current land use policies and/or aspirations (e.g. achieving a certain percentage of forest cover by 2050). Domestic agriculture- and forestry-specific

[3] https://www.daera-ni.gov.uk/news/northern-ireland-greenhouse-gas-projection-statistics-released
[4] In this report the term country" includes the administrations within the UK which have devolved governments (Scotland, Wales and Northern Ireland) and England which does not.

policies and funding are not in place to meet some of the aspirations, particularly for the *Low* and *Stretch* scenarios, and they must therefore be treated as exploratory. Separate projections have been developed for each administration (England, Scotland, Wales and Northern Ireland) and combined into a total for the UK.

2 Basis for projections

The LULUCF sector (sector 4 in the UNFCCC Common Reporting Format for national GHG inventory) is divided into six land use types for reporting of emissions/removals: Forest Land (4A), Cropland (4B), Grassland (4C), Wetlands (4D), Settlements (4E) and Other Land (4F)[5]. Net carbon stock changes from Harvested Wood Products (HWP) are reported under an additional category (4G). Finally, indirect emissions of N_2O from managed soils are reported without being allocated to a specific land use. Emissions of GHG to the atmosphere (CO_2, CH_4 and N_2O) are expressed as positive quantities, and removals of CO_2 as negative quantities. Emissions of all three GHG are combined into total CO_2 equivalents, using Global Warming Potential factors from the fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC), published in 2007: 1 for CO_2, 25 for CH_4 and 298 for N_2O. The net LULUCF emission is the total of emissions and removals across the seven categories (4A-4G). The balance between emissions and removals within the sector means that the net total LULUCF emission or removal may currently seem small in comparison with other individual sector totals. However, the LULUCF sector remains significant as it represents the net balance of much larger emissions and removals that if altered through changes in land-use practice could shift LULUCF between a net sink to source. Furthermore, LULUCF is the only sector which currently removes GHG from the atmosphere, offsetting emissions from other sectors.

Calculations in the LULUCF inventory are on the basis of activities, which can fall across several land use types (Table 1[6]). Consistency with the inventory (1990-2017) methodology is ensured throughout the projections. There are detailed descriptions of the datasets and methodology in Chapter 6 and Annex 3.4 of the National Inventory Report (Brown *et al*. 2019). The *Afforestation, forest management* and *Land-Use Change (soils)* activities contribute the majority of the emissions/removals in the LULUCF sector. Accordingly, most consideration was given to the corresponding activities and to *Deforestation* when developing the assumptions for the different scenarios. The modelling of ongoing emissions and removals arising from land use changes up to 2050 has been extended to 2100 (although post-2050 changes in land use are assumed to be zero). This is predominantly relevant for forest carbon stock change and soil carbon stock change from land use transitions. The corresponding mineralisation and fertilisation N_2O emissions have been estimated. For the other minor emissions either the 2050 value has been continued out to 2100, or a value of zero has been assigned (for emissions that occur within the year of land use change).

[5] There are currently no emissions or removals of GHG from the Other Land category in the UK.
[6] The reference to Tiers 1-3 in Table 1 refers to the sophistication of the methodological approach: Tier 1 uses simple equations and default GHG emission factors provided by the IPCC; Tier 2 uses the same equations with country-specific emission factors and higher resolution activity data; Tier 3 uses country-specific models and/or inventory measurement systems with high resolution activity data.

Table 1: Activities producing emissions/removals of GHG in the UK's LULUCF sector.

Activity	Description	Inventory category
Afforestation and forest management	Carbon stock gains and losses in trees, litter, soils and harvested wood products are calculated by the forest carbon accounting model CARBINE (Tier 3). The model uses administration-specific data on forest planting, productivity, and forest management/ harvesting patterns. N_2O emissions from fertilization and drainage of forest soils are calculated from the same planting data (Tier 1). Estimates are adjusted to take account of forest area losses due to deforestation. The changes in the Harvested Wood Products (HWP) pool reflect changes in the forest harvesting rate and the use of forest products.	4A Forest Land (carbon stock changes, N_2O emissions) 4G Harvested Wood Products (carbon stock changes)
Wildfires	Emissions of GHG due to wildfires on forest land, cropland and grassland are modelled with a Tier 1 approach; biomass and litter densities for forest land are taken from the CARBINE model output; biomass densities for Cropland and Grassland use UK-specific values.	4A Forest Land (CO_2, CH_4 and N_2O emissions), 4B Cropland (CH_4 and N_2O emissions), 4C Grassland (CH_4 and N_2O emissions)
Land-Use Change (LUC)	Changes in biomass and soil carbon stocks due to non-forest land use change are modelled by a dynamic model of carbon stock change driven by land use change matrices calculated from land surveys (1950-2007) (Tier 3). Continuing changes in soil carbon stocks due to historical LUC (>20 years before current year) are reported under the relevant IPCC category, e.g. Cropland remaining Cropland, and changes due to more recent LUC (<20 years) are reported under the transition sub-category e.g. Land converted to Cropland. Changes in biomass stocks are assumed to occur in the year of the land use change. N_2O emissions associated with land use change are calculated from the same activity data using the IPCC Tier 1 methodology.	4B Cropland (carbon stock changes, N_2O emissions) 4C Grassland (carbon stock changes, N_2O emissions) 4E Settlements (carbon stock changes, N_2O emissions)
Deforestation	Carbon stock changes in the soil due to deforestation to another land use are calculated using the dynamic model of carbon stock change, while changes in biomass and HWP are calculated using the CARBINE forest carbon accounting model (both Tier 3). A proportion of the felled trees are assumed to be burnt on site (releasing CO_2, CH_4 and N_2O), and the remainder are converted to timber products.	4A Forest Land (biomass carbon stock changes) 4B Cropland (soil carbon stock changes; CO_2, CH_4 and N_2O emissions) 4C Grassland (soil carbon stock changes; CO_2, CH_4 and N_2O emissions) 4E Settlements (soil carbon stock changes; CO_2, CH_4 and N_2O emissions) 4G Harvested Wood Products (carbon stock changes)
Cropland management	Changes in soil carbon stocks due to inputs of fertilizer, manure and crop residues and changes in biomass stock due to changes in crop type are calculated using the IPCC Tier 1 methodology except for reduced tillage or the absence of tillage.	4B Cropland (biomass and soil carbon stock changes)

Activity	Description	Inventory category
Grassland management	Changes in biomass carbon stocks due to changes between grassland types are calculated using the IPCC Tier 1 methodology.	4C Grassland (biomass carbon stock changes)
Agricultural drainage	Emissions from drainage on lowland agricultural organic soils are estimated using the IPCC Tier 1 methodology.	4B Cropland (soil carbon stock changes) 4C Grassland (soil carbon stock changes)
Peat extraction	The IPCC Tier 1 methodology is used to calculate on-site emissions from peat extraction and off-site emissions from the decomposition of domestically produced horticultural peat. Emissions from the extraction of horticultural peat imported to the UK is not included in the UK inventory.	4D Wetlands (soil carbon stock changes; CO_2 and N_2O emissions)

3 Assumptions underlying the scenarios

The scenario assumptions for each activity and country (summed to give the UK total) are described in this section. The following assumptions remain constant across all scenarios:

- Land areas for each country of the UK are assumed to remain constant. They are taken from the Standard Area Measurement[7] publication (national baseline). Land loss due to sea level rise is neglected in these scenarios, as are changes in the UK land area due to coastal re-alignment.
- LULUCF input data (for 1990-2017 in the Central, Low and Stretch scenarios and 1990-2009 in the Baseline 1 Baseline 2 scenarios) in the published GHG inventories[8] have not been changed and feed through as the initial condition for the projected emissions.

Graphs of UK-level activity data are shown in this section; a break-down by country is given in Annex 2. Table 2 shows which activities correspond to each UNFCCC land use category.

Table 2: UNFCCC land use categories and contributing activities.

UNFCCC LULUCF land use category	Carbon stock change or gas	Activity producing emissions/removals
Forest Land (4A)	Carbon stock change	Afforestation and forest management
	CO_2 emissions from burning	Wildfires
	CH_4 emissions	Wildfires
	N_2O emissions	Afforestation and forest management Wildfires
Cropland (4B)	Carbon stock change	Land-Use Change Deforestation Cropland management Agricultural drainage
	CO_2 emissions from burning	Deforestation
	CH_4 emissions	Wildfires Deforestation
	N_2O emissions	Wildfires Land-Use Change Deforestation
Grassland (4C)	Carbon stock change	Land-Use Change Deforestation

[7] https://www.ons.gov.uk/methodology/geography/geographicalproducts/otherproducts/ukstandardareameasurementssam
[8] https://www.gov.uk/government/statistics/final-uk-greenhouse-gas-emissions-national-statistics-1990-2017

UNFCCC LULUCF land use category	Carbon stock change or gas	Activity producing emissions/removals
		Grassland management
		Agricultural drainage
	CO_2 emissions from burning	Deforestation
	CH_4 emissions	Wildfires
		Deforestation
	N_2O emissions	Wildfires
		Land-Use Change
		Deforestation
Wetlands (4D)	Carbon stock change	Peat extraction
	N_2O emissions	Peat extraction
Settlements (4E)	Carbon stock change	Land-Use Change
		Deforestation
	CO_2 emissions from burning	Deforestation
	CH_4 emissions	Deforestation
	N_2O emissions	Land-Use Change
		Deforestation
Harvested Wood Products (4G)	Carbon stock change	Afforestation and forest management
		Deforestation

3.1 Afforestation and forest management

This activity is driven by the amount of new forest planting in each country and affects forest carbon stock changes, changes in the Harvested Wood Products pool, nitrogen fertilisation of forests and forest drainage (CO_2 and N_2O).

- The *Baseline 1* scenario uses the 2009 planting rates for all projection years (2010 onwards), as in the Forest Management Reference Level (FMRL) used in the Kyoto Protocol reporting.
- The *Baseline 2* scenario assumes average planting over the (2008-2009) will continue throughout the Rural Development Programme (until 2014), and then reducing to 10% of this rate for 2015-50.
- The *Central* scenario uses forest planting rates according to funding secured for grants within each country[9]. Later, from 2024 in England and after 2021 in the DAs, planting rates drop to the *Baseline 2* rates, reflecting the lack of secured funding beyond that time horizon as of June 2019.
- The *Low* (emissions) scenario uses forest planting rates observed until March 2019. Assumptions for the rest of 2019 and beyond are projected to reflect policy aspirations in each country.
- The *Stretch* scenario assumes an ambitious planting programme exceeding current policy

[9] The assumptions for Scotland in the scenario slightly underestimate secured funding which should have been 10kha in 2019 and 2020 instead of 7.559kha.

aspirations or funding (differentiated by country). It remains broadly consistent with the stretch scenario adopted as Maximum Technical Potential used in the Marginal Abatement Cost Curve for the development of the Impact Assessment for the 5th Carbon Budget regulations.

- Planting rates for the financial year 2018/19 have been published and have been used in setting assumptions for the calendar year 2018 (see Annex 3).
- Proportion of conifer/broadleaf planting: for the *Baseline 1* and *Baseline* 2 scenarios the conifer/broadleaf split reported for 2009 is projected forward; and for all other scenarios each country has proposed a conifer/broadleaf split consistent with current policy aspirations and grant availability/targeting (Scotland: 60% conifer; England: 30% conifer; Wales: 16% conifer (current 2014 value); Northern Ireland: 2% conifer (current default)).

The UK afforestation rates are presented in Figure 1, with a breakdown by country provided in Annex 3.

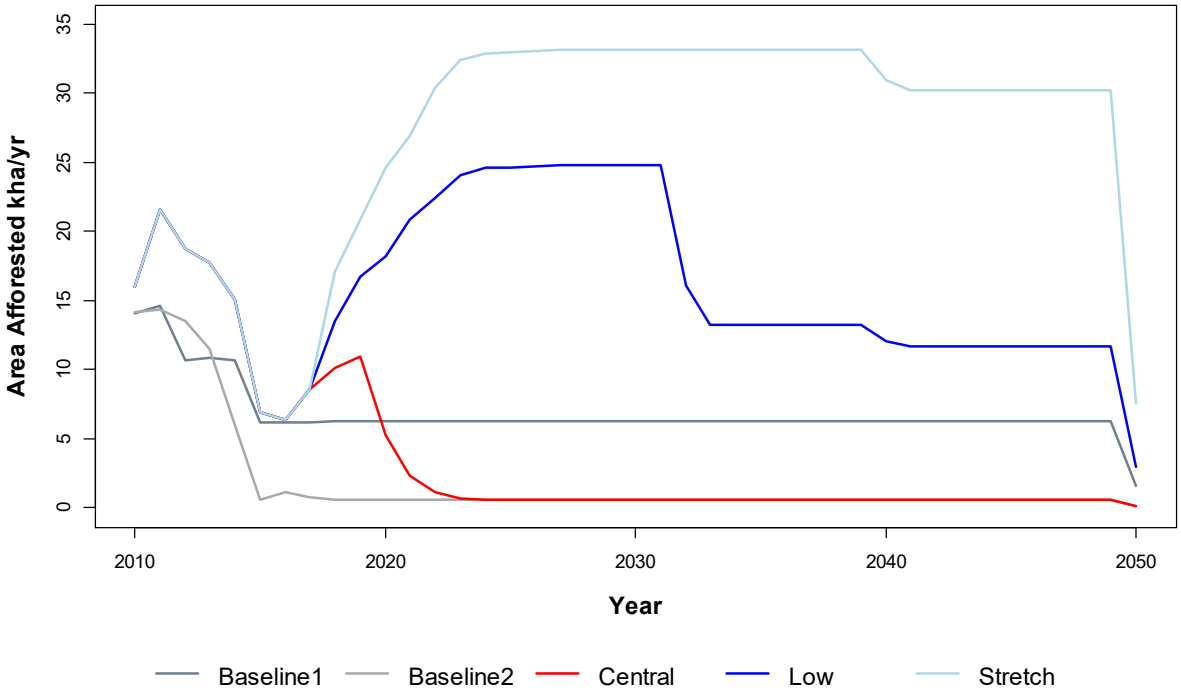

Figure 1: Afforestation rates for the emissions scenarios (UK). Note that a disaggregation of these data by country is provided in Annex 3.

Forest management is projected based on percentages of conifers and broadleaves that are used as productive forests and rotation lengths estimated using the "Reconcile" algorithm, through which the forest management assumptions are adjusted to match the volume of wood harvested estimated by CARBINE to the volume presented in national statistics. These rotations and level of harvesting are applied into the future, assuming no changes in the management of forests occur in the projection period.

For the 1990-2017 inventory, the "Reconcile algorithm was optimised in order to be able to test a much larger parameter space and to automatically choose the parameters that best match production in the period covered by the wood production statistics (1976-2017). This ensures that the parameters are selected objectively and that the parameter selection can be more easily justified and replicated.

This algorithm had the effect of significantly increasing the estimated wood production from 2011, which better matches the increase in production seen in the wood production statistics.

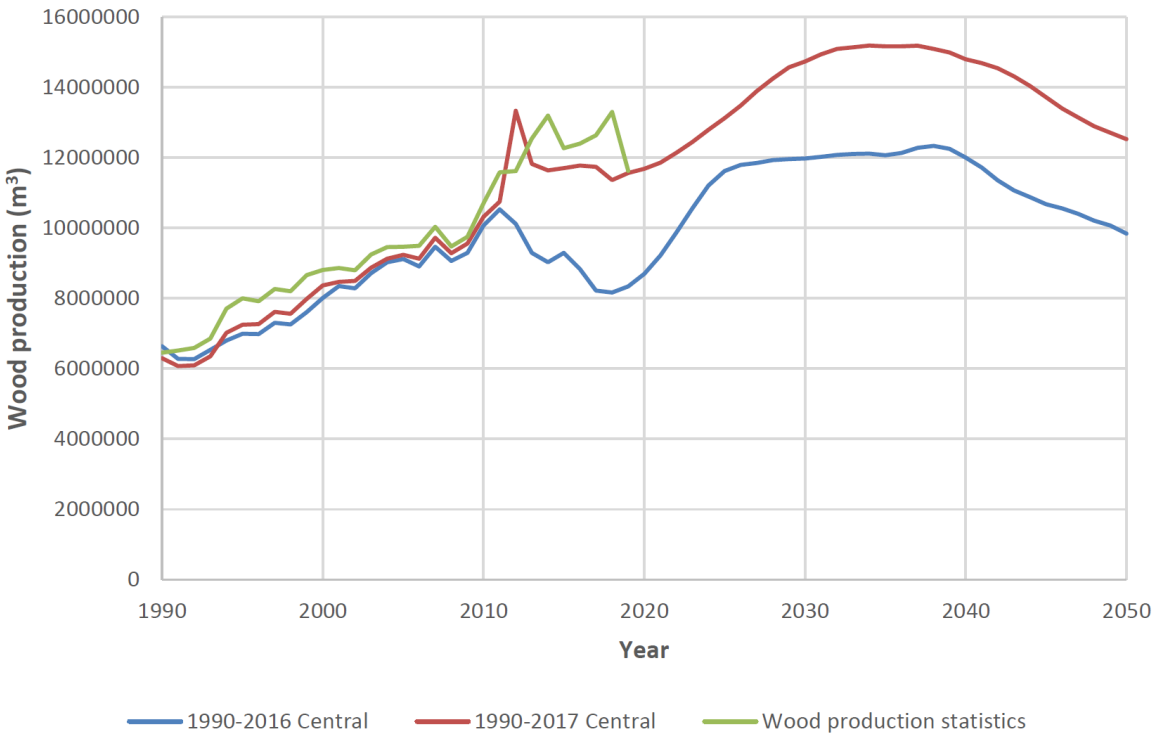

Figure 2: Comparison of wood production in this and the previous set of projections with the wood production statistics (UK).

3.2 Wildfires

Burnt area arising from wildfires on Forest, Cropland and Grassland are presented in Figure 3, Figure 4 and Figure 5, respectively. This activity is driven by the area of forest, cropland and grassland burnt annually in wildfires, affecting GHG emissions from burning (CO_2, CH_4 and N_2O)[10]. Carbon dioxide emissions from wildfires on cropland and grassland are assumed to be replaced within the year by vegetation regrowth, so only emissions of CH_4 and N_2O are reported in 4B and 4C. The amount of fuel available to forest wildfires varies for each scenario as afforestation rates are different.

The wildfire historical time series (not presented here) shows high inter-annual variability (dependent upon the weather conditions at certain times of year).

- In the *Baseline 1* scenario the annual burnt area from 2010 onwards equals the average burnt area during the historical baseline period (2000-2009 for forest wildfires and 2001-2009 for cropland and grassland wildfires where the available time series was shorter).
- In the *Baseline 2* and *Central* scenarios the annual burnt area from 2018 onwards equals the average annual burnt area for the decade up to the latest inventory year (2017).
- In the *Low* and *Stretch* scenario the annual burnt area from 2018 onwards is the value of the 5th percentile of the wildfire area time series for the decade up to the latest inventory year (2017).

[10] There are no non-forest wildfire data for Northern Ireland (NI), so the area burnt was estimated using the NI Countryside Survey areas for cropland and grassland scaled by the % burnt of cropland and grassland in Scotland 2010-2014. The time series was extended using the ratio of the estimated NI burnt area to the Great Britain (GB) burnt area.

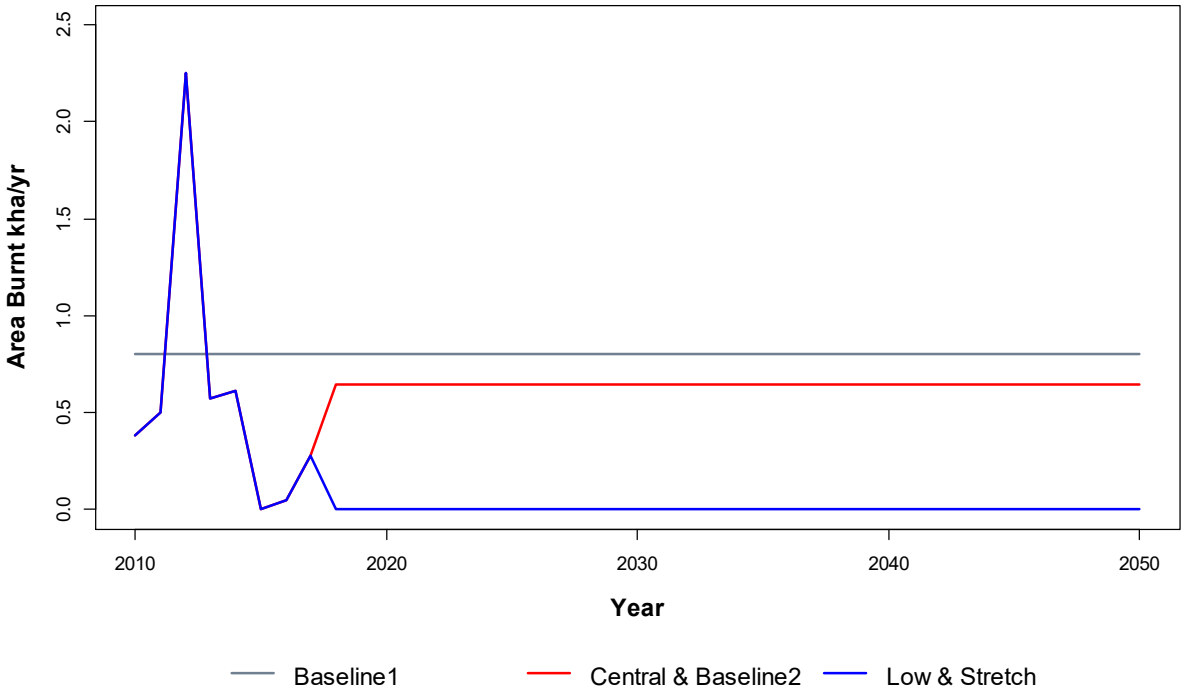

Figure 3: Forest wildfire activity data for the emissions scenarios (UK)

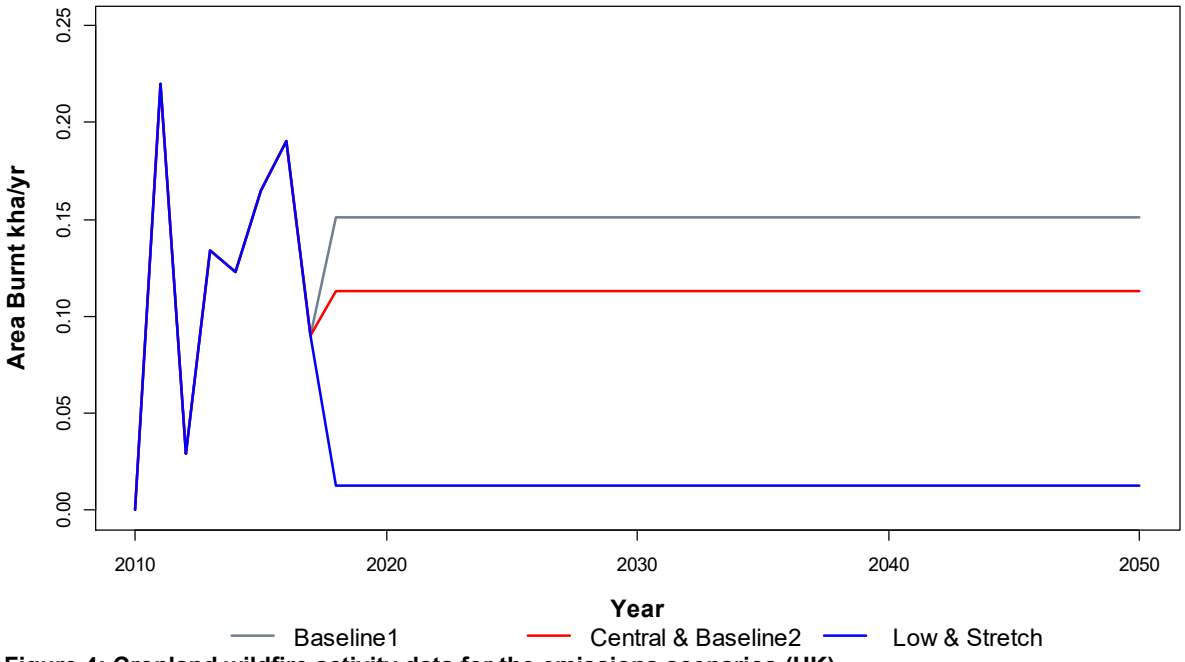

Figure 4: Cropland wildfire activity data for the emissions scenarios (UK)

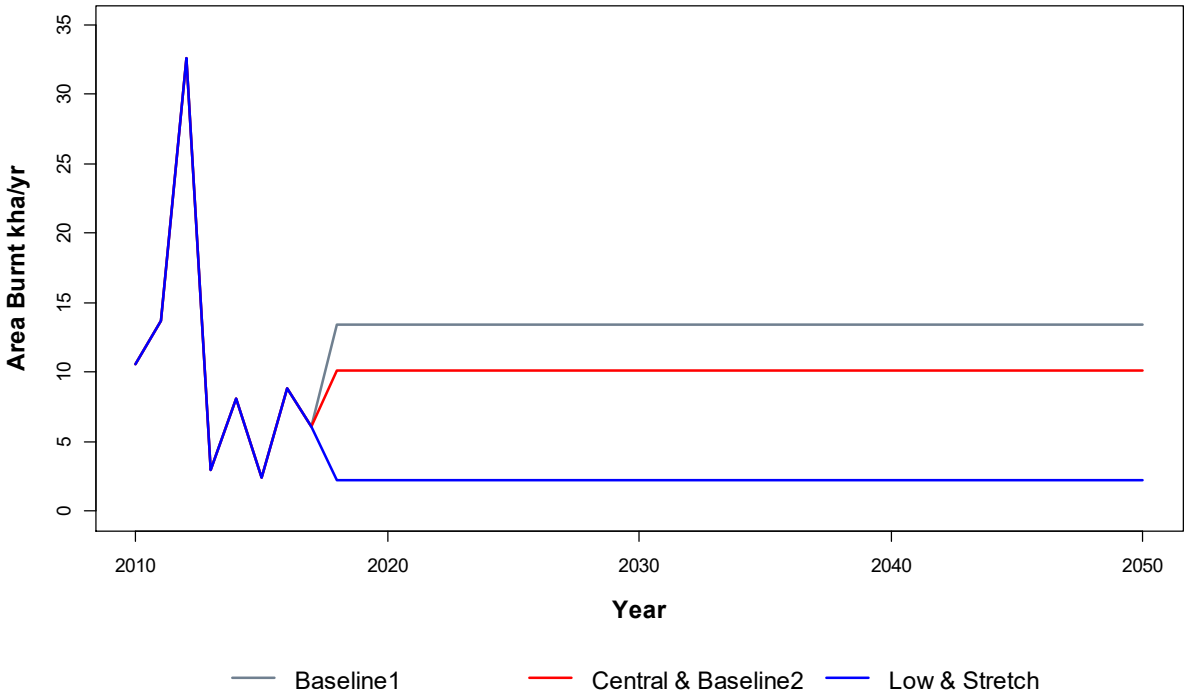

Figure 5: Grassland wildfire activity data for the emissions scenarios (UK)

3.3 Land-Use Change (LUC)

This activity is driven by the areas of annual land use change between Cropland, Grassland and Settlement (Figure 6, Figure 7 and Figure 8), affecting carbon stocks of biomass and soils, and N mineralisation to N_2O as a result of carbon stock changes from land use change. Conversion to and from Forest Land are taken into account within the Afforestation and Deforestation activities.

In all countries, it is assumed that there is a constant level of cropland-grassland conversion and vice-versa across all projection scenarios (with no net change in areas) to reflect agricultural land rotation. This is based on the average annual conversion each way 1990-2009 for each country (56.6 kha in England, 16.7 kha in Scotland, 5.2 kha in Wales and 4.2 kha in Northern Ireland each way). In addition, an additional flux of conversion of grassland to cropland is assumed in Wales (based on advice from Welsh Government).

Conversion to Settlement is based on different house-building scenarios (see Annex 1) and is assumed to be from Grassland (after taking Deforestation areas into account).

- In the *Baseline 1* scenarios decadal averages (2000-2009) are used for each land use transition except in the following case: a Grassland to Cropland conversion rate of 1 kha/y for Wales is assumed in addition to the rotation rate.
- In the *Baseline 2* and *Central* scenario decadal averages (2008-2017 – which is in practice equivalent to 2000-2009 when using the 1990-2017 inventory as a reference) are used for each land use transition except in the following cases:
    - conversion to Settlement assumes that house building is sufficient to meet the projected housing demand in each country;
    - a Grassland to Cropland conversion rate of 1 kha/y for Wales is assumed in addition to the rotation rate.
- The *Low* and *Stretch* scenarios are the same as in the *Central* scenario except that the total area converted to Settlement is 50% of the *Central* scenario annual conversion area for all countries. As the area of Forest to Settlement is fixed across scenarios and is deducted from the total settlement conversion flux first, the area of Grassland converted to Settlement in the

Low and Stretch scenario will be less than half of the Central scenario throughout the time series.

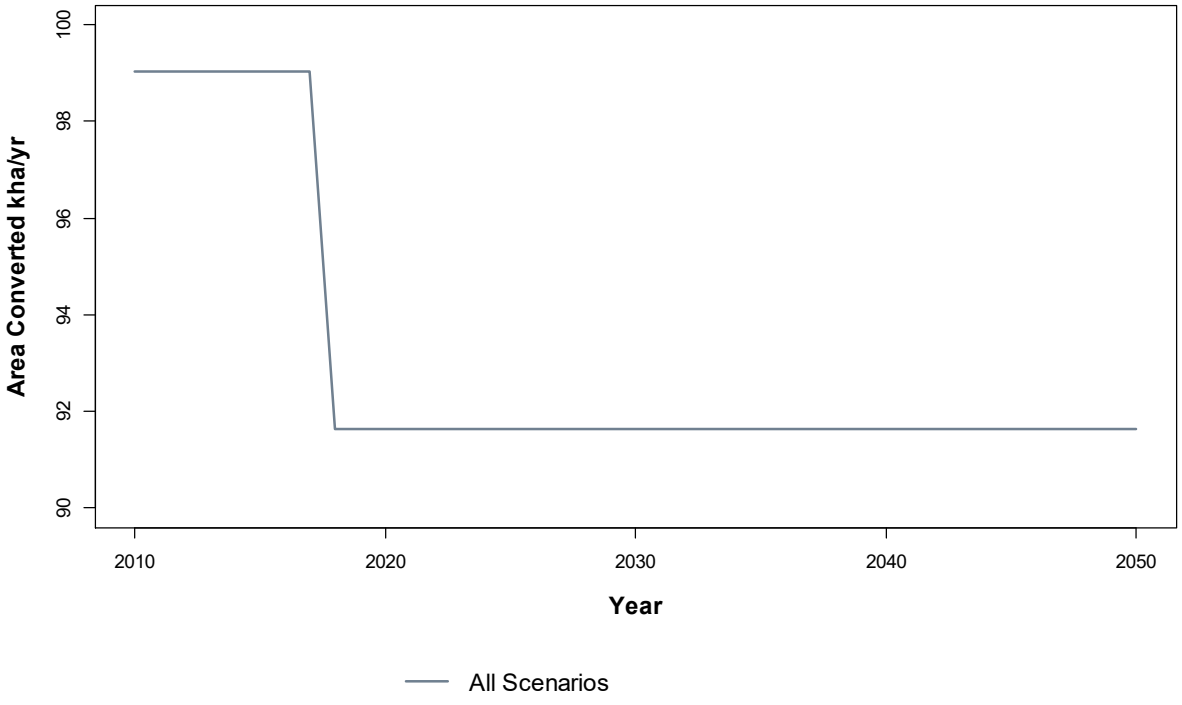

Figure 6: Activity data for Cropland to Grassland land use change for the emissions scenarios (UK)

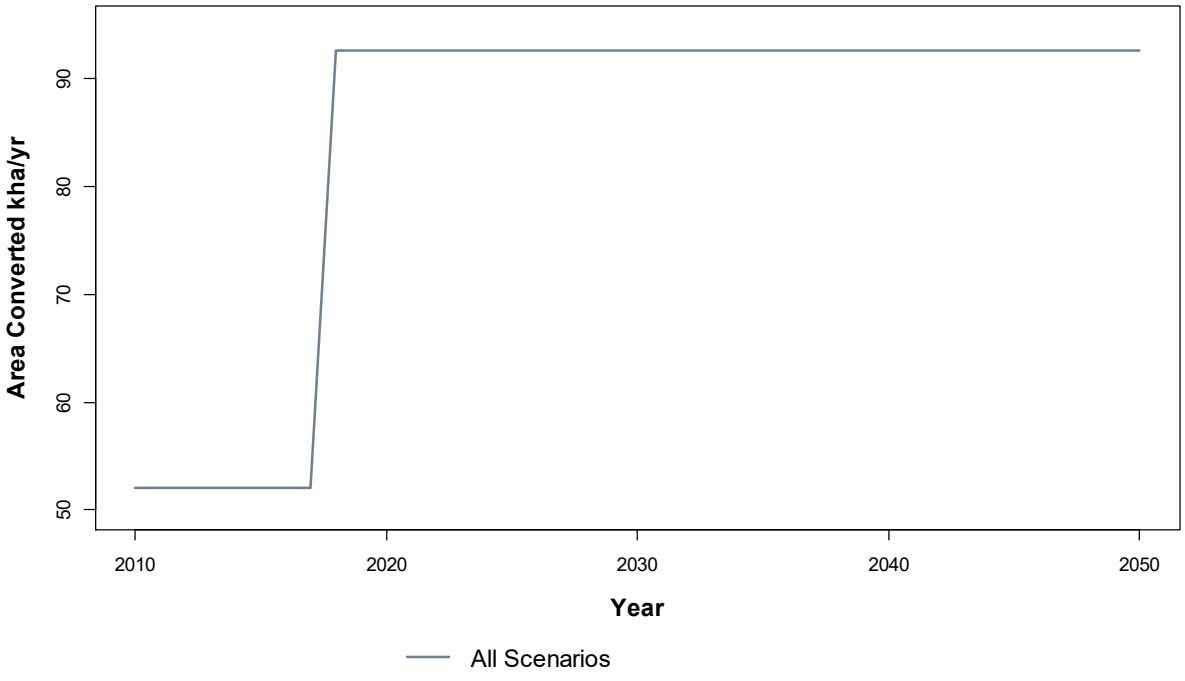

Figure 7: Activity data for Grassland to Cropland land use change for the emissions scenarios (UK)

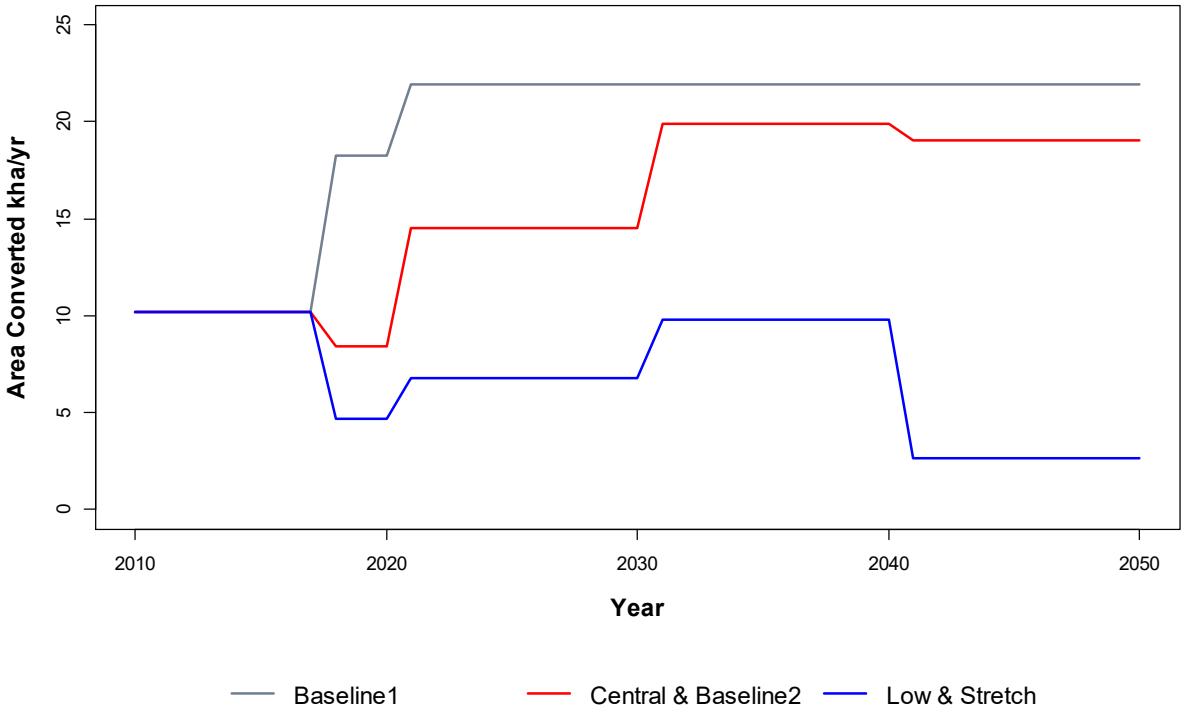

Figure 8: Activity data for Grassland to Settlement land use change for the emissions scenarios (UK)

3.4 Deforestation

This activity is driven by the area of forest annually converted to other land uses (Figure 9). It affects forest carbon stocks, the Harvested Wood Products pool and GHG emissions from biomass burning (CO_2, N_2O, and CH_4).

It is difficult to assign deforestation levels to specific afforestation/emissions scenarios, as in some cases a low deforestation rate might arise when planting rates are low, with policy responding to avoid net deforestation. Alternatively, deforestation might be independent of afforestation, responding to economic and housing development, for example. Although the Scottish Government's policy on 'the Control of Woodland Removal' and FCE's Open Habitats policy (When to convert woods and forests to open habitats in England) are mentioned in the UK's LULUCF Action Plan and the 2011 Carbon Plan, they are not associated with explicit estimates of potential abatement and the impact of their implementation cannot be quantified.

Two deforestation levels have been used: *Baseline 1* projects the 2009 levels of deforestation forward at a constant level to 2050; reflecting the lack of explicit policies (see above) to reduce deforestation prior to this date. However, as there is a limit to the potential area available for restoration from forest to open habitat (currently the main driver of deforestation) this assumption represents a high emission assumption.

The other scenarios use a linear transition from the 2008-2017[11] average in 2018 to a level corresponding to the rate equivalent to the average conversion to settlement over 2008-2017 from 2040 onwards.

[11] These deforestation levels were compiled by forestry experts using reported definite land cover change and administrative data on habitat restoration and deforestation for wind farm development.

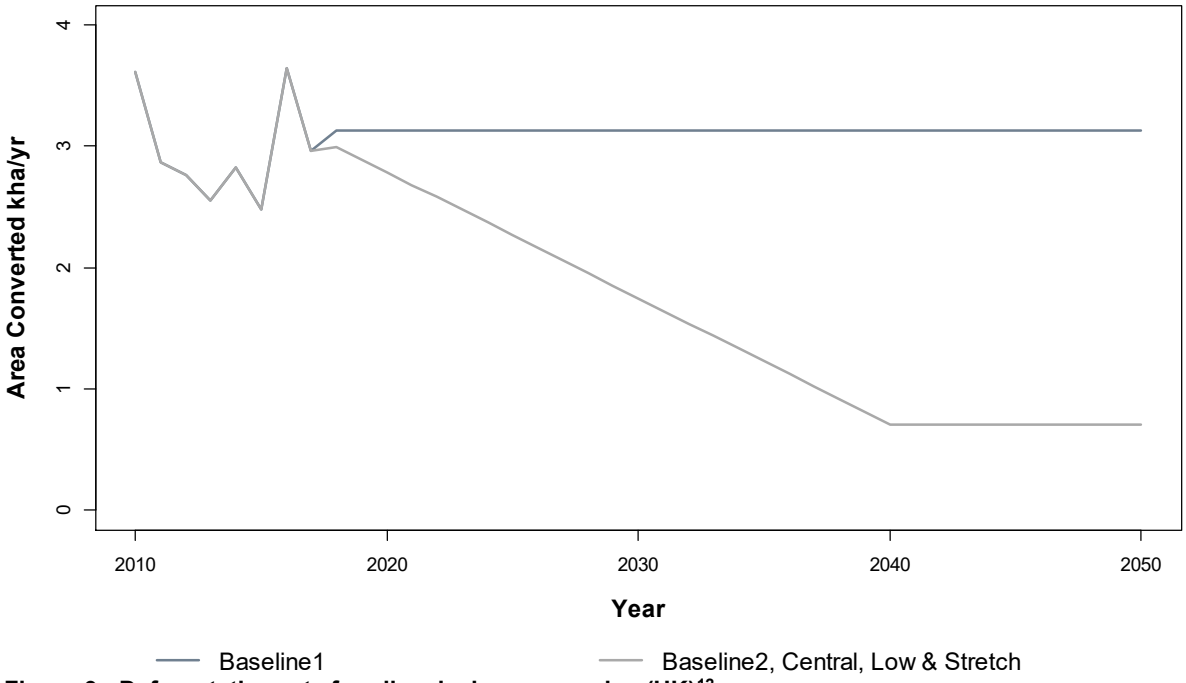

Figure 9 : Deforestation rate for all emissions scenarios (UK)[12].

3.5 Cropland and Grassland management

Cropland Management activity is driven by differences between land management on cropland, mainly the balance between perennial and annual crops, manure inputs and crop residue inputs. Grassland management activity is driven by within-grassland changes, e.g. from non-shrubby to shrubby grassland.

- For the *Baseline 1* scenario pre-2009 decadal average rates of management activities are used (Table 3).
- For the *Baseline2, Central* and *Low* scenarios, levels of management activity remain at 2017 levels until 2050.
- For the *Stretch* scenario the Cropland Management is as for the *Central* but for Grassland Management hedges are extended by 40% with a linear rate until 2050.

Table 3: Activity data for Cropland Management scenarios.

		England (E)/ Wales (W)/ Northern Ireland (NI)		Scotland	
		Baseline 1	***Baseline 2/Central/ Low/ Stretch***	***Baseline 1***	***Baseline 2/Central/ Low/ Stretch***
Soil carbon stocks	% crop area receiving mineral N fertiliser	90	88	96	96
	% crop area receiving Farmyard Manure	18	24	29	31
	Tillage: full inversion % area	56 (E, W) 94 (NI)	56(E, W) 92 (NI)	89	90
	Tillage: minimum	40 (E, W)	40 (E, W)	11	6

[12] Disaggregation of these data by country is provided in Annex 3.

		England (E)/ Wales (W)/ Northern Ireland (NI)		Scotland	
		Baseline 1	***Baseline 2/Central/ Low/ Stretch***	***Baseline 1***	***Baseline 2/Central/ Low/ Stretch***
	tillage % area	2 (NI)	6 (NI)		
	Tillage: None or direct seeding % area	4 (E, W) 5 (NI)	4 (E, W) 1 (NI)	0	4
	% crop residue removed (average)	55 (GB)	55 (GB)	55 (GB)	55 (GB)
	% land manured (average)	2.6 (GB)	3.2 (GB)	2.6 (GB)	3.2 (GB)
Biomass carbon stocks	Area of cropland, kha	4,472 (E)70-96 (2017-2050) (W) 56 (NI)	4,417 (E) 93- 127 (2018-2050) (W) 48 (NI)	623	592

3.6 Agricultural drainage

It is assumed that no new areas of agricultural organic soils have been drained since 1990 so the area drained remains steady throughout the projected time series.

3.7 Peat extraction

The area covered by peat extraction and extraction site restoration is small compared with other land use activities (Figure 10). Even after extraction ceases, this area may not always be converted to another land use and so remains in the Wetland category.

- For the *Baseline 1* and *Baseline 2* scenarios the area drained for peat extraction remains at 2009 levels for all DAs. In England, restoration to target habitats is assumed to have a 100% success rate for area drained for peat extraction with planned expiry dates. The volume of horticultural peat extracted (and decomposing) each year is projected to be fixed at the decadal average for 2000-2009.
- For the *Central* scenario the area drained for peat extraction remains at 2017 levels in all countries, except those in England with planned expiry dates, where restoration to target habitats is assumed to have a 50% success rate. The volume of horticultural peat extracted each year is projected to be fixed at the decadal average 2008-2017 for Scotland and Northern Ireland, but in England there is a projected 50% drop in volume production by 2030 on sites still in operation. There is no horticultural peat extraction in Wales.
- For the *Low* scenario it is assumed that there is a cessation of all peat extraction with 50% successful site restoration by 2050 for sites in Scotland, Wales and Northern Ireland. In England, extraction area in 2017 is the same as in the Central scenario, however with 100% restoration success of inactive sites to target habitats. The volume of horticultural peat extracted each year is projected to be fixed at the decadal average 2008-2017 for Northern Ireland, to decline to zero by 2050 for Scotland and drop to zero by 2030 for England.
- For the *Stretch* scenario, it is assumed that there is cessation of all peat extraction with 100% successful restoration in all countries by 2030, with a concomitant reduction in horticultural peat volume.

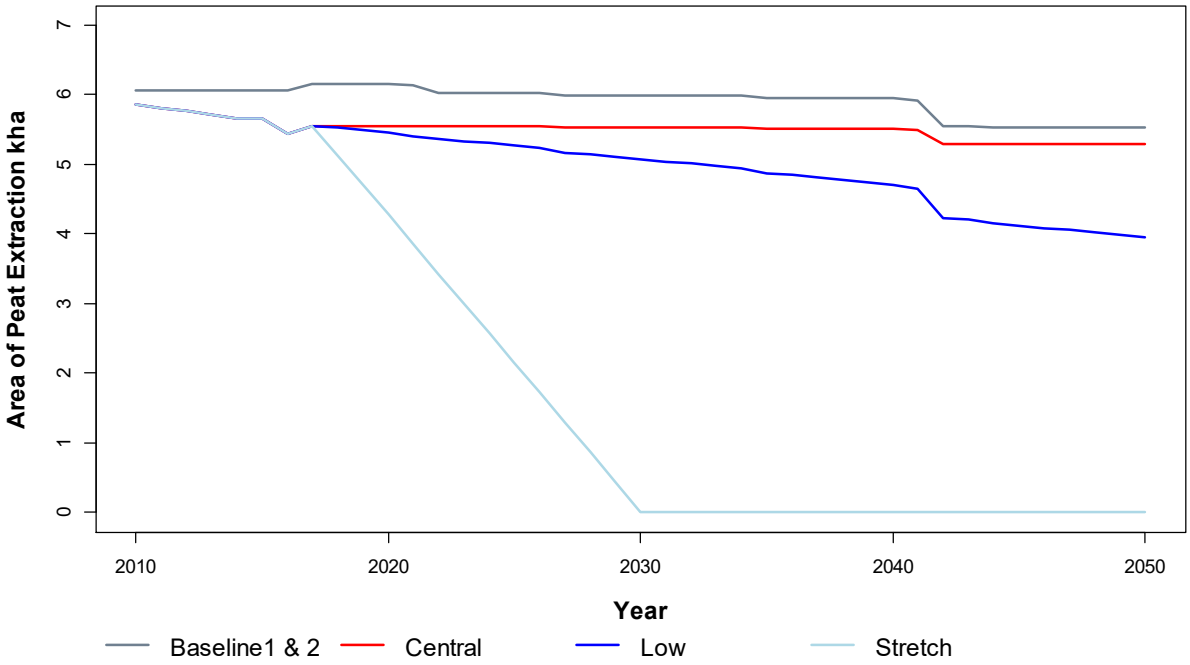

Figure 10: Peat extraction areas over time for all scenarios.

4 Projections 2017-2100

A summary of the results is given here. Detailed emission estimates by activity, country and scenario are available for download from the NAEI website[13].

4.1 Land-Use Areas

Table 4 shows the projected distributions of land use areas in the UK between 2017 and 2050 - the areas for each country are reported in Annex 2. The areas of land in each category were produced via extrapolation of the land use change matrices listed in the National Inventory Report (Brown *et al*., 2019). These land use change matrices rely largely on Countryside Survey datasets and may therefore differ from other national datasets. From 2051 to 2100 no further land use change is included in the scenarios but emissions and removals occurring from previous land use change are modelled.

There is greatest land use change in the *Stretch* emissions scenario at the UK and country level (due to increases in forest area and accompanying losses in grassland area). Wales shows the greatest land use changes under all scenarios, due to the assumption of additional grassland-cropland conversion in Wales. Grassland is lost at the expense of other land use types under all scenarios.

[13] https://naei.beis.gov.uk/reports/reports?report_id=1013

Table 4: Land use areas[14] 2017-2050 for the United Kingdom (24,419 kha).

Emission scenario	*Land use category*	*2017 area, kha*	*2020 area, kha*	*2030 area, kha*	*2040 area, kha*	*2050 area, kha*	*% of land area in 2017*	*% of land area in 2050*
Central	Forest land	3509	3526	3512	3505	3504	14%	14%
	Cropland	5078	5083	5093	5104	5114	21%	21%
	Grassland	13398	13306	13138	12924	12717	55%	52%
	Wetland	169	169	169	169	169	1%	1%
	Settlement	1788	1838	1996	2200	2397	7%	10%
	Other	497	516	531	537	537	2%	2%
Baseline 1	Forest land	3477	3487	3518	3549	3576	14%	15%
	Cropland	5078	5083	5093	5104	5114	21%	21%
	Grassland	13398	13265	12983	12707	12436	55%	51%
	Wetland	169	169	169	169	169	1%	1%
	Settlement	1788	1887	2115	2342	2569	7%	11%
	Other	529	548	560	568	575	2%	2%
Baseline 2	Forest land	3460	3453	3436	3429	3428	14%	14%
	Cropland	5078	5083	5093	5104	5114	21%	21%
	Grassland	13398	13337	13171	12957	12750	55%	52%
	Wetland	169	169	169	169	169	1%	1%
	Settlement	1788	1838	1996	2200	2397	7%	10%
	Other	546	559	574	580	580	2%	2%
Low	Forest land	3509	3549	3766	3899	4000	14%	16%
	Cropland	5078	5083	5093	5104	5114	21%	21%
	Grassland	13398	13279	12980	12749	12610	55%	52%
	Wetland	169	169	169	168	168	1%	1%
	Settlement	1788	1810	1869	1947	1963	7%	8%
	Other	497	549	561	572	583	2%	2%
Stretch	Forest land	3509	3563	3861	4178	4450	14%	18%
	Cropland	5078	5083	5093	5104	5114	21%	21%
	Grassland	13398	13254	12875	12470	12168	55%	50%
	Wetland	169	168	165	164	164	1%	1%
	Settlement	1788	1810	1869	1947	1963	7%	8%
	Other	497	560	576	576	579	2%	2%

[14] The percentages reflect the UK area including water bodies.

4.2 UK projected emissions and removals

Table 5, Table 6, Table 7 and Table 8 show projected emissions of CO_2, CH_4, N_2O and total CO_2 equivalents for the LULUCF sector for the UK, and the full dataset is available for download with this report from the NAEI website[15]. Graphs of GHG emissions at the UK and country level for the whole LULUCF sector and for the individual land use categories are shown in Figure 11, Figure 12, Figure 13, Figure 14 and Figure 15. These graphs show the projected data to 2100 together with the reported inventory data for 1990-2017 for the *Central, Low* & *Stretch* scenarios and 1990-2009 for the *Baseline 1* and *Baseline 2* scenarios.

At the UK level, (Figure 11) the net CO_2 equivalent emissions / removals from all parts of the LULUCF sector are combined to produce an increasing net carbon sink (increasing net removals) between 1990 and 2016. This trend reverses around 2022, driven by the decreasing net removals in the Forest Land category as now mature forests planted when afforestation rates were at a maximum from the 1950s to 1980s are harvested, and an increasing trend in net Cropland and Settlement emissions. The difference between scenarios widens in the the late 2030s/early 2040s, with the *Central* and *Baseline* scenarios continuing towards zero and the *Low* and *Stretch* scenarios becoming increasing sinks again. The main driver of the trend in net total LULUCF emissions / removals over the projected time series is the reduction in the forestry net removals (this varies between scenarios), although the increase in settlement emissions and the reversal in the declining trend in cropland emissions also contribute. From 2051 onward, only emissions/removals from forestry and from previous land use change are modelled, while other sources are assumed to remain constant. The results over 2051-2100 therefore only reflect the lag effects of policy implemented (and land-use change occurring) over the first half of the twenty first century.

Forestry is projected to be a net sink under all scenarios. It is an increasing sink between 1990 and 2010, and then shows some variation between then and 2020, before showing a net decrease in sink strength under all scenarios. This decrease continues until the mid-2030s when the *Central* and *Baseline* scenarios stabilise, while the net sink strength starts to increase again under the Low and Stretch scenarios. The scenarios are driven by the projected planting rates and management, with the biggest projected sink coming from the *Stretch* scenario with high planting rates, and the smallest sink coming from the *Baseline* and *Central* scenarios with the lower planting rates. The decrease in the sink between 2020 and 2035 is due to large numbers of trees being thinned or reaching maturity (some 35-50 years since planting) and hence being harvested, and a low planting rate from the 1990s.

Cropland is projected to be a slowly increasing source post-2017, mostly driven by land use change to Cropland in Wales and a higher level of crop-grass rotations than in 2000-2017. Grassland is projected to be a slowly increasing sink. There is little difference between the scenarios for either of these land use categories as the differences in the scenario land use change assumptions are small. Post 2050 with no further land use change the trends for Cropland and Grassland reverse as soil carbon losses / gains tail off.

The scale of changes in the Wetlands net source is small compared to the other land use categories. Figure 16 shows the changes in net emissions on a larger scale graph. The differences between scenarios are driven by assumptions about the reduction in peat extraction and the restoration of former extraction sites.

Emissions from land use change to Settlements are projected to decrease over the time period under the *Low* and *Stretch* scenarios, but to increase under the *Central* and *Baseline* scenarios (driven predominantly by the net emissions from England). Although Settlement areas are predicted to increase under all scenarios, the rate of change of land to Settlement (and hence emissions from land use change) varies between the different scenarios. The activity data for the projections have been revised this year and are discussed further in Annex 1. As in the case of Cropland, the Settlement emissions reduce post 2050 with no further transitions to the category.

Harvested Wood Products (HWPs) are projected to be a small sink over the period 2018 to 2050. The trend is driven by the balance between deforestation rates, thinning and felling regimes and the expected lifetime of the HWPs. There is little difference between the scenarios as the majority of harvest originates from trees planted before the projection time period, though the sink is slightly larger in the stretch scenario throughout the projections as the share of sawnwood and panels among Harvested Wood Products is assumed to be 5% higher in that scenario. In the second half of the century, the scenarios become distinguishable as the projected planted areas come into harvest. The largest sink occurs in the *Stretch* scenario matching the ambitious planting.

CO2, arising from soil and biomass carbon stock changes, is the main GHG associated with LULUCF (Figure 17), although N_2O emissions also make a significant contribution when the Global Warming Potential of N_2O of

[15] https://naei.beis.gov.uk/reports/reports?report_id=1013

298 is taken into account. These N_2O emissions arise from forest fertilisation, forest drainage, soil nitrogen mineralisation following land use change and from biomass burning. The *Stretch* scenario does not result in the lowest emissions of N_2O because the increased afforestation (with increased CO_2 removals) in this scenario also produces increased N_2O emissions from forest fertilisation and drainage. CH_4 emissions (Global Warming Potential of 25) arising from biomass burning are included in the projections but they do not make a significant contribution to the overall totals.

4.3 Country-level projected emissions and removals

England shows a sharp reduction in the net sink strength after 2020 (Figure 12), becoming a net source of LULUCF emissions by 2038-40 under the *Baseline* scenarios and 2041 under the *Central* scenario. The differences between the scenarios in the 2018-2050 time period come predominantly from differences in the Settlement category emissions, as there is little difference between the scenarios for the Forest Land category. Post 2050 forestry becomes more important as the longer-term carbon stock changes arising from planting up to 2050 are realised.

The projections for Scotland indicate a net LULUCF GHG sink for most scenarios with the exception of the *Baseline1* scenario which becomes a source over 2037-2050 and the *Baseline 2 scenarios over 2042-2045*. The overall pattern of projected emissions and removals for Scotland (Figure 13) is similar to the UK, being driven primarily by the Forest Land sink and Settlement source.

Wales (Figure 14) is a small net LULUCF GHG sink for all scenarios throughout the time series. Some differentiation between scenarios due to net removals from the Forest Land category becomes apparent in the 2040s.

Northern Ireland (Figure 15) is projected to be a net LULUCF GHG source for much of the time period to 2050, although under the *Stretch* scenarios it is projected to become a small net sink during the 2040s. This is mainly driven by the trend in emissions from Settlements, which peak in 2018 and then decrease to 2050. Without ongoing land use changes beyond 2050 the sink increases for all scenarios.

The relative contributions of the LULUCF sector from the DAs to the UK total are shown in Figure 18 (Central scenario).

4.4 Changes from the 1990-2016 projections

There have been some changes to activity data and methods used for estimating the LULUCF emissions and removals since the previous projections report. These differences are shown at the UK level in Figure 19 by comparing the *Central* projections based on the 1990-2017 and 1990-2016 inventories.

In the Forest Land category, significant improvement have been introduced in the 1990-2017 inventory (correcting of a double-counting error of input to deadwood pool at harvest and improvement in the representation of the actual harvest intensity in recent years, as described in more details in the National Inventory Report published in 2019). This has led to assume a higher harvest over the first decades of the projections as well and hence has an effect on both the Forest Land and Harvested Wood Products categories.

Projections from the Settlement category have changed because the published time series of house-building has been revised, leading to larger estimates of conversion to Settlement in England in particular. Further details are given in Annex 1.

The modelling of ongoing emissions and removals until 2100 arising from land use changes up to 2050 has been introduced. This is predominantly relevant for forest carbon stock change and soil carbon stock change from land use transitions. The corresponding mineralisation and fertilisation N_2O emissions have been estimated. For the other minor emissions either the 2050 value has been continued out to 2100, or a value of zero has been assigned (for emissions that occur within the year of land use change).

Table 5: LULUCF emissions and removals of CO_2 1990-2050.

Scenario	Country	1990 Gg CO_2	2017 Gg CO_2	2020 Gg CO_2	2030 Gg CO_2	2040 Gg CO_2	2050 Gg CO_2	2075 Gg CO_2	2100 Gg CO_2
Central	UK	-1996	-11323	-11767	-7355	-2615	-1385	-8785	-6538
Baseline 1	UK	-1996	-12260	-12075	-5862	-333	1166	-9735	-6901
Baseline 2	UK	-1996	-11508	-11965	-7171	-1893	-424	-8548	-6113
Low	UK	-1996	-11323	-11995	-8144	-5266	-7470	-14392	-9129
Stretch	UK	-1996	-11323	-12862	-9014	-5977	-9140	-20527	-10868

Table 6: LULUCF emissions and removals of CH_4 1990-2050.

Scenario	Country	1990 Gg CH_4	2017 Gg CH_4	2020 Gg CH_4	2030 Gg CH_4	2040 Gg CH_4	2050 Gg CH_4	2075 Gg CH_4	2100 Gg CH_4
Central	UK	0.64	1.13	1.34	1.03	0.69	0.71	0.50	0.50
Baseline 1	UK	0.64	1.32	1.58	1.58	1.52	1.54	0.63	0.63
Baseline 2	UK	0.64	1.13	1.34	1.03	0.69	0.71	0.50	0.50
Low	UK	0.64	1.13	0.91	0.60	0.26	0.27	0.06	0.06
Stretch	UK	0.64	1.13	0.91	0.60	0.26	0.27	0.06	0.06

Table 7: LULUCF emissions and removals of N_2O 1990-2050.

Scenario	Country	1990 Gg N_2O	2017 Gg N_2O	2020 Gg N_2O	2030 Gg N_2O	2040 Gg N_2O	2050 Gg N_2O	2075 Gg N_2O	2100 Gg N_2O
Central	UK	7.55	4.71	4.70	5.22	5.62	5.64	0.84	0.42
Baseline 1	UK	7.55	4.68	4.76	5.76	6.35	6.47	1.03	0.48
Baseline 2	UK	7.55	4.64	4.62	5.13	5.62	5.64	0.84	0.42
Low	UK	7.55	4.71	4.63	5.04	5.31	4.77	0.54	0.32
Stretch	UK	7.55	4.71	4.65	5.14	5.59	5.17	0.56	0.34

Table 8: LULUCF emissions and removals of CO_2 equivalents 1990-2050 (1 Mt CO_2eq = 1000 Gg CO_2eq).

Scenario	Country	1990 Gg CO_2 eq	2017 Gg CO_2 eq	2020 Gg CO_2 eq	2030 Gg CO_2 eq	2040 Gg CO_2 eq	2050 Gg CO_2 eq	2075 Gg CO_2 eq	2100 Gg CO_2 eq
Central	UK	270	-9893	-10332	-5774	-922	313	-8522	-6400
Baseline 1	UK	270	-10833	-10615	-4106	1598	3132	-9414	-6742
Baseline 2	UK	270	-10096	-10555	-5617	-202	1273	-8286	-5977
Low	UK	270	-9893	-10591	-6627	-3678	-6042	-14230	-9033
Stretch	UK	270	-9893	-11453	-7468	-4303	-7594	-20360	-10766

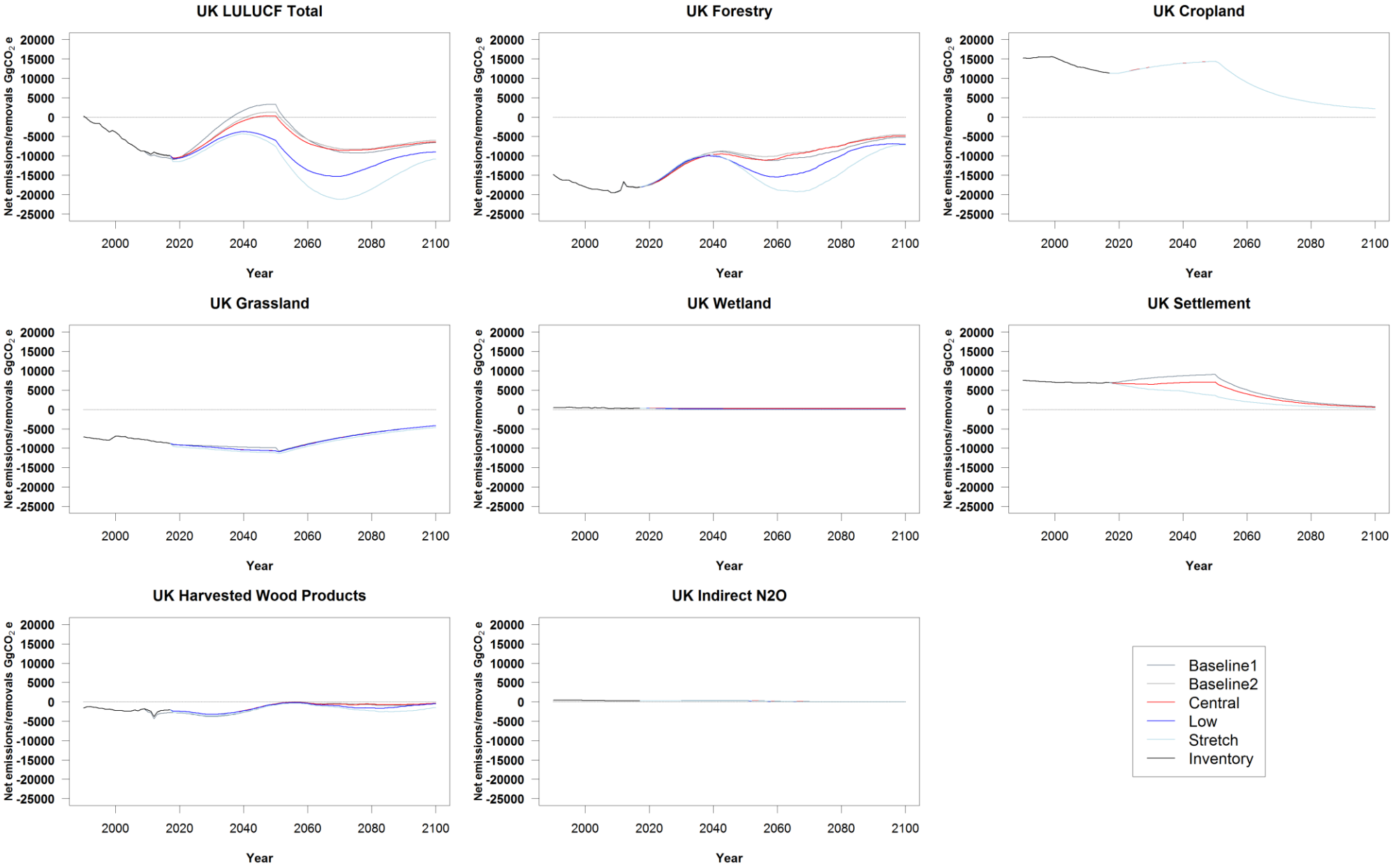

Figure 11: UK LULUCF CO_2 equivalent emissions scenarios 1990-2100. The individual graphs refer to LULUCF reporting categories; see Section 3 text for description of what is reported in these categories (1 Mt CO_2eq = 1000 Gg CO_2eq). Results from 2051 onward only reflect the lag effects of changes in Activity Data pre 2050.

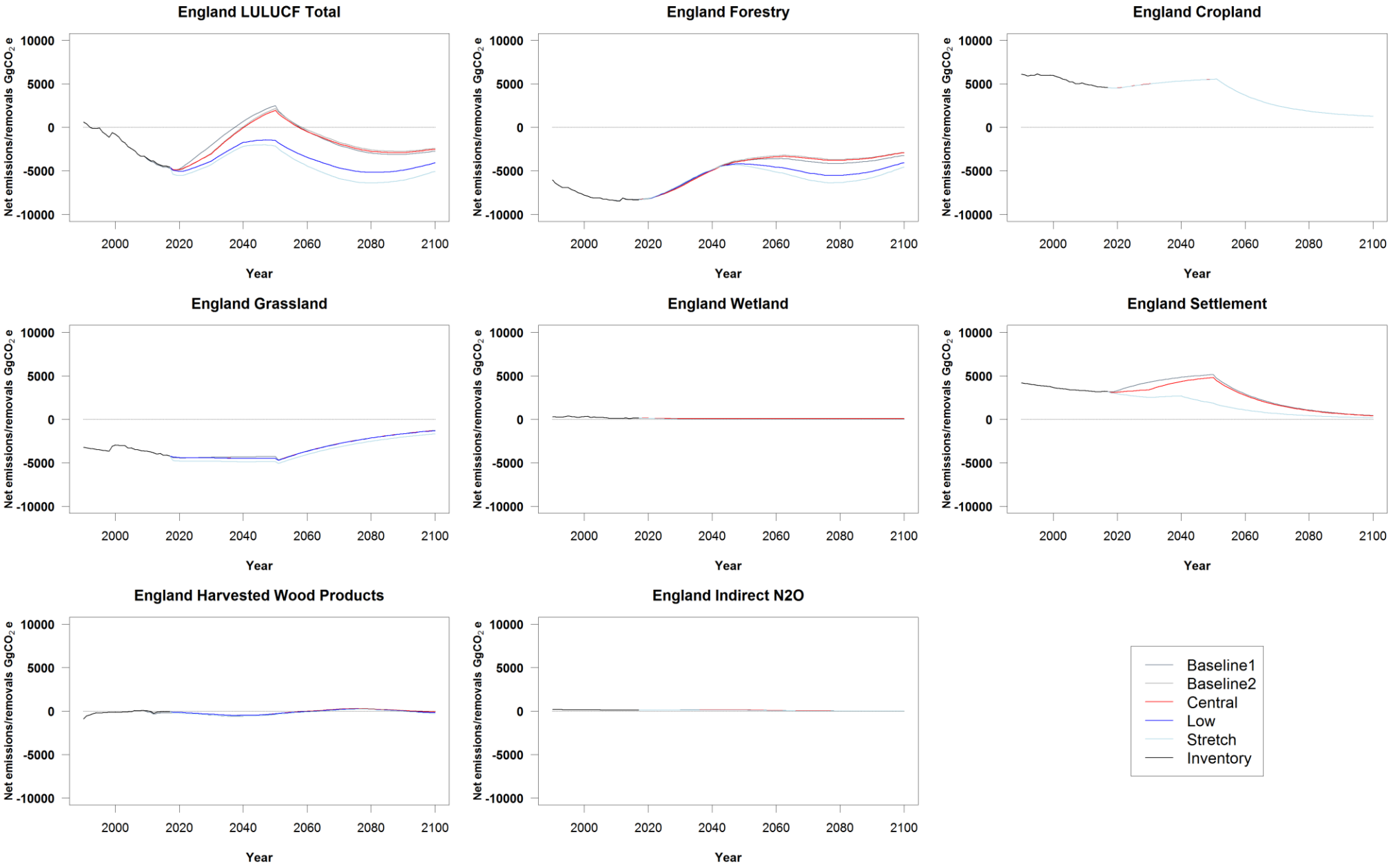

Figure 12: England LULUCF CO_2 equivalent emissions scenarios 1990-2100. The individual graphs refer to LULUCF reporting categories; see Section 3 text for description of what is reported in these categories (1 Mt CO_2eq = 1000 Gg CO_2eq). Results from 2051 onward only reflect the lag effects of changes in Activity Data pre 2050.

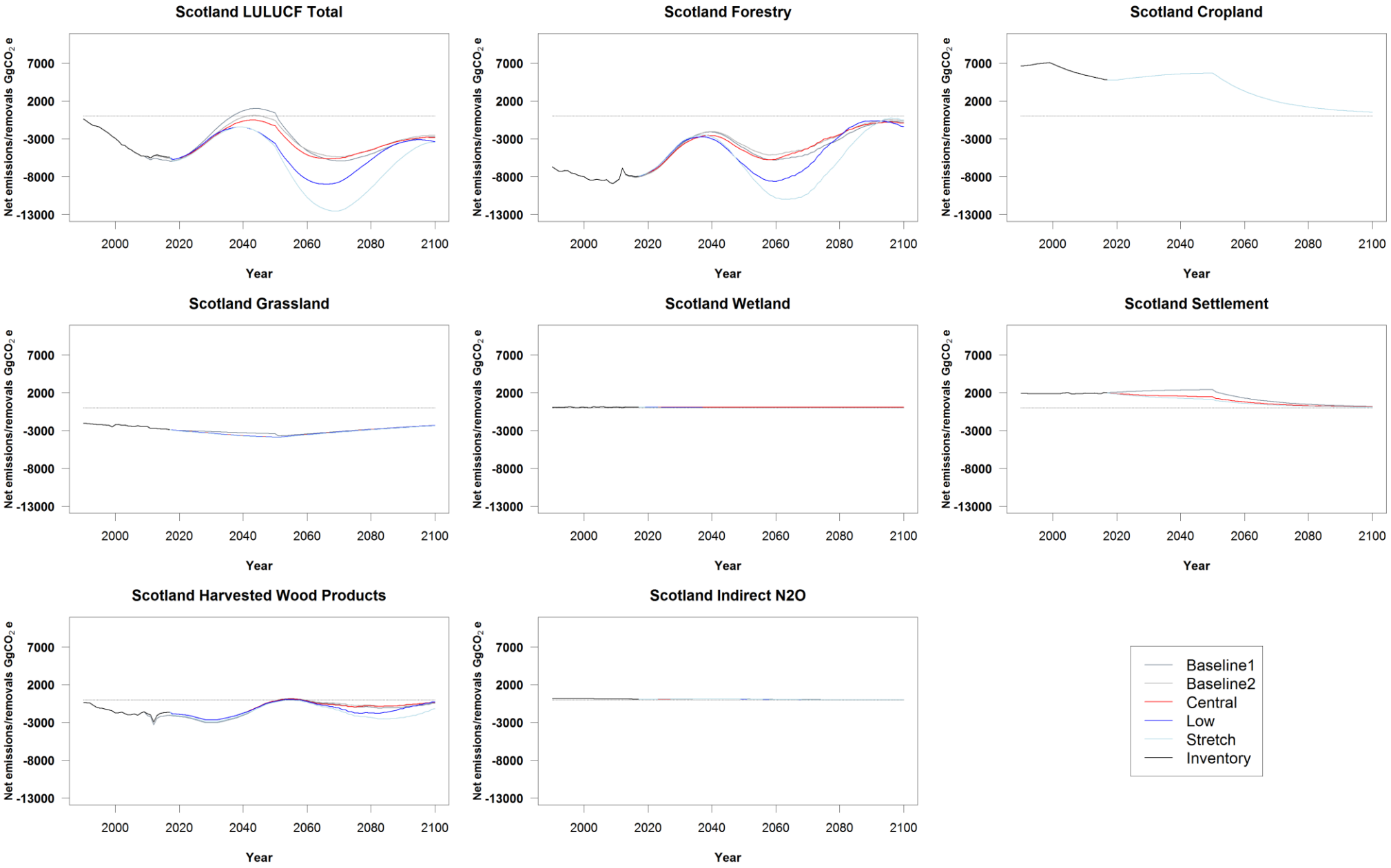

Figure 13: Scotland LULUCF CO_2 equivalent emissions scenarios 1990-2100. The individual graphs refer to LULUCF reporting categories; see Section 3 text for description of what is reported in these categories (1 Mt CO_2eq = 1000 Gg CO_2eq). Results from 2051 onward only reflect the lag effects of changes in Activity Data pre 2050.

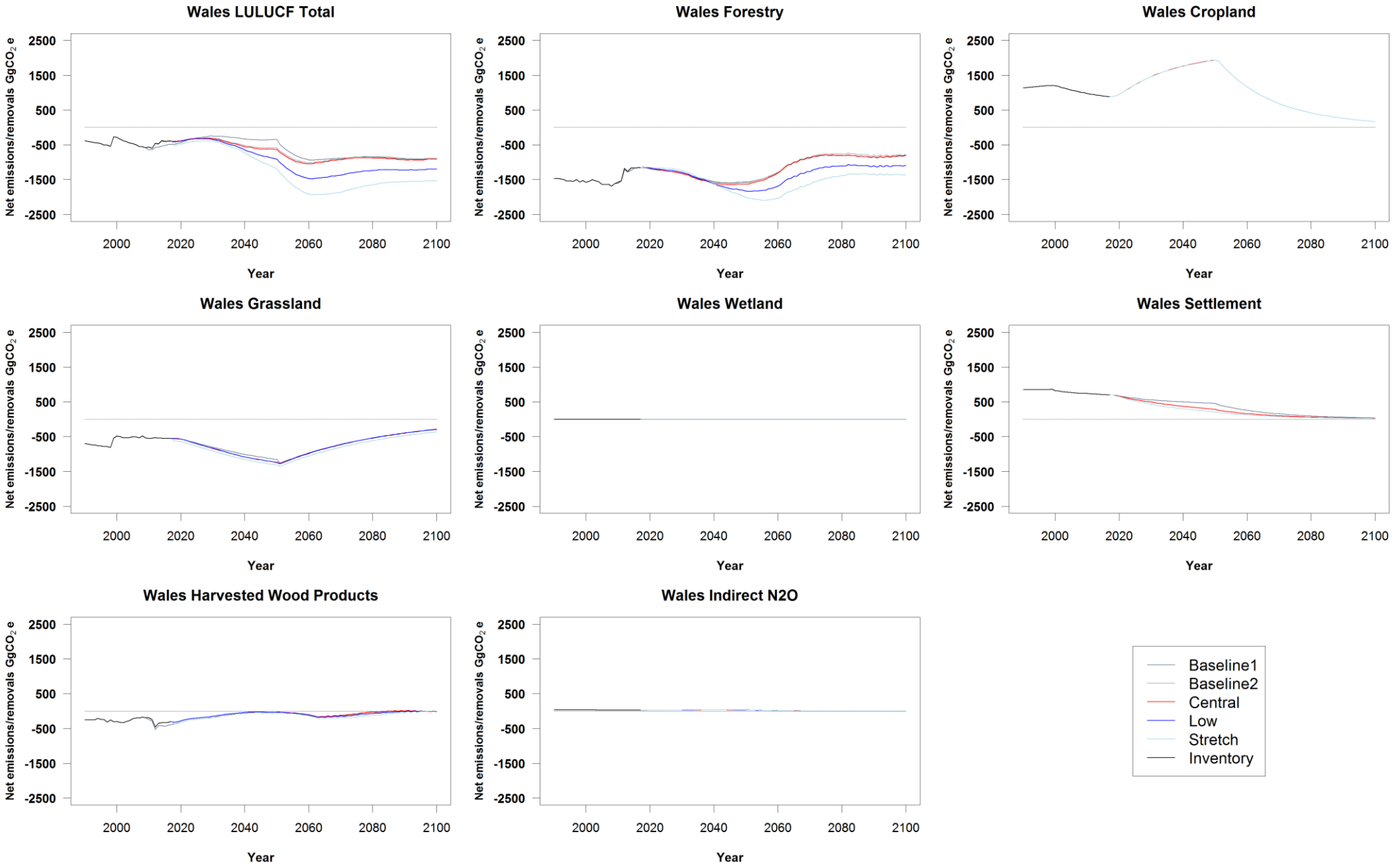

Figure 14: Wales LULUCF CO_2 equivalent emissions scenarios 1990-2100. The individual graphs refer to LULUCF reporting categories, which for cropland and grassland are mainly driven by land use change (1 Mt CO_2eq = 1000 Gg CO_2eq). Results from 2051 onward only reflect the lag effects of changes in Activity Data pre 2050.

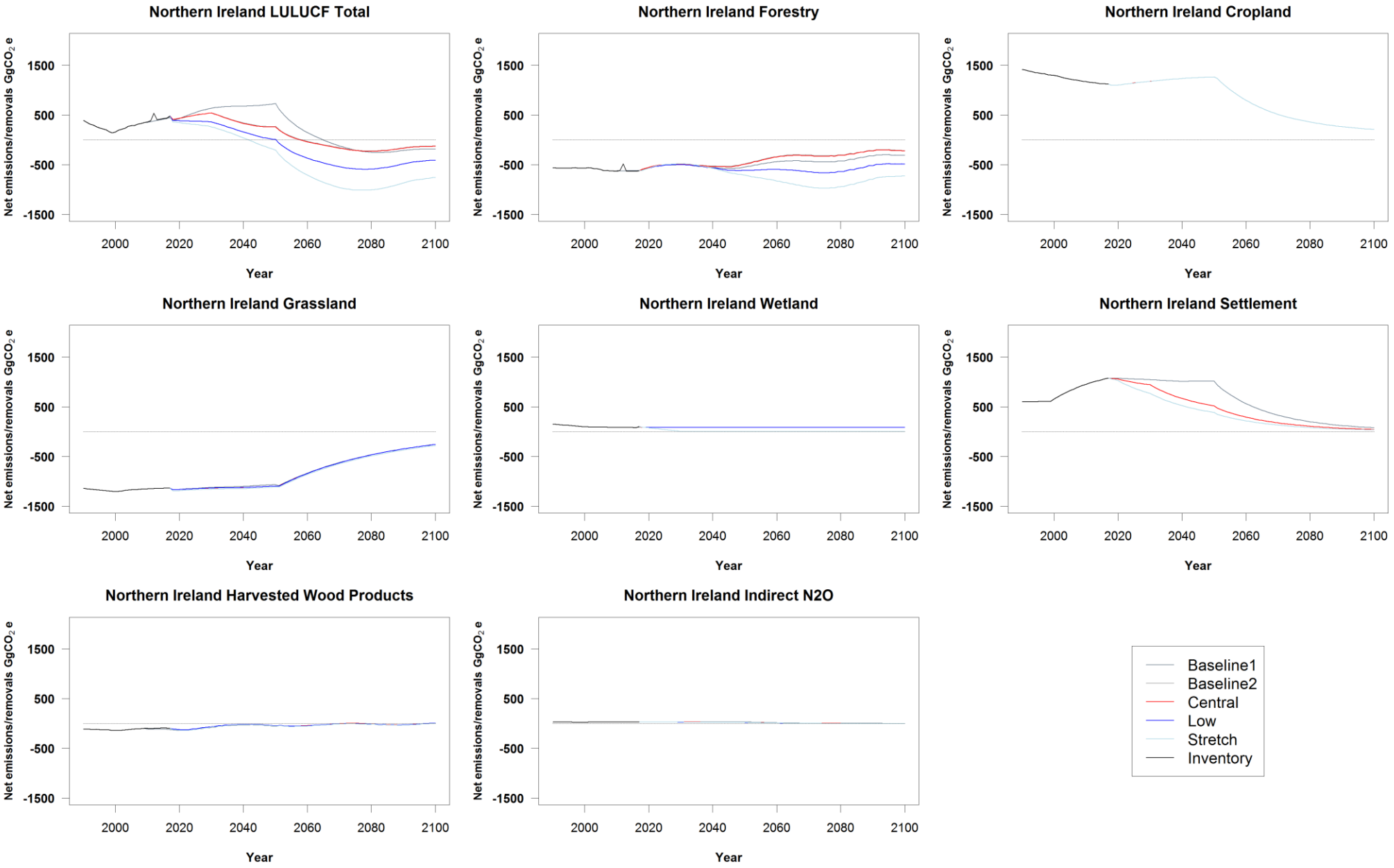

Figure 15: Northern Ireland LULUCF CO2 equivalent emissions scenarios 1990-2100. The individual graphs refer to LULUCF reporting categories; see Section 3 text for description of what is reported in these categories (1 Mt CO2eq = 1000 Gg CO2eq). Results from 2051 onward only reflect the lag effects of changes in Activity Data pre 2050.

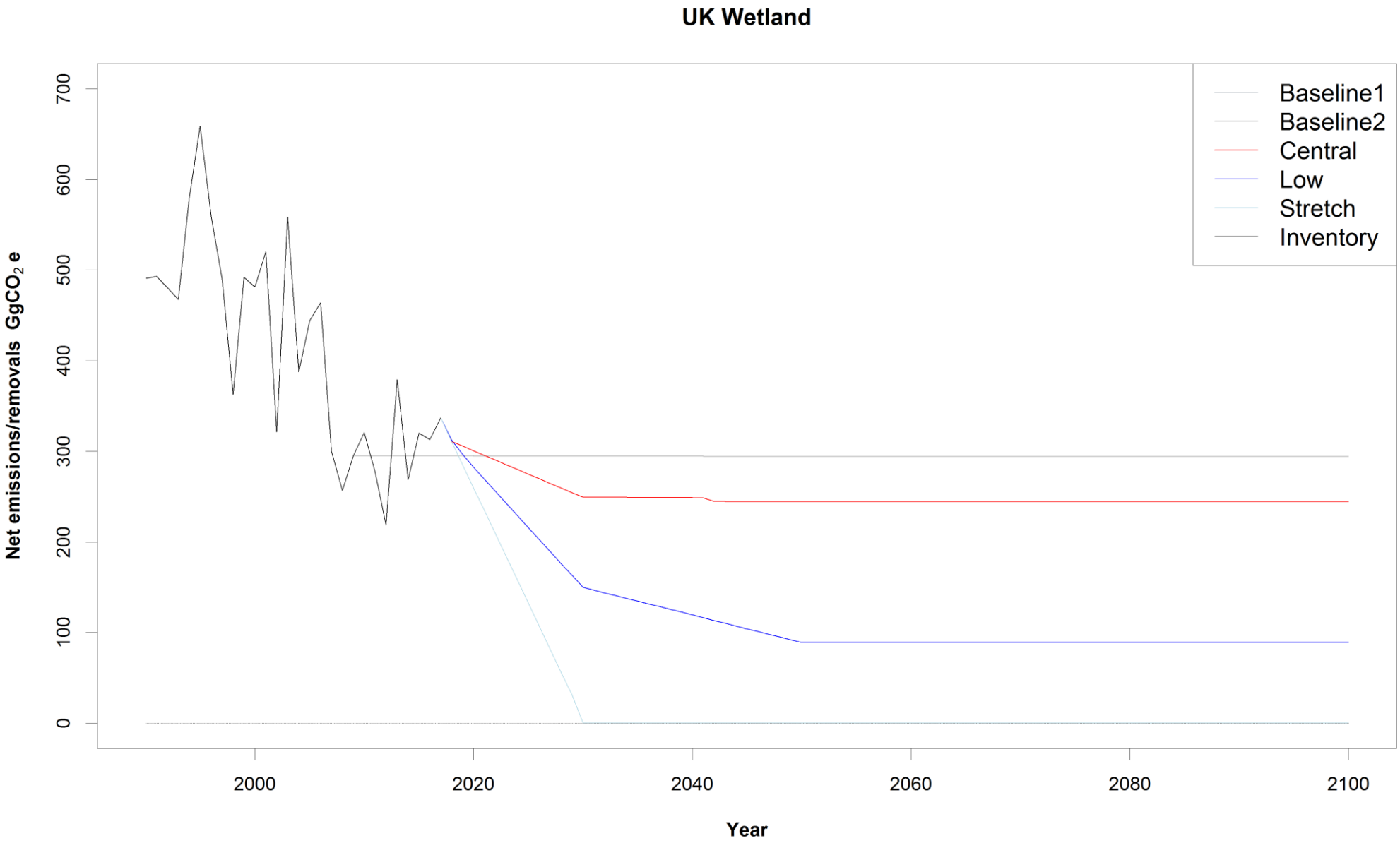

Figure 16: Net emissions from Wetlands under all scenarios (shown on larger scale for clarity) (1 Mt CO_2eq = 1000 Gg CO_2eq).

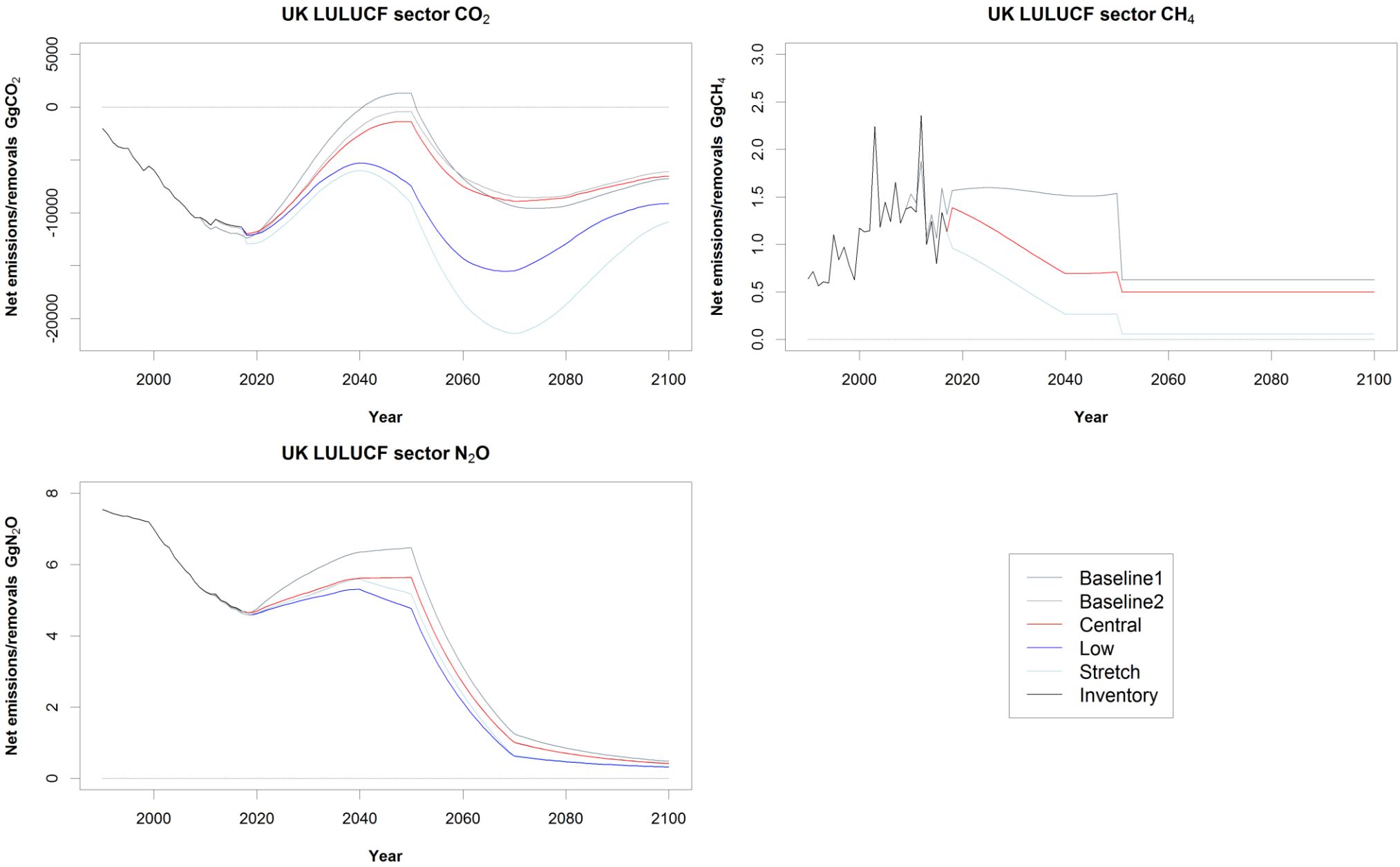

Figure 17: UK LULUCF Sector emissions of individual gases 1990-2100 (1 Mt CO2eq = 1000 Gg CO2eq). Results from 2051 onward only reflect the lag effects of changes in Activity Data pre 2050.

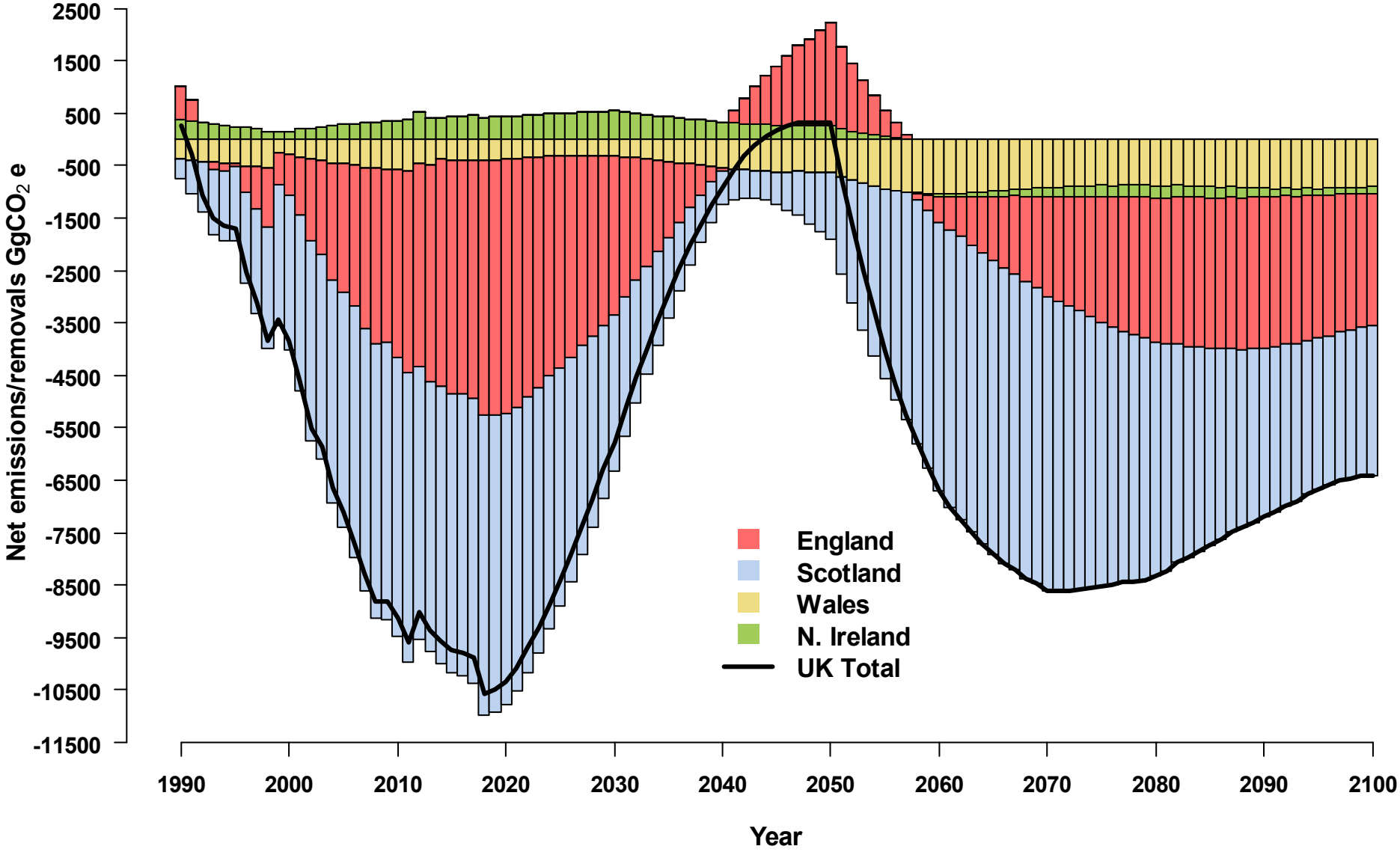

Figure 18: The combined total of the LULUCF emissions from each country for the *Central* emissions scenario. Results from 2051 onward only reflect the lag effects of changes in Activity Data pre 2050.

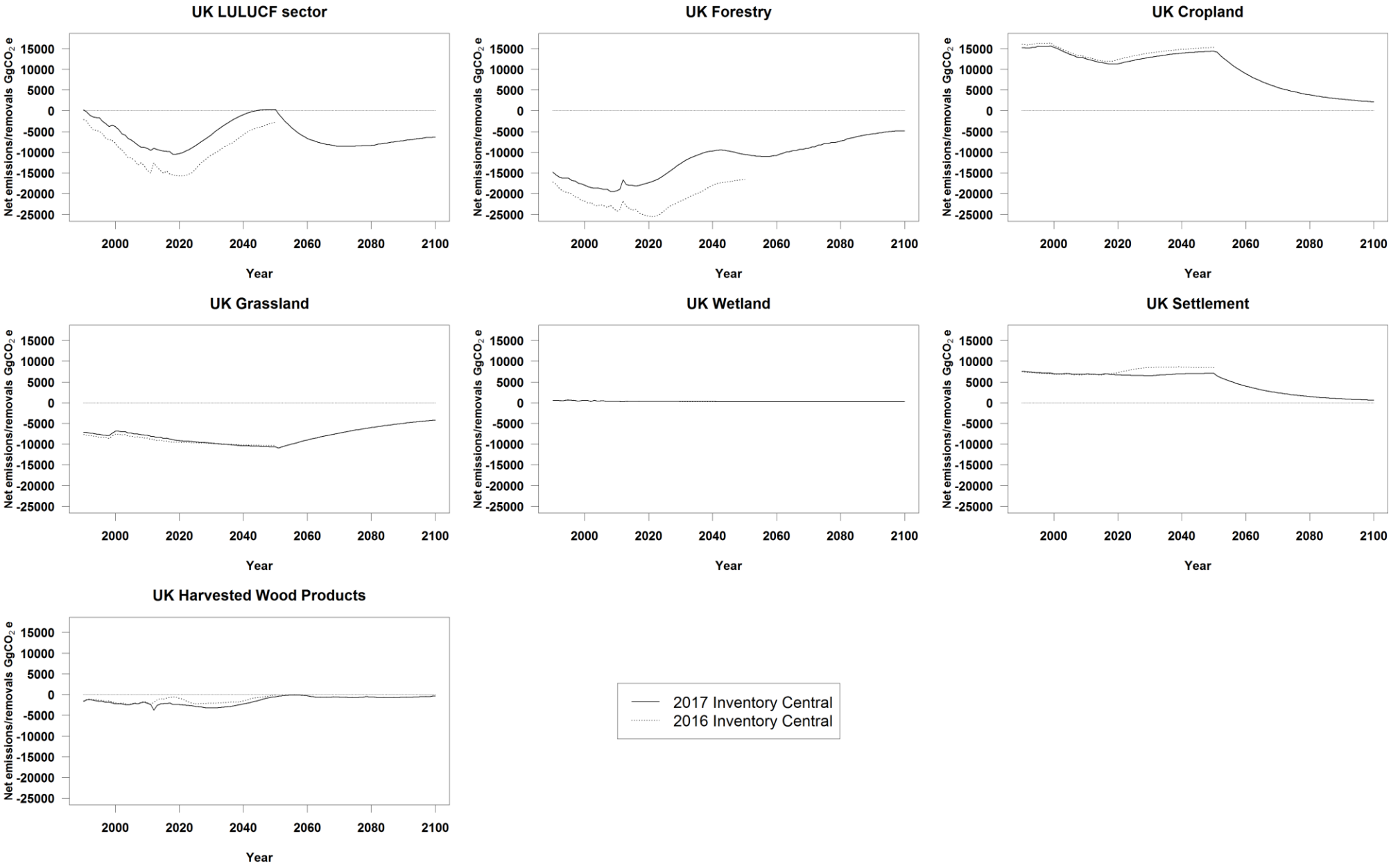

Figure 19 UK LULUCF CO_2 equivalent comparison of the Central emissions scenario for the 1990-2017 and 1990-2016 inventories respectively over 1990-2100 and 1990-2050 (1 Mt CO_2eq = 1000 Gg CO_2eq). Results from 2051 onward only reflect the lag effects of changes in Activity Data pre 2050.

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Annex 1: Methodology for projection of land use change to Settlement

Statistics on recent conversion of undeveloped land to developed land (i.e. land conversion to Settlement) suggest that the rate of land conversion has changed significantly in recent years (MHCLG, 2018a, b), compared with the rates of conversion between 1998 and 2007 (as calculated from the Countryside Survey data). There has also been much media coverage of the need for increased construction to meet housing demand in the future. A new methodology for projecting land use change to Settlement was implemented in the projections report for 1990-2013 and is updated here. This methodology is based on the Land-Use Change Statistics (LUCS) released by the Ministry of Housing, Communities and Local Government (MHCLG), and projections of the number of households in the UK and its constituent countries (ONS 2018).

The projections of household numbers (ONS 2018) use the latest national population census and trends in population demography and household formation to project household numbers to 2039 (Wales) or 2041 (England, Scotland, Northern Ireland).

The LUCS data describe land area change to developed use in England, based on the change to and from 28 land use categories. The latest LUCS data (2013-14 to 2017-18) available at the time of production of this GHG projections are derived by a methodology based on changes in Ordnance Survey products, rather than the physical observations of the previous methodology. The change in methodology was sought by Government to increase cost-effectiveness and to enable more detailed statistical and spatial analysis of the LUCS dataset (DCLG 2015). There are important differences between the two methodologies and "due to the changes in methodology and land use classification, comparison and interpretation between the two series is not recommended" (p.6, DCLG 2015).

The LUCS dataset reports the annual areas changing from previously non-developed to developed use, the area converted to residential use, the proportion of residential development compared to all development and the average density of new residential dwellings (25 dwellings/ha for England for 2013/14-2017/118).

In the LUCS methodology, the total area of change from a previously non-developed use to a developed use in 2013/14-2017/18 is between 13,049 and 21,446 ha a^{-1} (average 15,796 ha a^{-1}), of which an average of 3,106 ha a^{-1} is to residential use. The proportion (14-26%, average 20%) is also explicitly given in the LUCS. This ratio is used in the LULUCF projections to extrapolate total area converted to developed land (Settlement) from the estimated area converted to residential land (from household projections and average housing density for new residential dwellings).

In the LULUCF projections, the area of land converted to developed use is projected using the method described below and these key assumptions:

1) Settlement expansion increases to meet demand for housing and other built facilities.

2) Housing demand follows the projections in https://www.gov.uk/government/statistical-data-sets/live-tables-on-household-projections Table 401. A 7% increase in the number of households estimated by 2031. A flat rate is assumed post-2039/41`and until 2050 as household numbers are only projected to this point.

3) The projected number of households in the future can be used to scale for the total projected urban development.

4) The density of residential dwellings and the proportions of development on non-previously developed land in England are also representative of Scotland, Wales and Northern Ireland, in the absence of similar data for the DAs.

The *Central* (and *Baseline2*) scenario assumes that residential development on previously non-developed (PND) land, and proportionally all development, is sufficient to meet the demand for housing predicted by the household projections dataset, where:

$aALL_i$ = Area of ALL conversion to developed land, ha, in year i

pcRes = % of new dwellings on PND land

densRes = average density of residential addresses created on PND land, dwellings per hectare

pcALL = % of residential development of all development on PND land

$\Delta Household_i$ = annual change in number of households (by country) for year i compared to year i-1

$$aALL_i = ((\Delta Household_i * pcRes)/densRes)/pcALL$$

The other scenarios reflect what would happen if there was insufficient construction to meet demand, if there was an alteration in household demand, or if dwellings were constructed at a greater density or with a greater preference for previously developed sites, thereby reducing the amount of land use change. The *Baseline1* scenario uses the 2000-2009 average rate for conversion of PND land to developed land for England out to 2050, scaled by the household numbers for each country. The *Low* and *Stretch* scenarios use 50% of the decadal average of the *Central* scenario for all countries.

The area of developed land, i.e. land converted to Settlement, is divided between conversion categories, using the projected areas of deforestation to Settlement, with the remaining area assigned to Grassland converted to Settlement. For the purposes of calculating biomass and soil carbon stock change, it was assumed that land converted to settlement has the soil and biomass carbon stocks of Grassland, on average (there will be some conversion from Cropland and possibly Wetland, but the currently available data does not support further disaggregation).

Annex 2: Land use areas by country

Table A2.1: Land use areas 2017-2050 for England (13,046 kha).

Emission scenario	*Land use category*	*2017 area, kha*	*2020 area, kha*	*2030 area, kha*	*2040 area, kha*	*2050 area, kha*
Central	Forest land	1591	1597	1594	1592	1593
	Cropland	4327	4327	4327	4327	4327
	Grassland	5506	5458	5326	5147	4974
	Wetland	19	19	19	19	18
	Settlement	1437	1469	1594	1774	1950
	Other	167	177	186	187	185
Baseline 1	Forest land	1592	1597	1611	1626	1639
	Cropland	4327	4327	4327	4327	4327
	Grassland	5506	5420	5227	5037	4849
	Wetland	19	19	19	19	18
	Settlement	1437	1512	1687	1862	2037
	Other	165	173	176	176	176
Baseline 2	Forest land	1586	1584	1579	1578	1578
	Cropland	4327	4327	4327	4327	4327
	Grassland	5506	5467	5337	5158	4985
	Wetland	19	19	19	19	18
	Settlement	1437	1469	1594	1774	1950
	Other	172	180	190	190	188
Low	Forest land	1591	1597	1655	1720	1782
	Cropland	4327	4327	4327	4327	4327
	Grassland	5506	5468	5348	5208	5133
	Wetland	19	19	19	19	18
	Settlement	1437	1451	1500	1571	1581
	Other	167	184	197	201	205
Stretch	Forest land	1591	1600	1687	1783	1874
	Cropland	4327	4327	4327	4327	4327
	Grassland	5506	5463	5320	5152	5052
	Wetland	19	18	15	15	15
	Settlement	1437	1451	1500	1571	1581
	Other	167	187	197	197	197

Table A2.2: Land use areas 2017-2050 for Scotland (7,881 kha).

Emission scenario	*Land use category*	*2017 area, kha*	*2020 area, kha*	*2030 area, kha*	*2040 area, kha*	*2050 area, kha*
Central	Forest land	1490	1502	1492	1488	1487
	Cropland	606	606	606	606	606
	Grassland	5265	5239	5229	5213	5197
	Wetland	91	91	91	91	91
	Settlement	180	185	200	215	229
	Other	249	257	263	267	270
Baseline 1	Forest land	1462	1467	1482	1497	1510
	Cropland	606	606	606	606	606
	Grassland	5265	5239	5188	5138	5092
	Wetland	91	91	91	91	91
	Settlement	180	192	219	246	273
	Other	277	287	296	303	310
Baseline 2	Forest land	1449	1445	1436	1432	1431
	Cropland	606	606	606	606	606
	Grassland	5265	5260	5250	5234	5218
	Wetland	91	91	91	91	91
	Settlement	180	185	200	215	229
	Other	289	293	299	303	306
Low	Forest land	1490	1518	1652	1694	1721
	Cropland	606	606	606	606	606
	Grassland	5265	5207	5071	5019	4980
	Wetland	91	91	91	91	91
	Settlement	180	182	187	191	195
	Other	249	277	274	281	287
Stretch	Forest land	1490	1523	1682	1850	2007
	Cropland	606	606	606	606	606
	Grassland	5265	5198	5029	4854	4689
	Wetland	91	91	90	90	90
	Settlement	180	182	187	191	195
	Other	249	281	287	290	293

Table A2.3: Land use areas 2017-2050 for Wales (2,078 kha).

Emission scenario	*Land use category*	*2017 area, kha*	*2020 area, kha*	*2030 area, kha*	*2040 area, kha*	*2050 area, kha*
Central	Forest land	346	346	344	343	342
	Cropland	93	98	109	119	130
	Grassland	1487	1479	1464	1449	1435
	Wetland	5	5	5	5	5
	Settlement	108	111	119	123	127
	Other	39	40	39	39	40
Baseline 1	Forest land	340	340	339	339	338
	Cropland	93	98	109	119	130
	Grassland	1487	1477	1457	1437	1418
	Wetland	5	5	5	5	5
	Settlement	108	112	123	133	143
	Other	45	46	45	45	45
Baseline 2	Forest land	343	342	340	339	338
	Cropland	93	98	109	119	130
	Grassland	1487	1479	1464	1449	1435
	Wetland	5	5	5	5	5
	Settlement	108	111	119	123	127
	Other	43	43	43	43	43
Low	Forest land	346	351	369	387	391
	Cropland	93	98	109	119	130
	Grassland	1487	1472	1442	1414	1397
	Wetland	5	5	5	5	5
	Settlement	108	108	109	108	109
	Other	39	44	45	46	46
Stretch	Forest land	346	356	394	431	440
	Cropland	93	98	109	119	130
	Grassland	1487	1463	1415	1372	1351
	Wetland	5	5	5	5	5
	Settlement	108	108	109	108	109
	Other	39	47	46	44	44

Table A2.4: Land use areas 2017-2050 for Northern Ireland (1,413 kha).

Projections of Emissions and Removals from the LULUCF Sector to 2050/2100

Emission scenario	*Land use category*	*2017 area, kha*	*2020 area, kha*	*2030 area, kha*	*2040 area, kha*	*2050 area, kha*
Central	Forest land	82	82	82	82	81
	Cropland	52	52	52	52	52
	Grassland	1139	1130	1119	1115	1111
	Wetland	54	54	54	54	54
	Settlement	63	72	83	87	91
	Other	42	43	43	43	43
Baseline 1	Forest land	83	83	85	87	89
	Cropland	52	52	52	52	52
	Grassland	1139	1130	1112	1094	1077
	Wetland	54	54	54	54	54
	Settlement	63	71	86	101	116
	Other	42	43	44	44	44
Baseline 2	Forest land	82	82	81	81	81
	Cropland	52	52	52	52	52
	Grassland	1139	1130	1119	1116	1112
	Wetland	54	54	54	54	54
	Settlement	63	72	83	87	91
	Other	43	43	43	43	43
Low	Forest land	82	83	90	98	105
	Cropland	52	52	52	52	52
	Grassland	1139	1132	1119	1109	1099
	Wetland	54	54	54	54	54
	Settlement	63	69	74	76	78
	Other	42	43	44	44	44
Stretch	Forest land	82	84	98	114	129
	Cropland	52	52	52	52	52
	Grassland	1139	1130	1110	1092	1075
	Wetland	54	54	54	54	54
	Settlement	63	69	74	76	78
	Other	42	44	45	45	45

Annex 3: Afforestation and Deforestation data

Table A3.1 *Baseline 1* Scenario Afforestation Rates (kha).

	Annual Forest Planting Rate				
Year	England	Scotland	Wales	N. Ireland	UK Total
2010-2049	2.34	3.440	0.189	0.289	6.258
2050	0.58	0.86	0.047	0.072	1.564

Table A3.2 *Baseline 1* Scenario Deforestation Rates (kha).

	Annual Deforestation Rate				
Year	England	Scotland	Wales	N. Ireland	UK Total
2018-2050	0.864	1.917	0.253	0.093	3.127

Table A3.3 *Baseline 2* Scenario Afforestation Rates (kha).

	Annual Forest Planting Rate				
Year	England	Scotland	Wales	N. Ireland	UK Total
2010-2014	2.44	3.26	0.20	0.29	6.20
2015-2049	0.244	0.326	0.02	0.029	0.62
2050	0.061	0.082	0.005	0.007	0.155

Table A3.4 *Central* Scenario Afforestation Rates (kha).

	Annual Forest Planting Rate				
Year	England	Scotland	Wales	N. Ireland	UK Total
2018	2.335	7.454	0.140	0.209	10.137
2019	3.087	7.559	0.103	0.208	10.957
2020	3.033	2.134	0.041	0.074	5.281
2021	1.978	0.326	0.020	0.029	2.353
2022	0.797	0.326	0.020	0.029	1.172
2023	0.311	0.326	0.020	0.029	0.686
2024-2049	0.244	0.326	0.020	0.029	0.620
2050	0.061	0.082	0.005	0.007	0.155

Table A3.5 *Baseline 2/Central/Low/Stretch* Scenario Deforestation Rates (kha).

Year	Annual Deforestation Rate				
	England	Scotland	Wales	N. Ireland	UK Total
2018	0.959	1.637	0.305	0.093	2.994
2019	0.924	1.582	0.293	0.091	2.890
2020	0.890	1.526	0.281	0.089	2.787
2021	0.856	1.470	0.269	0.087	2.683
2022	0.822	1.415	0.257	0.085	2.579
2023	0.787	1.359	0.246	0.083	2.475
2024	0.753	1.304	0.234	0.081	2.371
2025	0.719	1.248	0.222	0.079	2.267
2026	0.685	1.192	0.210	0.077	2.163
2027	0.650	1.137	0.198	0.075	2.059
2028	0.616	1.081	0.186	0.072	1.955
2029	0.582	1.025	0.174	0.070	1.852
2030	0.547	0.970	0.162	0.068	1.748
2031	0.513	0.914	0.150	0.066	1.644
2032	0.479	0.858	0.138	0.064	1.540
2033	0.445	0.803	0.126	0.062	1.436
2034	0.410	0.747	0.114	0.060	1.332
2035	0.376	0.691	0.103	0.058	1.228
2036	0.342	0.636	0.091	0.056	1.124
2037	0.308	0.580	0.079	0.054	1.020
2038	0.273	0.524	0.067	0.052	0.916
2039	0.239	0.469	0.055	0.050	0.813
2040	0.205	0.413	0.043	0.048	0.709
2041	0.205	0.413	0.043	0.048	0.709
2042	0.205	0.413	0.043	0.048	0.709
2043	0.205	0.413	0.043	0.048	0.709
2044	0.205	0.413	0.043	0.048	0.709
2045	0.205	0.413	0.043	0.048	0.709
2046	0.205	0.413	0.043	0.048	0.709
2047	0.205	0.413	0.043	0.048	0.709
2048	0.205	0.413	0.043	0.048	0.709
2049	0.205	0.413	0.043	0.048	0.709
2050	0.205	0.413	0.043	0.048	0.709

Table A3.6 *Low* Scenario Afforestation Rates (kha).

Year	Annual Forest Planting Rate				
	England	Scotland	Wales	N. Ireland	UK Total
2018	2.341	9.285	1.601	0.281	13.508
2019	2.905	11.500	2.052	0.304	16.761
2020	3.750	12.000	2.020	0.462	18.231
2021	4.750	13.500	2.009	0.589	20.848
2022	5.750	14.000	2.009	0.651	22.411
2023	6.682	14.750	2.009	0.664	24.105
2024	6.909	15.000	2.009	0.664	24.582
2025	6.909	15.000	2.009	0.714	24.632
2026	6.909	15.000	2.009	0.764	24.682
2027	6.909	15.000	2.009	0.814	24.732
2028	6.909	15.000	2.009	0.864	24.782
2029	6.909	15.000	2.009	0.864	24.782
2030	6.909	15.000	2.009	0.864	24.782
2031	6.909	15.000	2.009	0.864	24.782
2032	6.909	15.000	2.009	0.864	24.782
2033	6.909	3.440	2.009	0.864	13.222
2034	6.909	3.440	2.009	0.864	13.222
2035	6.909	3.440	2.009	0.864	13.222
2036	6.909	3.440	2.009	0.864	13.222
2037	6.909	3.440	2.009	0.864	13.222
2038	6.909	3.440	2.009	0.864	13.222
2039	6.909	3.440	2.009	0.864	13.222
2040	6.909	3.440	2.009	0.864	13.222
2041	6.909	3.440	0.509	0.864	11.722
2042	6.909	3.440	0.509	0.864	11.722
2043	6.909	3.440	0.509	0.864	11.722
2044	6.909	3.440	0.509	0.864	11.722
2045	6.909	3.440	0.509	0.864	11.722
2046	6.909	3.440	0.509	0.864	11.722
2047	6.909	3.440	0.509	0.864	11.722
2048	6.909	3.440	0.509	0.864	11.722
2049	6.909	3.440	0.509	0.864	11.722
2050	1.727	0.860	0.127	0.216	2.931

Table A3.7 *Stretch* Scenario Afforestation Rates (kha).

Year	Annual Forest Planting Rate				
	England	Scotland	Wales	N. Ireland	UK Total
2018	2.523	11.160	3.062	0.353	17.098
2019	3.934	12.500	4.000	0.400	20.834
2020	5.361	14.375	4.000	0.850	24.586
2021	6.788	15.000	4.000	1.150	26.938
2022	8.216	16.875	4.000	1.275	30.366
2023	9.643	17.500	4.000	1.300	32.443
2024	10.000	17.500	4.000	1.300	32.800
2025	10.000	17.500	4.000	1.400	32.900
2026	10.000	17.500	4.000	1.500	33.000
2027	10.000	17.500	4.000	1.600	33.100
2028	10.000	17.500	4.000	1.700	33.200
2029	10.000	17.500	4.000	1.700	33.200
2030	10.000	17.500	4.000	1.700	33.200
2031	10.000	17.500	4.000	1.700	33.200
2032	10.000	17.500	4.000	1.700	33.200
2033	10.000	17.500	4.000	1.700	33.200
2034	10.000	17.500	4.000	1.700	33.200
2035	10.000	17.500	4.000	1.700	33.200
2036	10.000	17.500	4.000	1.700	33.200
2037	10.000	17.500	4.000	1.700	33.200
2038	10.000	17.500	4.000	1.700	33.200
2039	10.000	17.500	4.000	1.700	33.200
2040	10.000	17.500	4.000	1.700	33.200
2041	10.000	17.500	1.000	1.700	30.200
2042	10.000	17.500	1.000	1.700	30.200
2043	10.000	17.500	1.000	1.700	30.200
2044	10.000	17.500	1.000	1.700	30.200
2045	10.000	17.500	1.000	1.700	30.200
2046	10.000	17.500	1.000	1.700	30.200
2047	10.000	17.500	1.000	1.700	30.200
2048	10.000	17.500	1.000	1.700	30.200
2049	10.000	17.500	1.000	1.700	30.200
2050	2.500	4.375	0.250	0.425	7.550