UK Rural Land Use Archetypes – Part 2

Transforming rural UK land-use to high-carbon store, climate resilient, nature rich and economically productive systems

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Contents

Executive Summary

In this project we have modelled the multiple impacts of a range of land-based mitigation measures applied to 12 UK rural archetypes (Table ES 1) that cover 55% of the UK rural land area[1]. Some measures are applicable across a wide range of rural landscapes, e.g. agroforestry and hedgerow creation, and some apply to only certain archetypes, e.g. peatland restoration. The archetype transitions illustrate a range of land-use and land management futures and how they contribute to GHG mitigation, agricultural production, ecosystem services and renewable energy generation. Alternative transitions have been explored for a subset of archetypes, exploring the outcomes of a more production-focussed versus a more mitigation-focussed transition in the same archetype. The analysis has explored the trade-offs between measures, such as potential carbon sequestration versus loss of biodiversity or net farm incomes. Much of rural UK land area not captured by these archetypes is a blend of short-listed archetypes and the findings of this project is also applicable to those areas.

Table ES 1 Archetype transition pathways

Archetype groups	Archetypes	Transitions
Predominantly arable archetypes	Archetype 9. Intensive and valley/floodplain arable on chalk/clay soils in England	1- Expansion of on-farm tree cover and bioenergy crops
		2-Tree planting for habitat creation, expansion of on-farm tree cover and solar power generation
	Archetype 10. Arable on sandy soils in England and Scotland	1-Expansion of on-farm tree cover and bioenergy crops
Improved grassland lowland archetypes	Archetype 3. Intensive grassland in Wales and south-west England	1- Plantation woodland creation and expansion of on-farm tree cover, increased stocking
		2- Expansion of on-farm tree cover, bioenergy crops and solar power generation, increased stocking
	Archetype 7. Enclosed pasture in England and Wales	1- Plantation woodland creation, expansion of on-farm tree cover and bioenergy crops
	Archetype 11. Lowland agriculture in Northern Ireland	1- Tree planting for production and habitat creation, expansion of on-farm tree cover, restoration of degraded organic soils
Upland grassland archetypes	Archetype 5. Hilly farmland on improved and semi-natural	1-Plantation woodland creation and expansion of on-farm tree cover, reduced stocking

[1] https://www.theccc.org.uk/publication/archetypes-representative-of-current-uk-rural-land-use-and-land-management-ukceh/

Archetype groups	Archetypes	Transitions
	grassland on nonorganic soils in GB	
	Archetype 6. Open pasture on the upland fringe in England and Scotland	1-Plantation woodland creation and expansion of on-farm tree cover
		2-Tree planting for habitat creation and on-farm tree cover expansion, increased stocking
	Archetype 8. Acid grassland on hilly uplands in GB	1-Tree planting for habitat creation, reduced stocking
Organic soil archetypes	Archetype 1. Highly degraded lowland organic soils in GB	1-Restoration and sustainable management of lowland organic soils
	Archetype 2. Degraded upland grazing land and forest on organic soils in GB	1-Restoration of upland organic soils.
	Archetype 12. Uplands with large extent on organic soils in Northern Ireland	1-Restoration of degraded organic soils, reduced stocking and hedgerow expansion
Suburban fringe archetype	Archetype 4. Farming on the suburban fringe in England	1-Tree planting for habitat creation and hedgerow expansion
		2-Expansion of on-farm tree cover, bioenergy crops and solar power generation

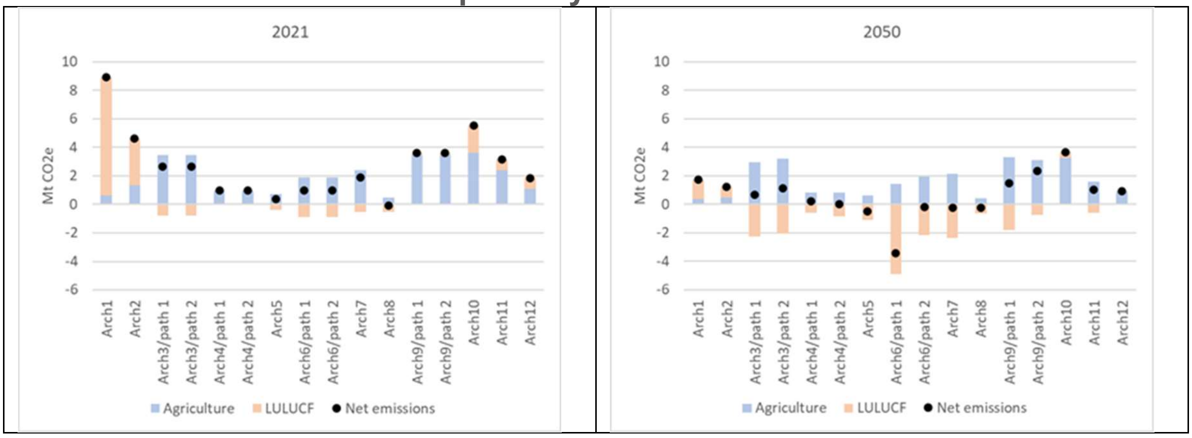
The impact of the transition pathways on 2050 metrics compared to the baseline pathway is shown for GHG emissions (ES Figure 1), economic cost-benefits (ES Figure 2) and ecosystem metrics (ES Figure 3).

Mitigation measures in the transition pathways can contribute 45-53% of the 7th Carbon Budget Balanced Pathway reduction in combined agriculture and LULUCF GHG emissions, in line with their 55% coverage of all UK land area (excluding landscapes dominated by existing forest). There are complex changes in ecosystem metrics across the archetypes in the transition pathways but, compared to the baseline, there are:

- increases in carbon storage and soil ecosystem services;
- small increases in recreation services;
- a reduction in production services, in line with a reduction in arable and improved grassland area;
- very small decreases in most biodiversity measures.

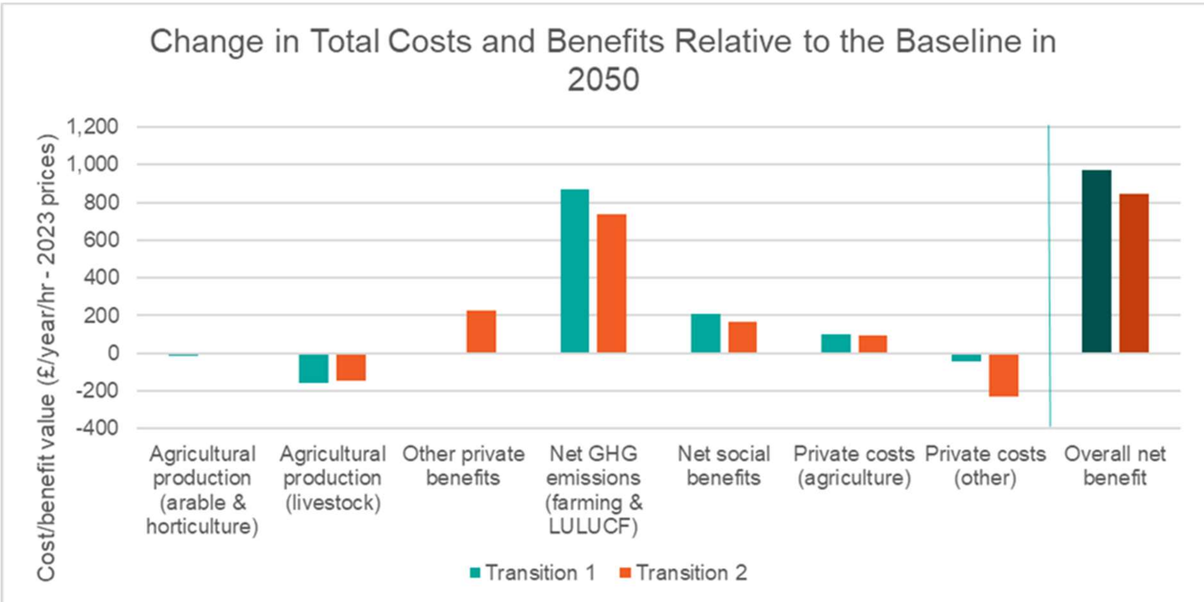
The economic cost-benefit analysis indicates that net private and social benefits increase under the transition pathways, but the private cost/benefit balance may not, so additional financial incentives may be required to encourage change. We have also explored and qualitatively assessed a range of climate change risk impacts on carbon sequestration, biodiversity, agricultural production and ecosystem services on the archetypes. Agricultural land is more impacted by climate change and in certain archetypes, climate change limits the mitigation measures that can be implemented, although this can be modified by adaptation measures.

ES Figure 1: Combined Agriculture and LULUCF net GHG emissions in 2021 and 2050 under the transition pathways

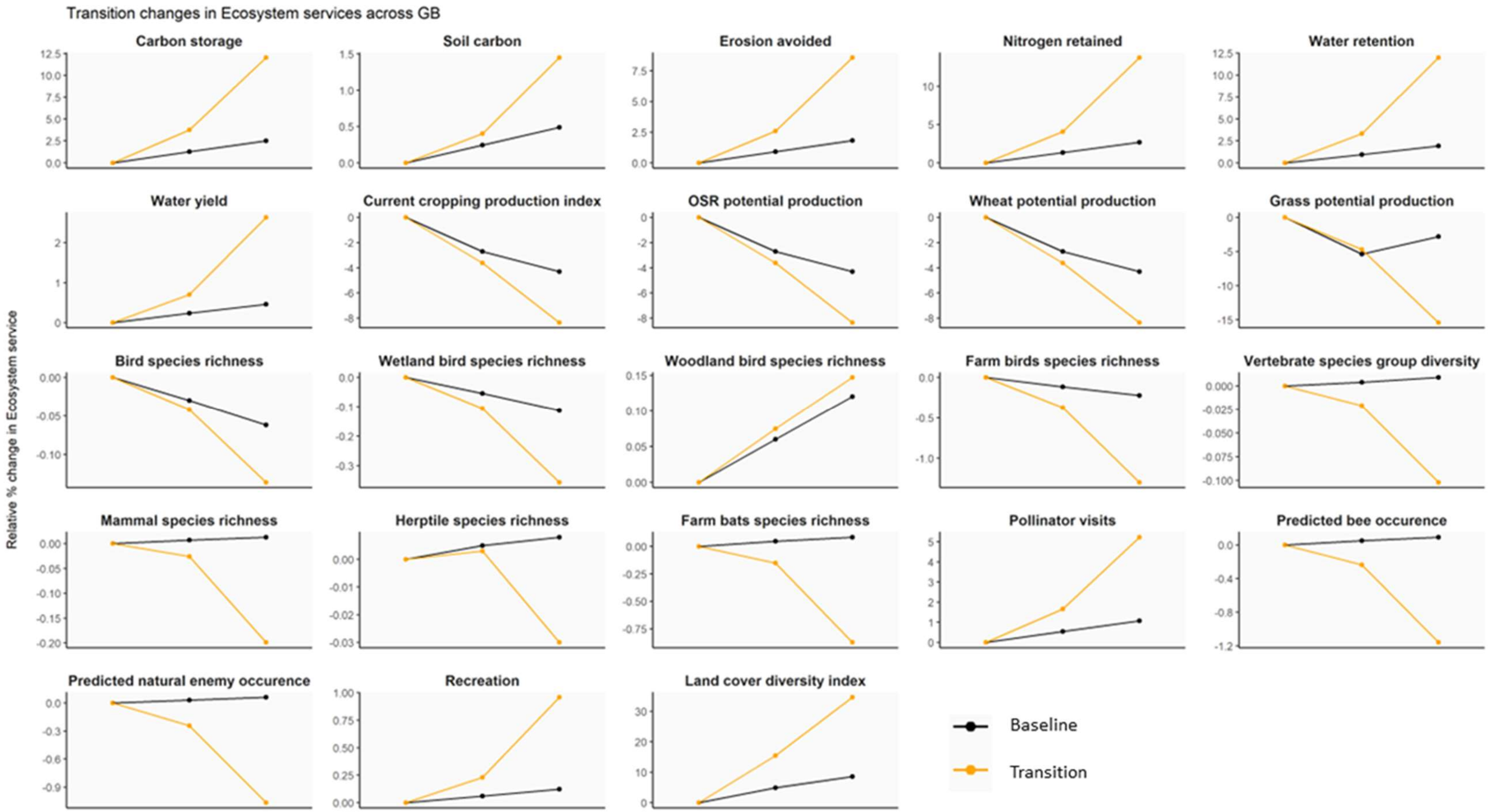


Archetypes: 1-Lowland organic soils; 2- Upland organic soils; 3- Intensive grassland; 4- Suburban fringe; 5- Hilly farmland; 6- Open pasture; 7- Enclosed pasture; 8- Acid upland grassland; 9- Arable on chalk/clay; 10- Arable on sandy soils; 11- Lowland agriculture in Northern Ireland; 12- Uplands in Northern Ireland.

ES Figure 2: Change in costs and benefits under the transitions relative to the Baseline



ES Figure 3: Relative percentage change in ecosystem service provision across all archetypes 2021-2050



1. Introduction

1.1 Background and overall aims of the archetypes project

The CCC's advice on the level of Sixth Carbon Budget (CCC 2020) for the 2030s was accepted by Government in 2021. Meeting the Sixth Carbon Budget and the longer-term Net Zero target by 2050 (CCC, 2019) requires contribution from all sectors of the economy, including the agriculture and land use, land use change and forestry (LULUCF) sectors. This will require a transformation in how land is used in the UK, with some land converted from agricultural production to alternative lower-emission uses, such as woodland creation, peatland restoration and bioenergy crops. How and where we transition agricultural land to these other land uses will determine their effectiveness. An improved evidence base to inform this will be a vital part of the transition.

The land use transition will need to consider wider objectives than just climate mitigation, including for climate adaptation and nature recovery. The CCC's third Independent Assessment of UK Climate Risk (CCRA3) identified priority risk areas as being critical for climate adaptation in the next two years, four of which relate to the natural environment and the use of land:

- Risks to natural carbon stores and sequestration from multiple hazards leading to increased emissions
- Risks to soil health from increased flooding and drought
- Risks to crops, livestock and commercial trees from multiple hazards
- Risks to the viability and diversity of terrestrial and freshwater habitats and species from multiple hazards.

The CCC wishes to understand how effective action to change land use can be targeted before further climate change impacts the land, which will enable land managers to protect and enhance the land's ability to maintain ecosystem services delivery. To date, analysis has focused on estimating the impact of land-use change/management on carbon and GHG emissions at the national level (i.e. England and each of the devolved administrations (DAs)). In practice, the changes needed to mitigate and prepare for climate change vary depending on climatic, economic, social and environmental factors, at the farm, catchment and landscape level.

The archetypes project aims to quantify the impact of a set of plausible land-use transitions (towards higher-carbon stores, resilient, productive and nature-rich states) for a range of representative rural land use 'archetypes'[2] situated across England and the DAs, then estimate climate risks to these land-use transitions under various degrees of warming. The project was split into two parts.

[2] Archetypes represent a typical example of something, in this case land use and management at a farm or landscape level.

1.2 Part 1 of the archetypes project

Part 1 of the archetypes project focussed on developing the set of rural land use archetypes for the UK, as described in Young and Thomson (2023). A set of 12 archetypes were developed to represent current UK rural land use and land management across England and the DAs, spanning differences in geography, land use, agriculture, land management and spatial scale. Ten of the archetypes cover areas of GB and were created based on the Tier 1 Landscape Archetypes and Tier 2 Farmed Landscape Archetypes developed by Goodwin *et al.,* 2022) and the Greenhouse Gas Inventory Peat Condition maps (Clilverd *et al.,* forthcoming). The two archetypes in Northern Ireland were based on the Northern Ireland Landscape Character Assessments (LCAs), combined with information from the GHG Inventory peat condition maps (Clilverd et al., forthcoming) and the Land Cover Map (Marston *et al.,* 2022).

The Young and Thomson (2023) report provides a description of each archetype, including the total area covered in each country of the UK, a summary of the climate, soil conditions and agricultural land classes, the predominant agricultural use and Land Cover Map categories, and an estimate of LULUCF and Agriculture sector emissions in 2021.

1.3 Part 2 of the archetypes project

The aim of this work, the second part of the archetypes project, is to assess the impact of land-use transitions in the archetypes on a range of carbon, environmental and food production metrics, and to understand the climate risks to the effectiveness of these transitions under various degrees of warming. The transitions will aim to deliver co-benefits including increasing carbon sequestration, reducing GHG emissions, sustainable domestic food production, supporting nature recovery and improving climate resilience. Any trade-offs will be identified.

While LULUCF and Agriculture emissions per archetype were estimated in Part 1 of the archetypes project, by apportioning the UK Local Authority (LA) LULUCF and Agriculture emissions[3] according to the proportions of each LA in each archetype, for Part 2 improved emissions estimates will be provided, based on archetype-specific land-use and other data.

The main outputs of the project are:

1. Quantified metrics for the 12 identified archetypes plus an additional Archetype 100 (covering rural non-archetype areas) for a baseline pathway for 2021, 2035 and 2050. The baseline pathway assumes a continuation of current rates of land use change (e.g. woodland creation).
2. Quantified metrics for each archetype for future transition pathways for 2035 and 2050. Each archetype has at least one transition pathway associated with it, developed by the CCC and the project team.

[3] https://www.gov.uk/government/statistics/uk-local-authority-and-regional-greenhouse-gas-emissions-national-statistics-2005-to-2021

3. Quantified climate risks to the effectiveness of the land use transitions under degrees of warming of 1.5 to 4°C
4. Evaluation of the costs and benefits of the baseline and transition pathways for each archetype.

2. Archetype locations

The first part of the archetypes project (Young and Thomson, 2023) identified 12 archetypes (10 in Great Britain (GB) and two in Northern Ireland). There have been minor updates to the original archetype areas following stakeholder feedback. In Northern Ireland, archetype 19 from the longlist (Improved grassland on mineral soils in Northern Ireland) has been combined with shortlisted archetype 11 (Lowland agriculture around Lough Neagh, Northern Ireland) to create a larger archetype 11 area, now named “Lowland agriculture in Northern Ireland”. The Northern Ireland archetypes have now also been converted from vector shapefiles to a 1km raster grid to match the format of the GB archetypes and allow for ease of analysis.

In the GB archetypes, adjustments were made to the archetypes to ensure that degraded organic soils areas were assigned to archetypes consistently, in particular that areas of Modified Bog (drained and undrained) are assigned to archetype 2 (Degraded upland grazing land and forest on organic soils in GB) rather than split across archetypes 2 and 8.

Figure 1 shows the updated locations of archetypes 1-12. These archetypes cover 55% of the UK rural land area.

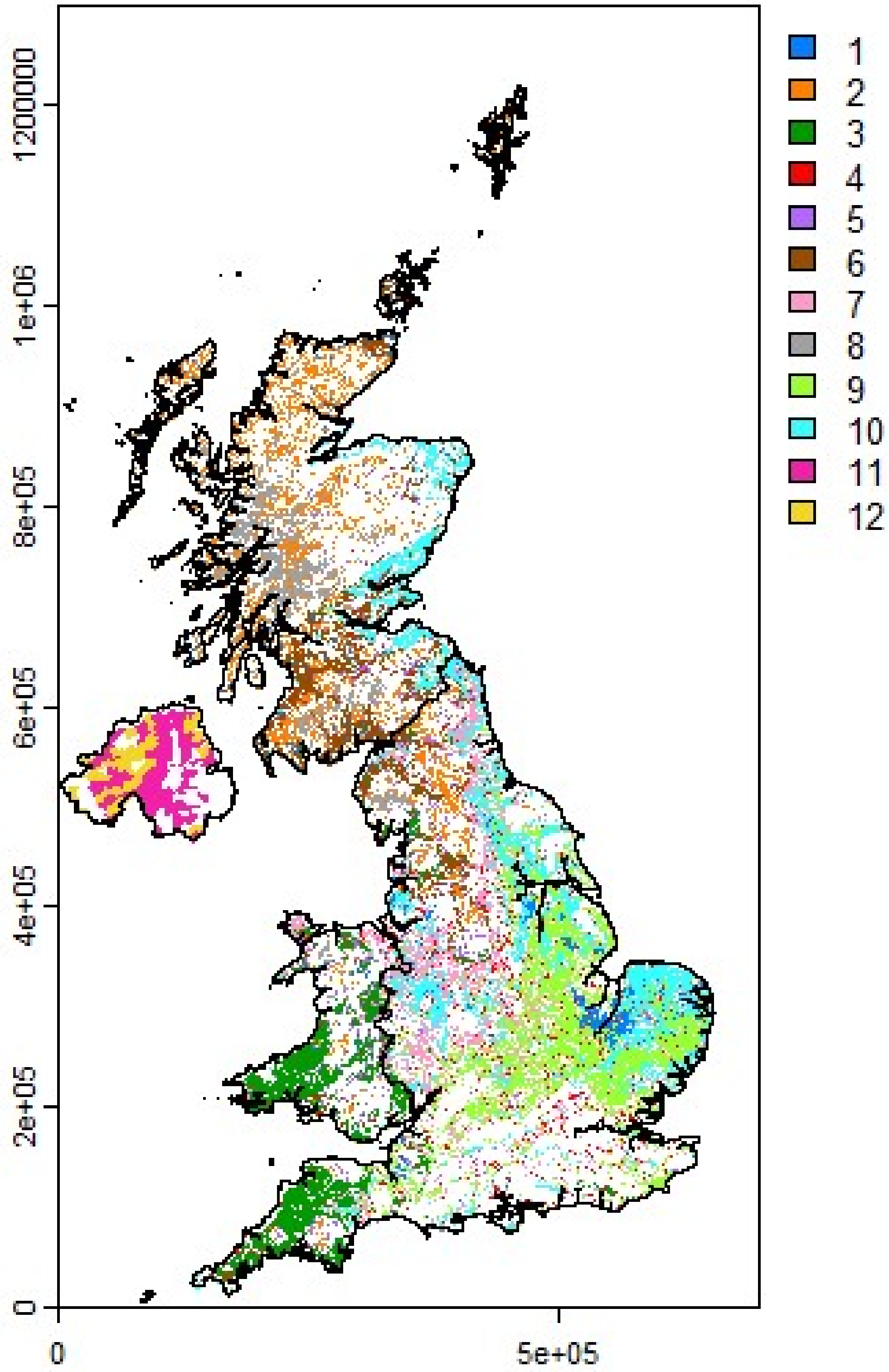


Figure 1: Locations of Archetypes 1-12

In addition to the 12 archetypes, we will also analyse baseline metrics for the area of rural land in the UK falling outside the 12 archetypes. For this we created archetype 100, which covers the UK land outside of the 12 archetypes, with the exception of any 1km grid cells where the dominant land use taken from the Land Cover Map is Urban or Suburban land. Figure 2 shows the locations of archetype 100, which includes most UK extensive forest as well as a broad range of other land uses.

Error! Reference source not found. lists the final archetypes (full descriptions are in Young and Thomson, 2023). The broad differences between the archetypes is illustrated by Figure 3 using the high-level LULUCF categories. More details on land cover in the archetypes are given in Section 4.

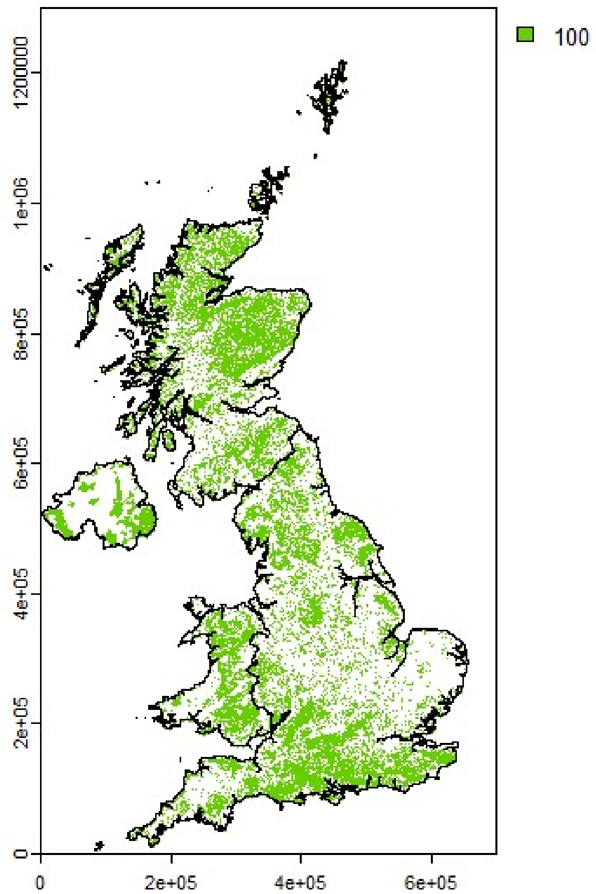


Figure 2 Location of Archetype 100 (All other rural land)

Table 1: The final list of archetypes

Archetype	Description	% of UK rural land area
1	Highly degraded lowland organic soils in GB	2%
2	Degraded upland grazing land and forest on organic soils in GB	7%
3	Intensive grassland in Wales and south-west England	6%
4	Farming on the suburban fringe in England	3%
5	Hilly farmland on improved and semi-natural grassland on nonorganic soils in GB	2%
6	Open pasture on the upland fringe in England and Scotland	5%
7	Enclosed pasture in England and Wales	5%
8	Acid grassland on hilly uplands in GB	3%
9	Intensive and valley/floodplain arable on chalk/clay soils in England	9%
10	Arable on sandy soils in England and Scotland	9%
11	Lowland agriculture in Northern Ireland	3%
12	Uplands with large extent on organic soils in Northern Ireland	1%
100	All other rural land	45%

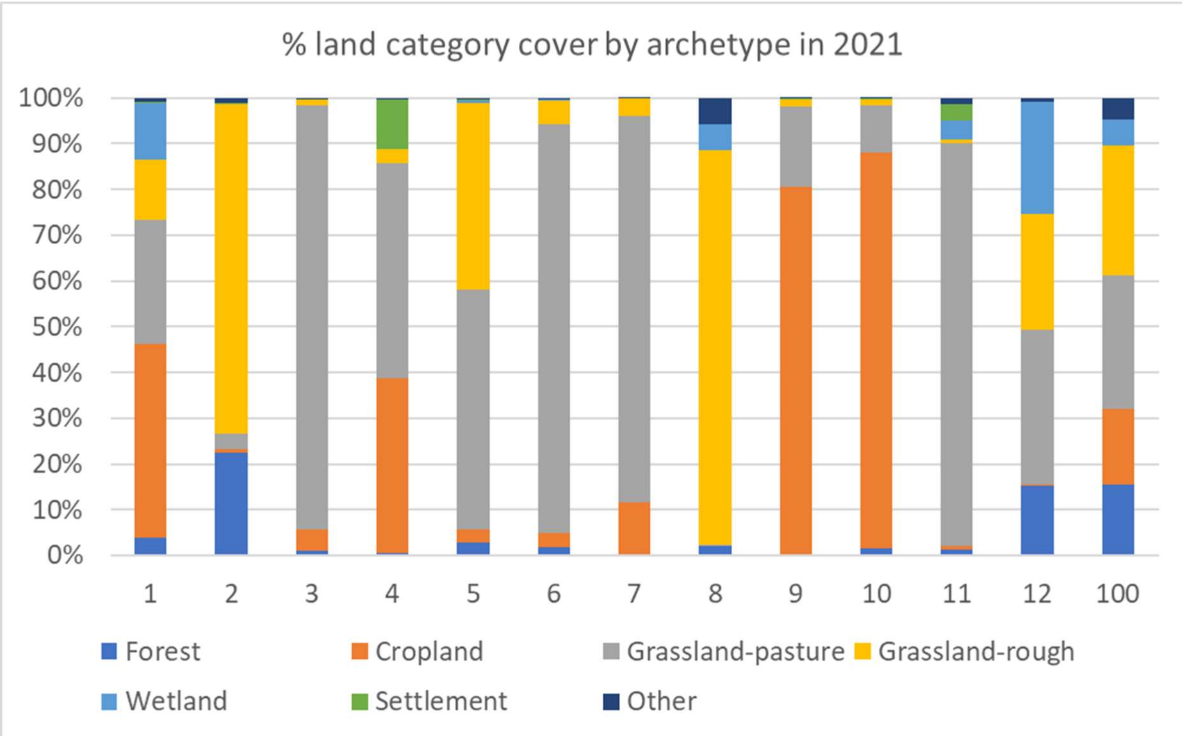


Figure 3: Proportions of LULUCF land cover categories in each archetype

3. Mitigation options

Land-based mitigation options that are considered for the archetype transition pathways are established practices, with a clear scientific evidence base, that are understood to either increase carbon sequestration in soils and biomass or to reduce greenhouse gas emissions from land. These include increases in tree cover (through woodland creation and expansion of agroforestry and hedgerows), increased areas devoted to perennial energy crops, and peatland restoration and sustainable management. These match options that were included in the CCC's 6th Carbon Budget and the 7th Carbon Budget. Other farm-based activities, such as increased areas of solar photo-voltaic (PV) panels and reversion of intensive agriculture to semi-natural grassland habitats are also considered.

The following sections provide descriptions of land-based mitigation options that have been applied in transition pathways, and comparisons with the 7th Carbon Budget where appropriate.

3.1 Woodland creation and forestry

The Afforestation measure is tree planting on previously unforested land. This does not include Short Rotation Forestry or agroforestry, which are included under other measures. Woodland creation can either be for the purpose of creating plantations for timber or fuel production, or for creating woodland habitat by planting or encouraging natural regeneration. New plantations are assumed to comply with the UK Forest Standard[4] in terms of species mix, proportions of open space within the planted area and avoidance of organic soils.

Estimation of afforestation carbon stock changes

Assumptions on the area planted and the type, productivity (yield class) and management of the trees planted are needed to estimate the net carbon sequestration. Carbon stock changes in forest biomass (including deadwood and litter) and soils were estimated using data tables for each species, yield class and management combination. These were extracted from the Q4C data cube (Matthews *et al.,* 2022) and provided by Robert Matthews of Forest Research. The data tables have been derived from the CARBINE model and can represent forest management as "Standard thinning and rotation management", "Continuous cover management" and "No thinning and no felling management". The data tables estimate net emissions from soil for mineral soils and organo-mineral soils. The methodology is also used for the 7th Carbon Budget modelling and is consistent with the CARBINE model used for the UK GHG inventory and includes better representation of the carbon stock losses associated with forest establishment, particularly from soils

[4] https://www.gov.uk/government/publications/the-uk-forestry-standard

Sitka spruce is used as the representative plantation conifer species, Birch as the representative broadleaved species and Scots pine as the representative conifer species for habitat creation. Standard management is assumed for plantation species and a mixture of continuous cover and no thinning management for habitat creation.

3.2 Agroforestry and hedgerows

This measure aims to increase the amount of permanent vegetation on agricultural land (and thus increased carbon sequestration in biomass and soils) whilst maintaining agricultural production. This can be done by increasing hedgerow lengths and/or converting agricultural land to agroforestry systems. Agroforestry in the UK context includes silvo-pastoral systems on grassland that integrate low density woodland with livestock grazing, and silvo-arable systems on cropland that integrate narrow strips of economically valuable woodland with arable cropping (alley cropping or shelter belts).

As tree planting is low-density in agroforestry systems it was assumed that only a small percentage of land was lost to productive agricultural use. For silvo-pastoral this is 14% of the converted grassland area, equivalent to a planting density of 400 trees/ha. For silvo-arable agroforestry 6.7% of the converted arable area is lost to agriculture, equivalent to planting a 2m-wide strip for each tree row, with 8m between trees in a row and 30m between each row. These definitions are consistent with previous CCC analyses. Carbon stock changes were calculated using the same method as woodland creation, assuming planting of Beech yield class 12 in silvo-arable systems, and Birch yield class 6 in silvo-pastoral systems with no thinning.

Increasing hedgerow length is considered not to affect the agricultural land available as these will occur along existing field boundaries where hedges may be degraded or where there is potential to replace fence lines.

3.3 Energy crop production

This measure covers the planting of second-generation biomass energy crops such as *Miscanthus*, Short Rotation Coppice (SRC) and Short Rotation Forestry (SRF).

Carbon stock changes and harvest yields in Miscanthus and Short Rotation Coppice were calculated using the same method as the CCC 7th Carbon Budget. Carbon stock changes and yields in Short Rotation Forestry were calculated using the same method as woodland creation, assuming planting of Beech yield class 12 with no thinning.

3.4 Peatland restoration and sustainable management

This measure covers the restoration, rewetting and sustainable management of degraded peatlands (organic soils) currently under agricultural, extraction and forest land use. Degraded peatlands no longer function like natural peatlands because of drainage and grazing or burning management, resulting in net GHG emissions to the atmosphere rather than net removals. Mitigation actions on these degraded peatlands by 2035 and 2050 will reduce GHG emissions rather than increase net GHG removals due to the long time-profile required to sequester carbon following restoration, and relatively slow rate of peat formation in natural or close to naturally functioning systems.

Restoration of degraded peatlands will generally take them out of agricultural usage, although low levels of seasonal conservation grazing may be used for habitat maintenance. Sustainable management of cropland on organic soils is manipulation of the water table to reduce GHG emissions while maintaining agricultural production, for either conventional or paludiculture crops. Restoration of areas used for forestry or peat extraction is assumed to return the area to a near-natural state.

3.5 Other restoration of semi-natural habitats

This measure captures restoration of all other semi-natural habitats other than woodland and restored peat. These are primarily composed of semi-natural grasslands (neutral, calcareous and acidic), fens, marshes and swamps on non-peat soils, and dry lowland heathland. Such restoration may primarily be driven by biodiversity related targets, e.g. area-based targets in the 25 Year Environment Plan or proportion of protected land under 30by30[5], but will also have consequences for GHG emissions and capture. Generally, semi-natural habitats will have reduced emissions and increased capacity for GHG sequestration when compared to the intensive agricultural land (either arable or improved grassland) which they replace under this measure (Gregg *et al.,* 2021).

Targets for habitat restoration may be met by a range of actions, including active management or passive cessation of agricultural activities and subsequent natural regeneration, but we do not distinguish between these here. We also do not distinguish between large-scale restoration at the extent of whole fields or above (‘land sparing’), and the creation of smaller habitat patches within agricultural landscapes (‘land sharing’), with the focus being the total area of restored habitat per archetype.

For modelling purposes, all restored semi-natural habitats are assumed to function similarly, in terms of both GHGs and ecosystems services, as part of a broad “semi-natural grassland” class. Whilst other semi-natural habitats exist and may be targets for restoration (e.g. coastal sand dunes, reedbeds), they occupy comparatively small areas dependent on specific local conditions are therefore beyond the scope of assessment via the spatial and thematic resolution of the archetypes.

[5] https://assets.publishing.service.gov.uk/media/65807a5e23b70a000d234b5d/Delivering_30by30_on_land_in_England.pdf

3.6 Solar energy generation on agricultural land

This measure covers the installation of solar photovoltaic (PV) energy on agricultural land. The calculations were based on the following data sources:

- Current energy production and targets for 2035 and 2050 under Transition 2 pathways are based on assumptions used in the CCC's 2023 Delivering a Reliable Decarbonised Power System report (70GW and 105GW respectively). Total production in the UK has been apportioned to the 12 Archetypes based on the 2021 distribution of grassland. For the baseline and Transition 1, it is assumed that the current solar energy production is maintained.
- The land footprint is based on average land per MW of production from National Policy Statements.
- Construction and Operation and maintenance (O&M) costs are based on DESNZ's Electricity Generation Costs 2023.
- The grid export price available to farmers is based on the system wholesale price estimated by the CCC for CB7.

For Transition 2 pathways, 70% of the uplift in solar PV installation to meet the 2035 and 2050 targets (49GW and 73.5GW respectively) has been modelled to occur in Archetypes 3,4 and 9, with the remaining 30% (21GW and 31.5GW respectively) occurring in the other Archetypes.

4. Baseline metrics

Metrics are quantified for 2021, 2035 and 2050 under the Baseline pathway. The Baseline pathway assumes that current rates of land use change continue. In particular:

- Average annual rates of woodland creation over 2018-2022 are used for projection years 2022-2050
- Average annual rates of peatland restoration over 2017-2021 are used for projection years 2022-2050
- Urban/suburban development continues at rates to match the demands of increasing household numbers. These rates are maintained under the transition.

4.1 Land Use Areas

2021 Baseline

Land Cover in each of the archetypes in 2021 (A.2.1) was assessed using the Land Cover Map 2021 1km-gridded dominant land cover dataset (Marston et al. 2022). The dominant land cover is the category with the largest area within the 1km grid cell, but smaller areas of other land cover categories can also occur, e.g. a dominant improved grassland grid cell could contain areas of cropland and broadleaf woodland. Grassland (62%) and cropland (26%) categories dominate the UK rural land cover (Figure 4). Non-vegetated LCM categories (Inland rock, Saltwater, Freshwater, Supralittoral rock, Littoral rock and Littoral sediment) cover <2% of the non-rural area and are omitted from graphs for clarity.

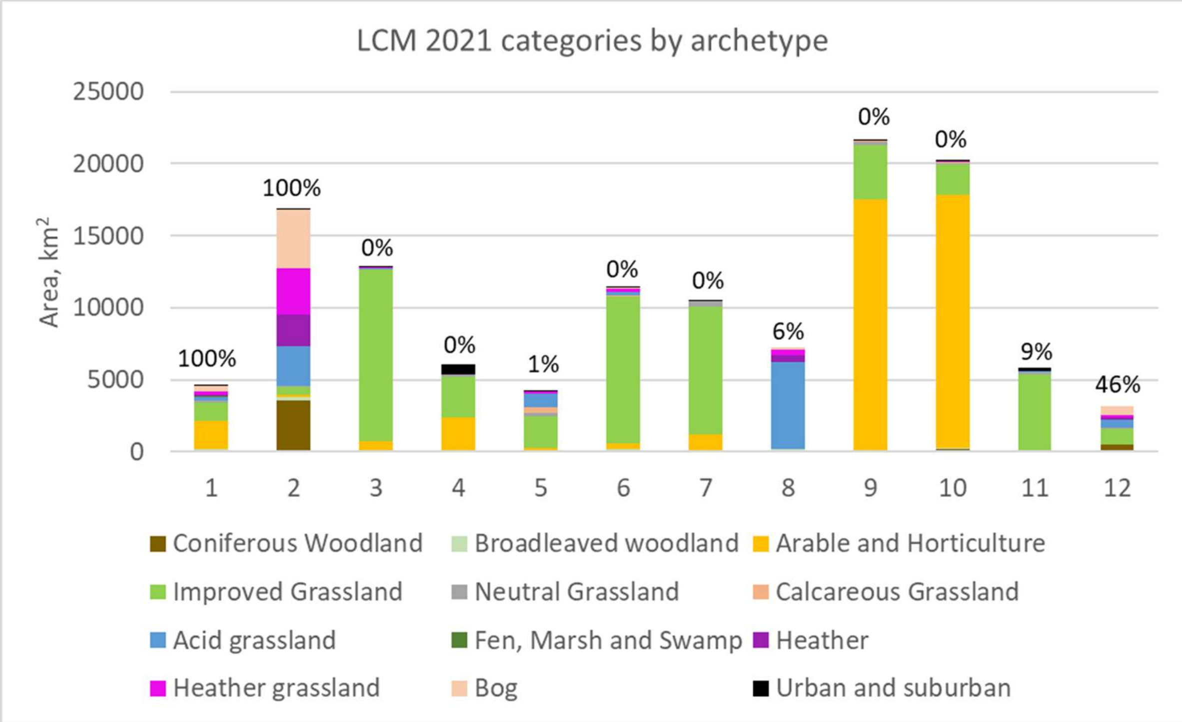


Figure 4: Land Cover Map categories in 2021 by archetype. The percentage of the archetype covered by organic soil is given above each bar.

The areas of agricultural land use were required for agricultural metrics. The Land Cover Plus: Crop Map 2021 (Upcott *et al.,* 2023) was used to partition areas of improved grassland into permanent and temporary grassland, using the field records of annual crop types 2015-2021. Fields where the crop was grass in all years 2015-2021, except a maximum of one non-grass crop to account for uncertainty in classification, were assigned as permanent grassland. All other fields which were grass in 2021 were assigned as temporary grassland. The area of the permanent and temporary grass fields in each archetype were summed to give totals for 2021. The Crop Map covers GB, so for Northern Ireland the split between permanent and temporary grassland was based on the areas reported in the Northern Ireland 2021 June Agricultural Survey (83% permanent pasture, 17% temporary grassland).

Organic soil areas in each archetype in 2021 were calculated using the peat map developed for the LULUCF GHG inventory (Clilverd *et al.,* forthcoming). Grid cells were assigned a peat condition category if the middle of the grid cell intersected with a condition in the peat map (to keep area data on the 1km grid). The area of peat condition category in each archetype is given in the appendix.

Greenhouse gas emission metrics are estimated consistently with the UK's national GHG Inventory (using IPCC guidance). For land-use, this requires mapping between the inventory land-use categories and those in the Land Cover Map (**Error! Reference source not found.**). The GHG inventory also includes a Wetlands category, which can be broadly defined as land that is permanently saturated with highly organic soils and is not managed for other uses (e.g., grazing). In the UK this covers near-natural bogs and fens, peat extraction sites and larger areas of freshwater. There is overlap with the Fen, marsh and swamp and Bog LCM categories. Organic soils can occur under any land category. The land categories reported in the June Agricultural Surveys are also mapped to the other classifications.

Table 2: Comparison between GHG inventory land-use categories and Land Cover map categories

GHG Inventory land-use category	Land Cover Map categories	Agricultural land categories
Forest	Broadleaved woodland Coniferous woodland	NA
Cropland	Arable and horticulture	Cropland
Grassland (pasture)	Improved grassland	Permanent pasture Temporary pasture
Grassland (semi-natural)	Neutral grassland Calcareous grassland Acid grassland Fen, marsh and swamp Heather Heather grassland Bog Supralittoral sediment Saltmarsh	Rough grazing
Settlement	Urban Suburban	NA
Other	Inland rock Saltwater Freshwater Supralittoral rock Littoral rock Littoral sediment Not categorised	NA

Baseline Projections of land use to 2035 and 2050

Baseline land use change was based on the LULUCF inventory projections (DESNZ, unpublished 2023) and datasets for woodland creation, peatland restoration and urban development.

Woodland creation and forestry. The average tree planting rates for 2018-2022 were assumed to continue to 2050. These rates are collated by Forest Research and used for the annual UK GHG inventory (Brown *et al*., 2024), disaggregated by country, conifer/broadleaf planting and pre-woodland creation land type.
Not all land within an archetype is suitable for tree planting. A look-up table was used to categorise LCM habitats within each archetype as suitable/unsuitable for tree planting and calculate the total available area:

- Broadleaved woodland, Coniferous woodland, Fen, marsh and swamp, Bog, Inland rock, Saltwater, Freshwater, Supralittoral rock, Supralittoral sediment, Littoral rock, Littoral sediment, Saltmarsh, Urban: *unsuitable for tree planting in all archetypes*.
- Arable and horticulture. Improved grassland, Heather, Suburban: *unsuitable on Archetypes 1 and 2 (dominated by highly organic soils)*
- Neutral grassland, Calcareous grassland, Acid grassland, Heather grassland: *unsuitable on lowland or highly organic archetypes (1-4, 7, 8 (acid grassland), 9-11)*

The total suitable area was used to apportion the estimated national tree planting area between archetypes by 2035 and 2050. These planted areas were compared with the total area with potential for woodland creation in each archetype using the RSPB/University of Stirling map (Bradfer-Lawrence *et al.,* 2021). This dataset maps the areas in the UK with potential for woodland creation. It excludes existing woodland, higher quality agricultural land, nature conservation sites, priority habitats, peatlands, buildings, infrastructure and archaeological features. The potential woodland creation area was generally much greater than the projected areas across the archetypes (Figure 5).

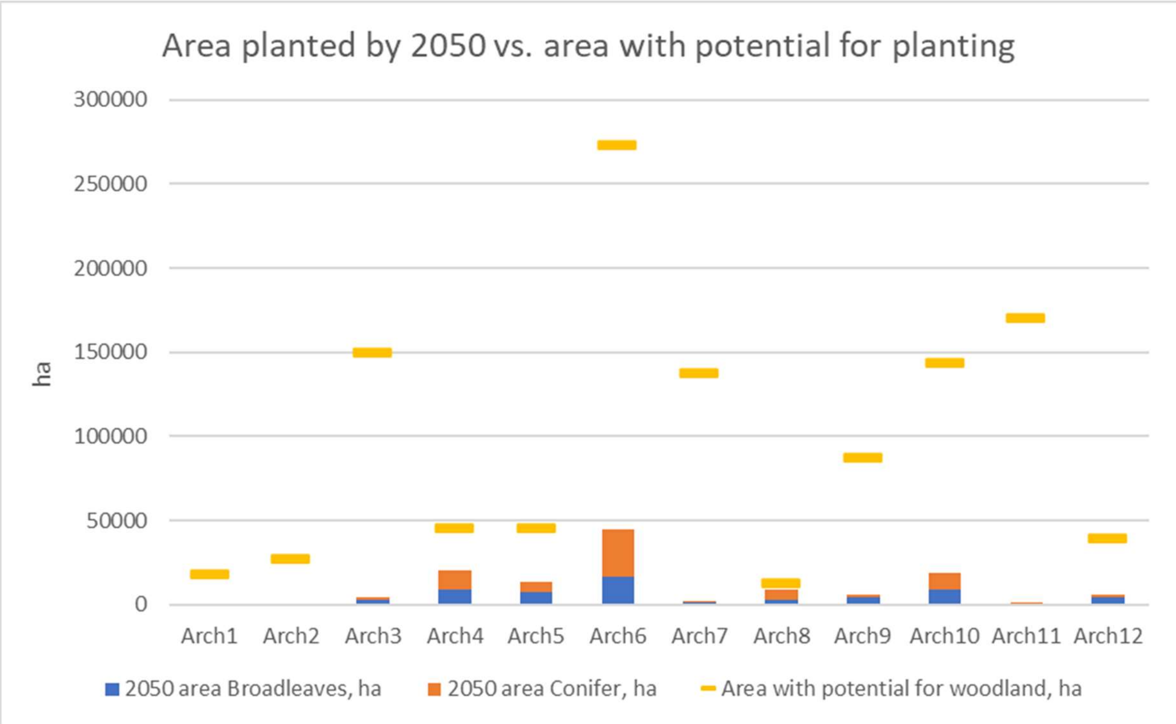


Figure 5: Comparison of Baseline projected vs. potential woodland creation area

Peatland restoration

Average peatland restoration rates for 2017-2021 were assumed to continue to 2050. Peatland restoration time-series data from the LULUCF GHG Inventory was used, with peatland restoration locations and areas for 2017-2021 mapped to archetype locations to give average annual rate of peatland restoration in each archetype. These annual rates were continued to 2035 and 2050.

Urban expansion

There is continued land demand for housing and infrastructure out to 2050, summarised as 'urban expansion' although this can also occur in rural areas. This is assumed to correlate to the increase in households (population), as in the LULUCF GHG inventory projections. Projections in the increase in the number of households are available at the national and local authority level[6] and the proportion of local authority area by archetype was used to create a projected household increase for each archetype. These values were used with the LULUCF projection methodology (DESNZ, unpublished 2023) to estimate the urban expansion land demand by archetype. Annual land demand in all archetypes was estimated to be between 0.00% and 0.07% and reducing over time. Demand was highest in Archetype 4 (suburban fringe) and lowest in rural upland archetypes such as 2 and 8.

When the land areas required for Baseline pathway woodland creation, peatland restoration and urban expansion are considered, the coverage of arable and improved grassland across the archetypes declines slightly, while coverage of woodland, urban/suburban and bog categories increase (Figure 6). Land cover areas for 2035 and 2050 are given in the Appendix workbook. Semi-natural habitats (excluding LCM categories Coniferous woodland, Arable and horticulture, Improved Grassland and Urban and suburban land) increased by 203 km^2 by 2035 and 462 km^2 by 2050, covering 22.5% of the archetype area.

[6] https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationprojections/datasets/householdprojectionsforengland

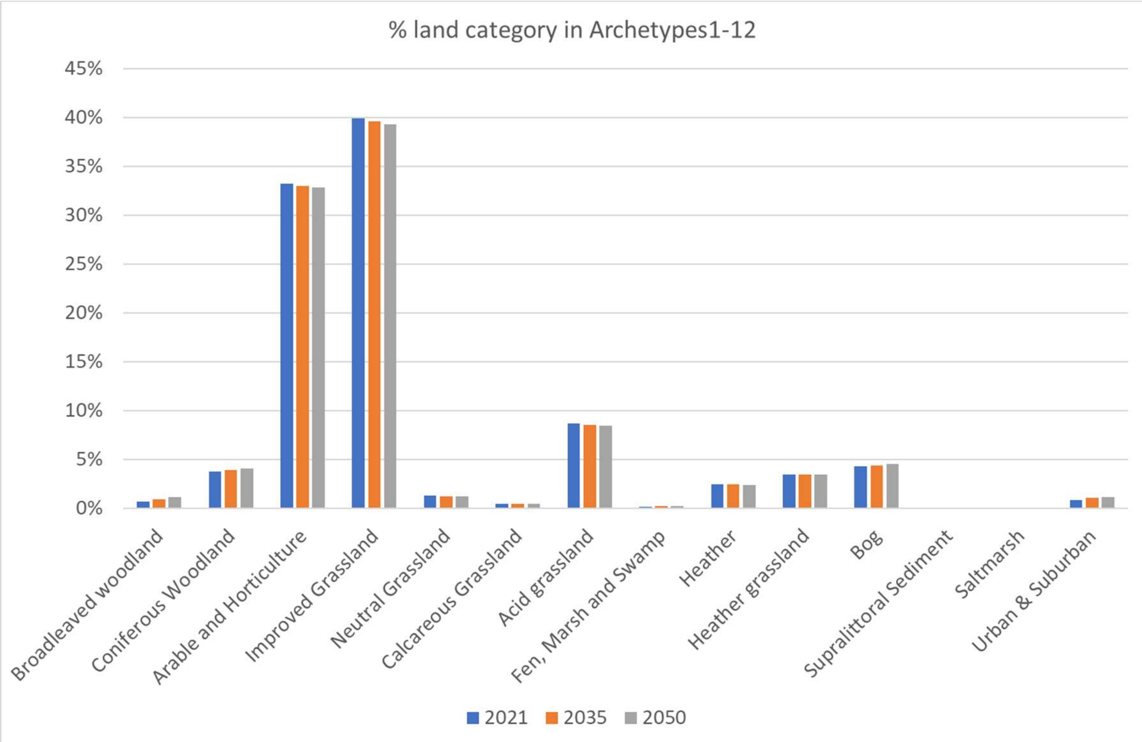


Figure 6: Percentage of each land category under Baseline projection

4.2 Livestock numbers and production

Livestock numbers for the 2021 baseline were compiled for each archetype using categories of cattle and calves, sheep and lambs, pigs and poultry. Livestock populations from the 2021 June Agricultural Survey are reported by local authorities/sub-regions for England[7], Scotland[8] and Northern Ireland[9]. No agricultural survey was undertaken in Wales in 2021 so the small area statistics from 2020 were used[10] and combined into the larger Local Authority areas. The Scottish sub-region livestock data was disaggregated, where necessary, in proportion to the area of rural land in each local authority area in the sub-region. This compiled dataset of livestock numbers by local authority was then disaggregated to archetypes based on the proportion of rural land by local authority and archetype (calculated by spatial map overlay) (Figure 7 and A.2.5).

Cattle numbers were split between Dairy cattle, Other dairy cattle and Beef cattle using the country herd proportions: England (22%/ 17%/ 61%), Scotland (10%/ 9%/ 81%), Wales (22%/ 18%/ 60%), and Northern Ireland (19%/ 15%/ 66%). This was

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[7] https://www.gov.uk/government/statistical-data-sets/structure-of-the-agricultural-industry-in-england-and-the-uk-at-june

[8] https://www.gov.scot/publications/results-scottish-agricultural-census-june-2021/documents/

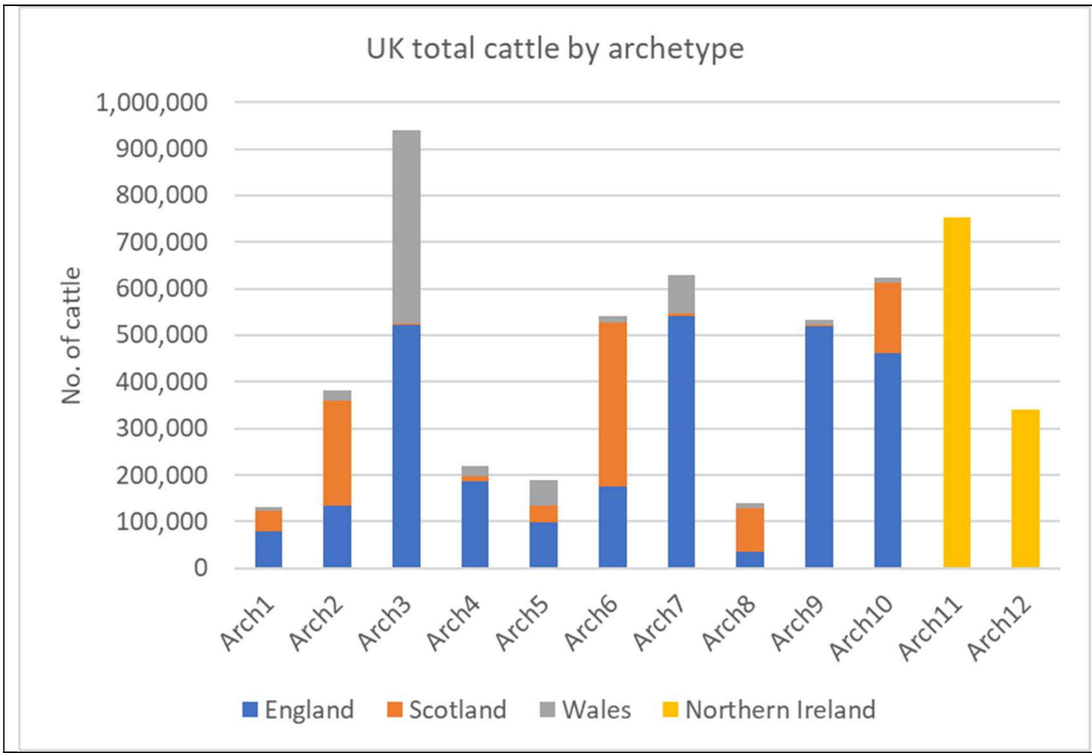
[9] https://www.daera-ni.gov.uk/publications/agricultural-census-northern-ireland-2021

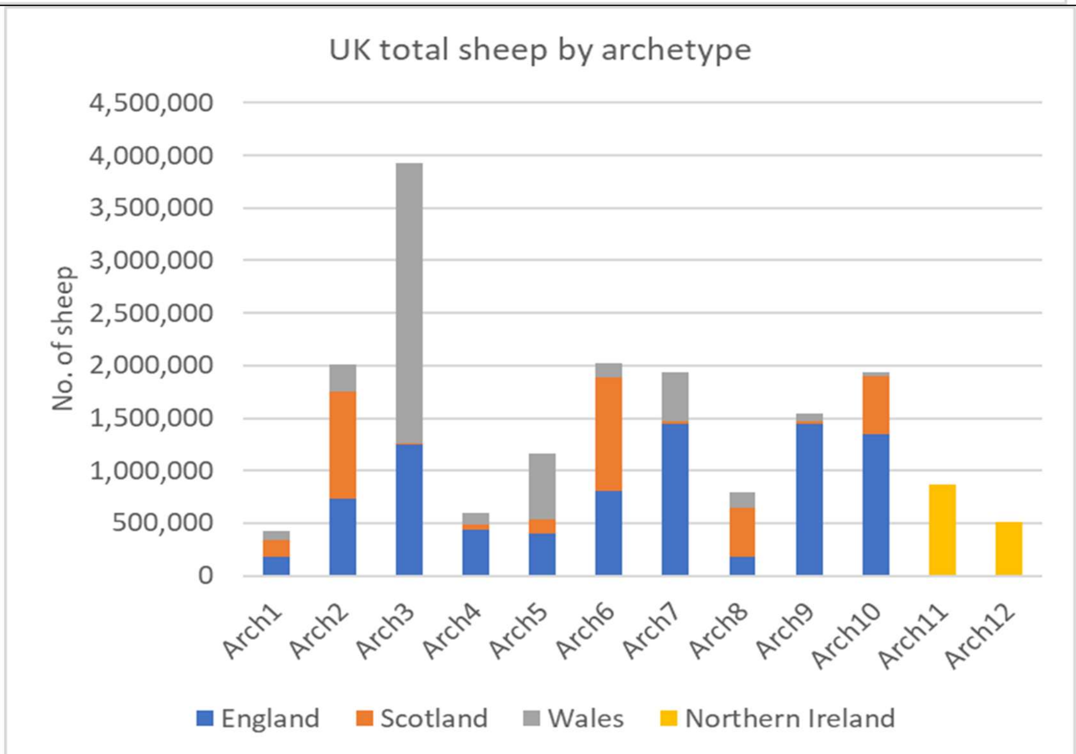
[10] https://www.gov.wales/agricultural-small-area-statistics-2002-2020

in order to utilise the livestock GHG emission factors used by the CCC in previous analyses (Thomson *et al*. 2018; CCC 2019, 2021).

Of total UK livestock, 42% of cattle, 45% of sheep, 33% of pigs, and 34% of poultry, are assigned to Archetype 100. Archetype 3 (intensive grassland) has the highest numbers of cattle and sheep, but other arable-dominated archetypes (9 - Arable on chalk/clay and 10 - Arable on sandy soils) also have comparatively high numbers of cattle, reflecting their large area coverage. Archetypes 9 and 10 also have the highest numbers of pigs and poultry. Archetypes 7 (Enclosed pasture) and 11 (Lowland agriculture in Northern Ireland) also have large livestock populations, particularly considering 11's relatively small areal coverage.

Livestock numbers were projected to change over time out to 2050. Numbers of dairy cows and other dairy cattle were projected to decline slightly (by 4%), while numbers of beef cattle, sheep, pigs and poultry were projected to increase over time (by 18%) to maintain food calorie production per capita. This was in accordance with assumptions made in previous CCC CB6 analyses.


UK total cattle by archetype
No. of cattle
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
Arch1
Arch2
Arch3
Arch4
Arch5
Arch6
Arch7
Arch8
Arch9
Arch10
Arch11
Arch12
England
Scotland
Wales
Northern Ireland


UK total sheep by archetype
No. of sheep
4,500,000
4,000,000
3,500,000
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
Arch1
Arch2
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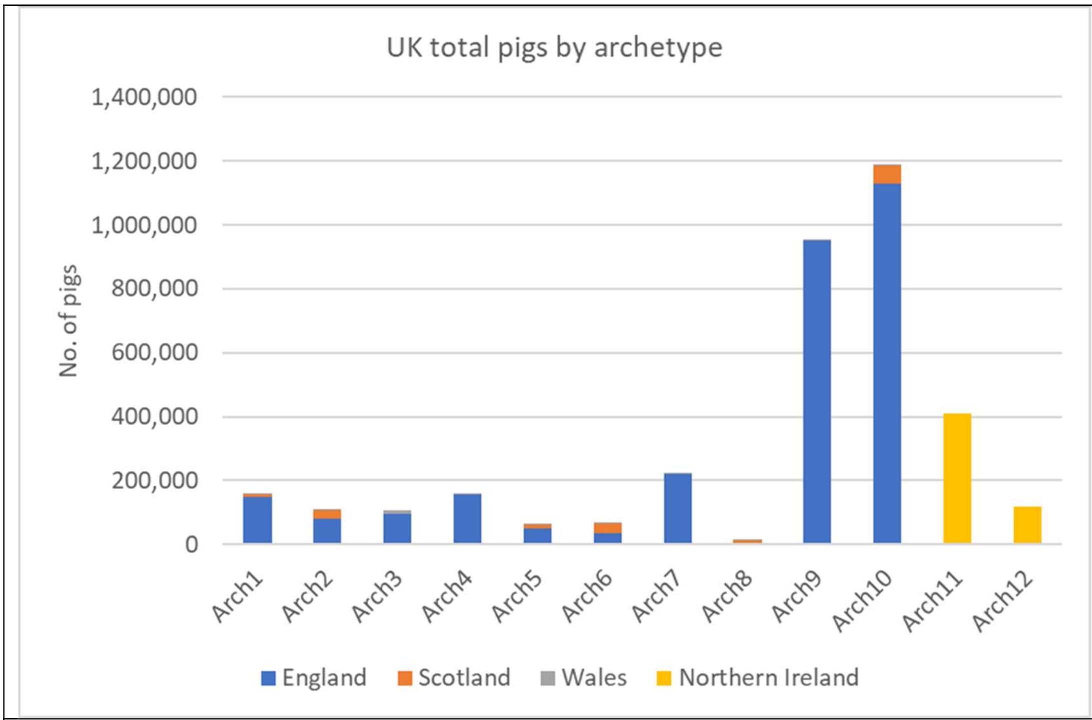
England
Scotland
Wales
Northern Ireland



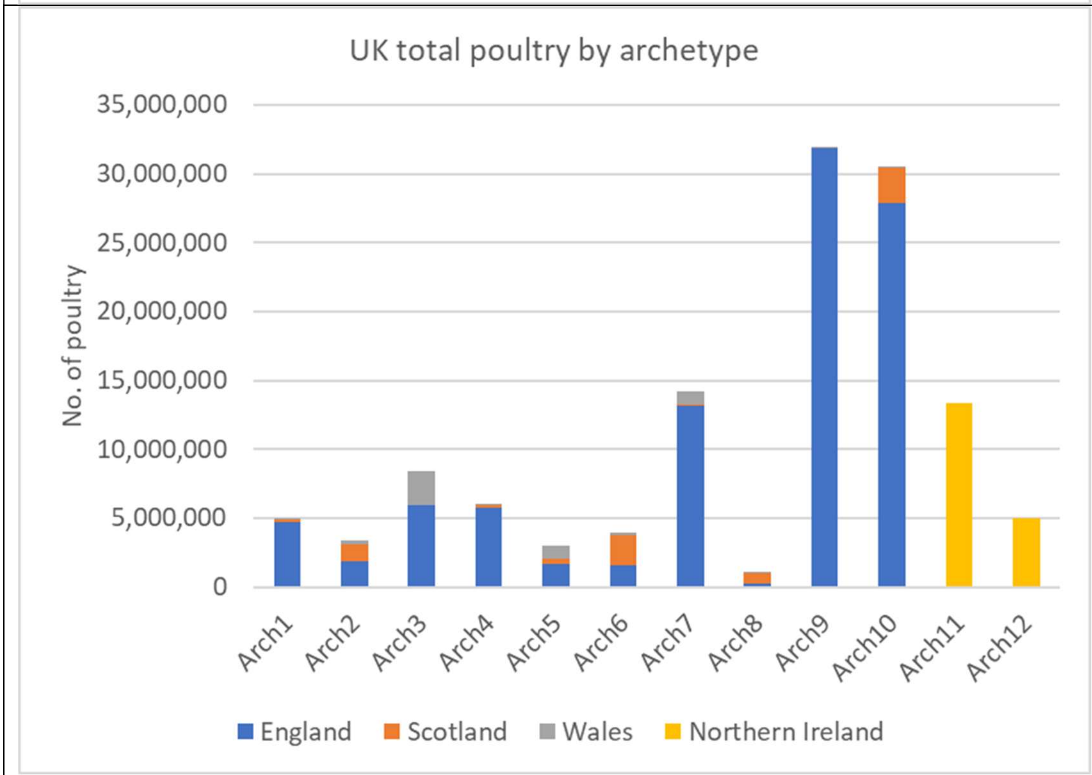


Figure 7: Estimated livestock numbers by archetype in 2021

Archetypes: 1-Lowland organic soils; 2- Upland organic soils; 3- Intensive grassland; 4- Suburban fringe; 5- Hilly farmland; 6- Open pasture; 7- Enclosed pasture; 8- Acid upland grassland; 9- Arable on chalk/clay; 10- Arable on sandy soils; 11- Lowland agriculture in Northern Ireland; 12- Uplands in Northern Ireland.

Livestock production output per head of livestock used factors from previous CCC analyses based on the Business-As-Usual scenario, i.e., no change when projected forward to 2050, with the exception of milk production which was projected to increase over time (19% by 2050). Emission factors can vary between countries due to variation in breeds or management. The factors (**Error! Reference source not found.**) were multiplied with the estimated livestock numbers per archetype.

Table 3: Production factors used to estimate livestock production, 2021 values

Country	Milk (litres/dairy cow)	Beef and veal (t/head)	Mutton and lamb (t/head)	Pig meat (t/head)	Poultry meat (t/head)
England	8024	0.148	0.008	0.180	0.011
Wales	8057	0.160	0.008	0.237	0.015
Scotland	7444	0.124	0.009	0.213	0.008
N Ireland	7338	0.135	0.010	0.181	0.009

Archetype 3 (Intensive grassland) has the highest milk production of the archetypes, while Archetypes 1 (Lowland organic soils) and 8 (Acid upland grassland) have the lowest, reflecting their respective numbers of dairy cattle. Meat production is dominated by pig and poultry meat (Figure 8), particularly in Archetypes 9 (Arable on chalk/clay) and 10 (Arable on sandy soils). Both meat and milk production are projected to increase over time under the Baseline pathway, in line with changes in livestock numbers and milk yields.

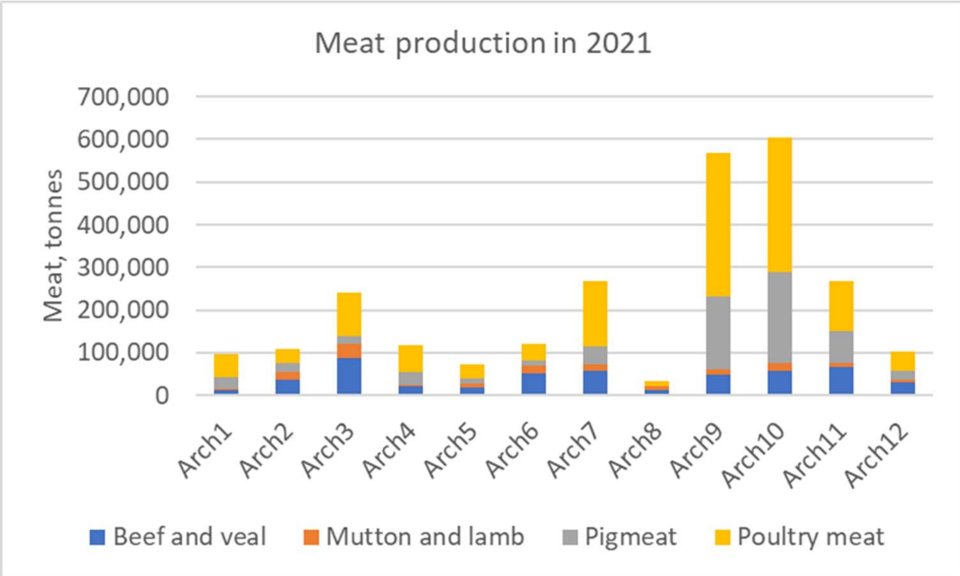


Figure 8: Estimated meat production in 2021 by archetype

Archetypes: 1-Lowland organic soils; 2- Upland organic soils; 3- Intensive grassland; 4- Suburban fringe; 5- Hilly farmland; 6- Open pasture; 7- Enclosed pasture; 8- Acid upland grassland; 9- Arable on chalk/clay; 10- Arable on sandy soils; 11- Lowland agriculture in Northern Ireland; 12- Uplands in Northern Ireland.

4.3 Agriculture GHG Emissions

GHG emissions from livestock arise from enteric fermentation (CH_4), manure management (CH_4, N_2O) and manure fertilisation of soils by grazing livestock (N_2O). Emission factors from previous CCC analyses are used based on the Business-As-Usual scenario, i.e., emission factors do not change when projected forward to 2050, with the exception of factors for dairy cows which are projected to increase over time (15% by 2050) with increased milk productivity. Emission factors can vary between countries due to variation in breed, herd composition or management. The factors are multiplied with the estimated livestock numbers per archetype (Table 4). These emission factors are in line with those used in the Agriculture sector of the UK GHG Inventory, but are not an exact match because the inventory uses a finer scale breakdown of livestock and management types. All emission factors are converted into tonnes CO_2 equivalent per head of livestock, using IPCC AR5 Global Warming Potential values.

Table 4: Emission factors used to estimate GHG emissions from livestock, 2021 values, tCO_2e/head.

Livestock type	Country	CH_4 from enteric fermentation and manure management	N_2O from manure management (direct and indirect emissions)	N_2O from grazing returns (direct and indirect emissions)
Dairy cows	England	4.59	0.20	0.04
	Wales	4.59	0.23	0.04
	Scotland	4.50	0.40	0.04
	N Ireland	4.20	0.06	0.07
Other dairy cattle	England	1.92	0.18	0.08
	Wales	1.95	0.17	0.08
	Scotland	1.98	0.15	0.08
	N Ireland	1.85	0.09	0.07
Beef cattle	England	1.80	0.21	0.05
	Wales	1.84	0.19	0.05
	Scotland	1.93	0.18	0.04
	N Ireland	1.94	0.13	0.05
Sheep	England	0.13	0.00	0.01
	Wales	0.11	0.00	0.0
	Scotland	0.15	0.00	0.01
	N Ireland	0.14	0.00	0.01
Pigs	England	0.19	0.06	0.01
	Wales	0.19	0.06	0.01
	Scotland	0.19	0.06	0.01
	N Ireland	0.19	0.02	0.01
Poultry	England	0.00	0.00	0.00
	Wales	0.00	0.00	0.00
	Scotland	0.00	0.00	0.00
	N Ireland	0.00	0.00	0.00

Agricultural areas (cropland, permanent pasture, temporary grassland and rough grazing) were estimated by archetype (Figure 9). Baseline agricultural areas were calculated from the Land Cover Crop Map 2021[11] (see Section 4.1). The baseline area of rough grazing was estimated as the difference between the sum of all arable and grassland Land Cover Map categories (excluding woodland, other and urban/suburban categories) and the other three agricultural areas. Agricultural areas in 2035 and 2050 were projected by taking account of land-use change arising from woodland creation, peatland restoration and urban development (see Section 4.1).

[11] https://www.ceh.ac.uk/data/ceh-land-cover-plus-crops-2015

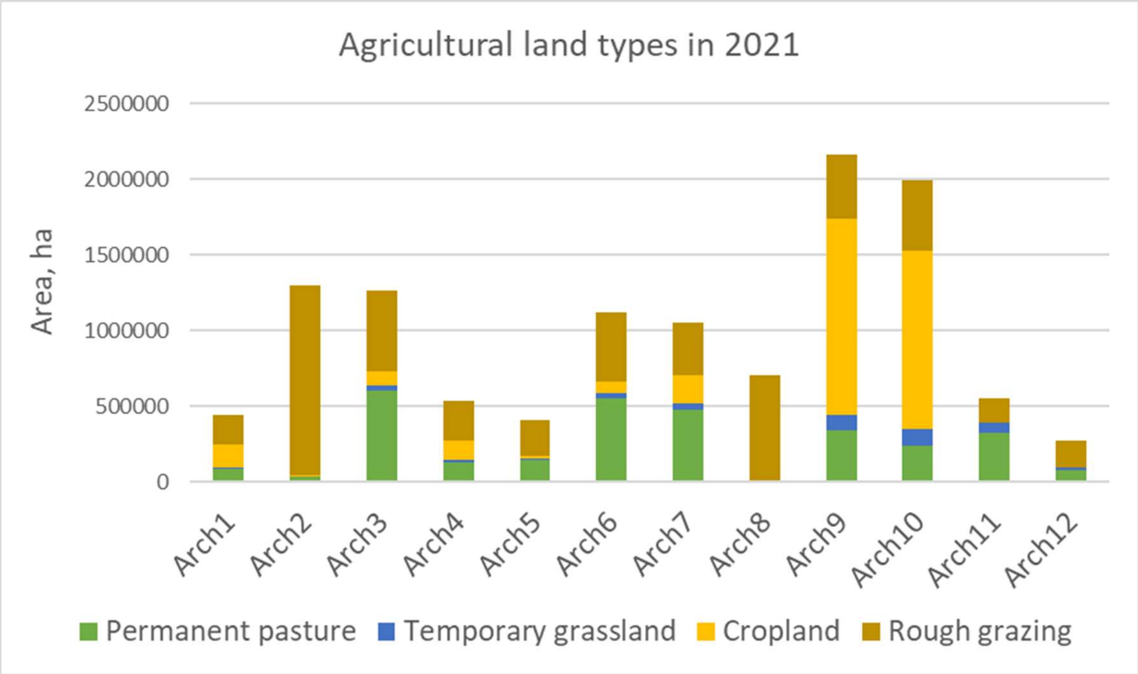


Figure 9: Agricultural areas by archetype in 2021

Archetypes: 1-Lowland organic soils; 2- Upland organic soils; 3- Intensive grassland; 4- Suburban fringe; 5- Hilly farmland; 6- Open pasture; 7- Enclosed pasture; 8- Acid upland grassland; 9- Arable on chalk/clay; 10- Arable on sandy soils; 11- Lowland agriculture in Northern Ireland; 12- Uplands in Northern Ireland.

Agricultural emissions from land areas are N_2O emissions from synthetic fertilizer/sewage sludge application to soil, crop residues and soil mineralisation and associated indirect emissions. These are assumed not to occur on rough grazing land. Emission factors from previous CCC analyses are used based on the Business-As-Usual scenario, i.e., emission factors do not change when projected forward to 2050. Emission factors can vary between countries due to variation in land management and soil type. These emission factors are in line with those used in the Agriculture sector of the UK GHG Inventory, but are not an exact match because the inventory uses a more detailed approach taking account of rainfall patterns and different management practices. The factors are multiplied with the estimated agricultural areas per archetype (Table 5).

Table 5: Emission factors used to estimate N2O GHG emissions from agricultural areas, 2021 values, t CO_2e/km^2.

Agricultural Area	Country	Synthetic fertilizer application	Sewage sludge application	Crop residues	Soil mineralisation
Permanent and temporary grassland	England	18.03		1.75	
	Wales	32.15		1.20	
	Scotland	28.48		1.90	
	N Ireland	40.58		1.90	
Cropland	England	50.44	6.20	37.97	4.21
	Wales	63.13	19.25	44.87	42.03
	Scotland	49.31	2.21	31.66	39.29
	N Ireland	55.18	3.73	44.05	76.48

The combined livestock and soil agricultural emissions for 2021 are shown in Figure 10 and emissions per unit area in Figure 11, illustrating the dominant contribution from livestock emissions and the relatively high intensity of emissions in the Northern Ireland Archetypes 11 and 12. Agricultural GHG emissions are projected to gradually increase in the Baseline pathway (by 10.3%), in line with the projected growth of the human population.

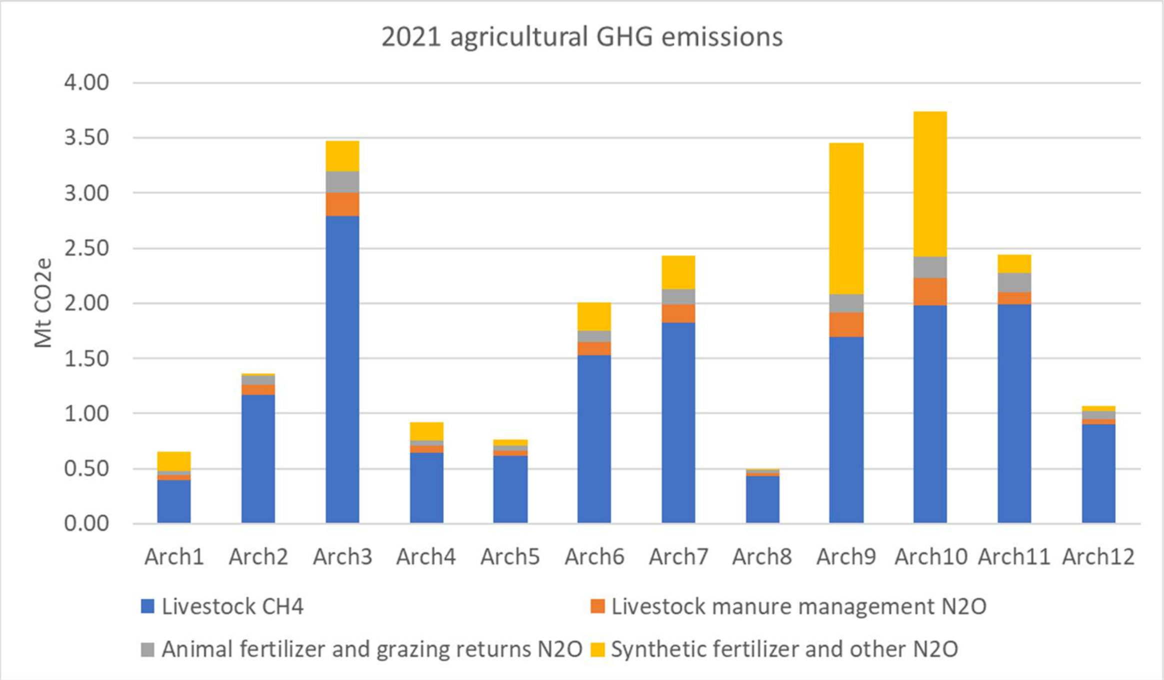


Figure 10: 2021 agricultural GHG emissions. .

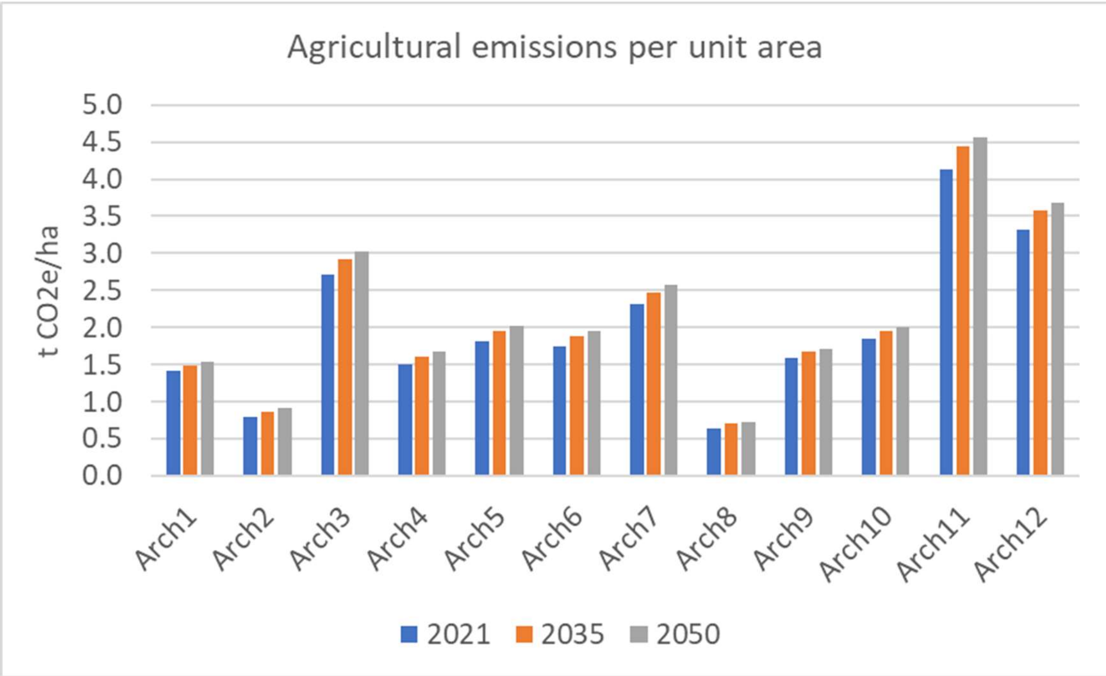


Figure 11: Baseline Agricultural emissions per unit area by archetype.

Archetypes: 1-Lowland organic soils; 2- Upland organic soils; 3- Intensive grassland; 4- Suburban fringe; 5- Hilly farmland; 6- Open pasture; 7- Enclosed pasture; 8- Acid upland grassland; 9- Arable on chalk/clay; 10- Arable on sandy soils; 11- Lowland agriculture in Northern Ireland; 12- Uplands in Northern Ireland.

Minor sources of agricultural emissions are not included in the archetype projections and are assumed not to change from the 2021 baseline. These are livestock emissions from deer, goats and horses (0.55 Mt CO_2e in 2021 in the UK inventory) and soil emissions from liming and urea application (1.43 Mt CO_2e in 2021).

4.4 LULUCF Emissions

We explicitly disaggregated the national LULUCF emissions by archetype using the same method as is used for the UK's Local Authorities, National Parks and Areas of Outstanding Natural Beauty. Full details of the method can be found in the Local Authority report (Young *et al*., 2023). There are three main approaches used:

- The majority of emissions categories are disaggregated using a dataset of annual land use maps, which were used to calculate land use change variables, then used to disaggregate emissions based on land use or change in land use in each location. As this is a gridded land use dataset, the grid cells are assigned to the archetypes in the same way as they would be assigned to the LAs.
- Organic soils emissions are disaggregated based on the peatland condition category areas, taking account of rewetting, in each archetype (This uses the shapefile areas from the peat map to give condition category areas per

archetype, with the rewetting point locations applied to the archetype they fall in. Therefore, there may be organic soil emissions assigned to archetypes not on organic soil in our land use map, because the shapefiles provide more detailed localised data than the 1km gridded data.).
- Emissions sources where there are point data for their locations – such as wildfires and creation of reservoirs – are assigned to the archetypes those points fall in.

Figure 12 shows that across the 12 archetypes, total emissions per archetype are highest in Archetype 1 (Lowland organic soils). This archetype has a large proportion of area on organic soils, much of which are farmed as cropland and grassland, and so this archetype has high emissions in the cropland, grassland and wetland sectors. Archetype 2 (Upland organic soils) also has high grassland emissions as this archetype includes upland grazed peatlands. Archetypes 3-9 and 11-12 have generally much lower emissions, in particular 3 and 5-8 are net sinks.

Figure 13 shows the LULUCF emissions on a per hectare basis, illustrating that Archetypes 11 and 12 have higher per unit area emissions than the many of the other archetypes as these cover smaller areas. Archetype 10 (Arable on sandy soils in England and Scotland) has relatively high cropland emissions as this primarily an arable archetype. The majority of woodland areas in the UK falls outside the 12 archetypes in Archetype 100 (see Section 2), and this can be seen with the large sink from the Forestry sector in this area.

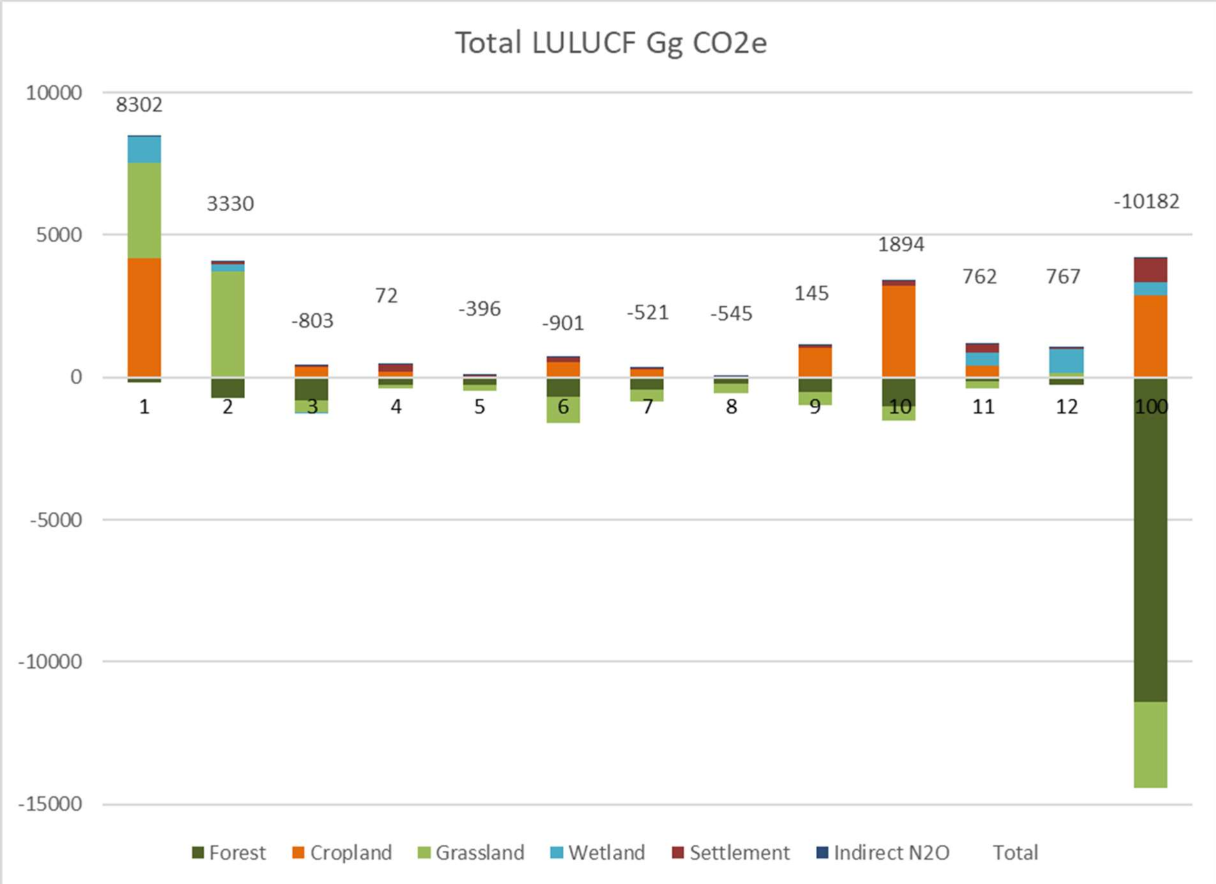


Figure 12: Sources and sinks of LULUCF emissions and net emissions per archetype in 2021.

Archetypes: 1-Lowland organic soils; 2- Upland organic soils; 3- Intensive grassland; 4- Suburban fringe; 5- Hilly farmland; 6- Open pasture; 7- Enclosed pasture; 8- Acid upland grassland; 9- Arable on chalk/clay; 10- Arable on sandy soils; 11- Lowland agriculture in Northern Ireland; 12- Uplands in Northern Ireland.

Projections of emissions under the Baseline pathway were based on the following assumptions:

- Woodland creation continues average tree planting rates from 2018-2022, using the method described in Section 3.1. The species and yield classes used were simplified from the most commonly planted tree species in the National Forest Accounting Plan: low yield broadleaves (Birch YC4 and YC6, and Beech YC8 in N. Ireland), high yield plantation conifers (Sitka spruce YC14 and YC16) and low-medium yield native conifers (Scots pine YC4 and YC8). Results were scaled so that 2021 net carbon stock change matched the GHG inventory 2021 value.
- Forest wildfires – the average annual area burned from 2010-2021 was used for all projection years.
- Deforestation: it was assumed that in 2035 and 2050:

    - Deforestation to cropland emissions were zero.
    - Deforestation to grassland emissions matched those in the DESNZ GHG Inventory Baseline projection and were assumed to all occur in Archetype 100.
    - Deforestation to settlement emissions matched those in the DESNZ GHG Inventory Baseline projection, and were disaggregated to archetypes based on forest to settlement areas in each archetype
    - Deforestation to wetlands emissions were the average of emissions in 2017-2021 per archetype.
- Peatland restoration – the average annual rates from 2017-2021 per archetype were used for all projection years while degraded peatland was available to be restored.
- Other cropland, grassland, settlement emissions – the DESNZ GHG Inventory Central projection scenario was used to calculate average per km^2 emissions for cropland, grassland and settlement per DA. These averages were used to adjust the 2021 emissions in each archetype according to how much land has changed to/from those land uses.
- Indirect N_2O – emissions for 2021 per archetype scaled by the DESNZ GHG Inventory Central projection UK difference between 2021 and 2035/2050.

Figure 14 and Figure 15 show the combined Agricultural and LULUCF emissions in 2021 and 2050 respectively. Most archetypes remain net sources under the Baseline projection, with half including net sources of LULUCF emissions in 2050. LULUCF emissions dominate in Archetypes 1 and 2 on organic soils, while highest Agricultural emissions can be seen in Archetypes 3, 9, 10, 11 reflecting those archetypes with highest numbers of livestock. The key assumptions affecting how LULUCF emissions are projected to change are woodland creation and peatland restoration. Emissions in Archetype 1 (Lowland organic soils) show a small decrease to 2035 and 2050 as more peatland restoration occurs. Particularly in archetypes 4, 5, 6 and 10 there are large increases in the carbon sink to 2050 due to woodland creation in these archetypes (Figure 15). Overall, LULUCF emissions in the Baseline pathway fall by 9% by 2050 from 2021 and combined emissions fall by 2% by 2050 from 2021.

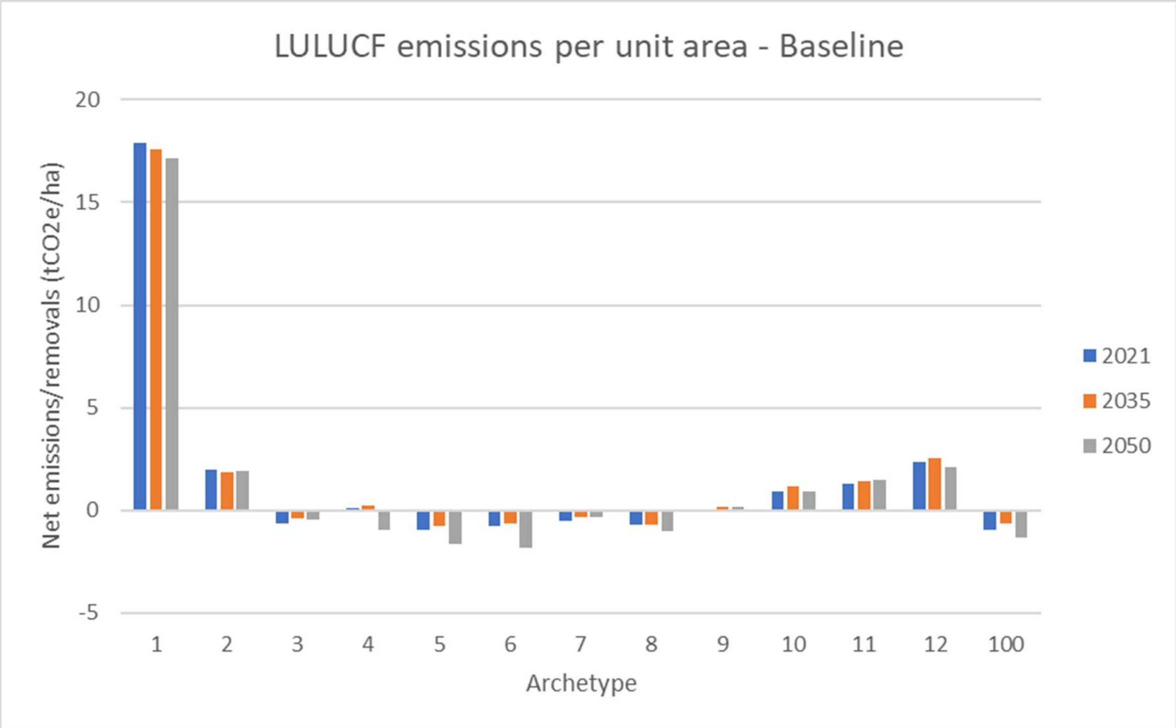


Figure 13 LULUCF emissions under Baseline projection per unit area

Archetypes: 1-Lowland organic soils; 2- Upland organic soils; 3- Intensive grassland; 4- Suburban fringe; 5- Hilly farmland; 6- Open pasture; 7- Enclosed pasture; 8- Acid upland grassland; 9- Arable on chalk/clay; 10- Arable on sandy soils; 11- Lowland agriculture in Northern Ireland; 12- Uplands in Northern Ireland.

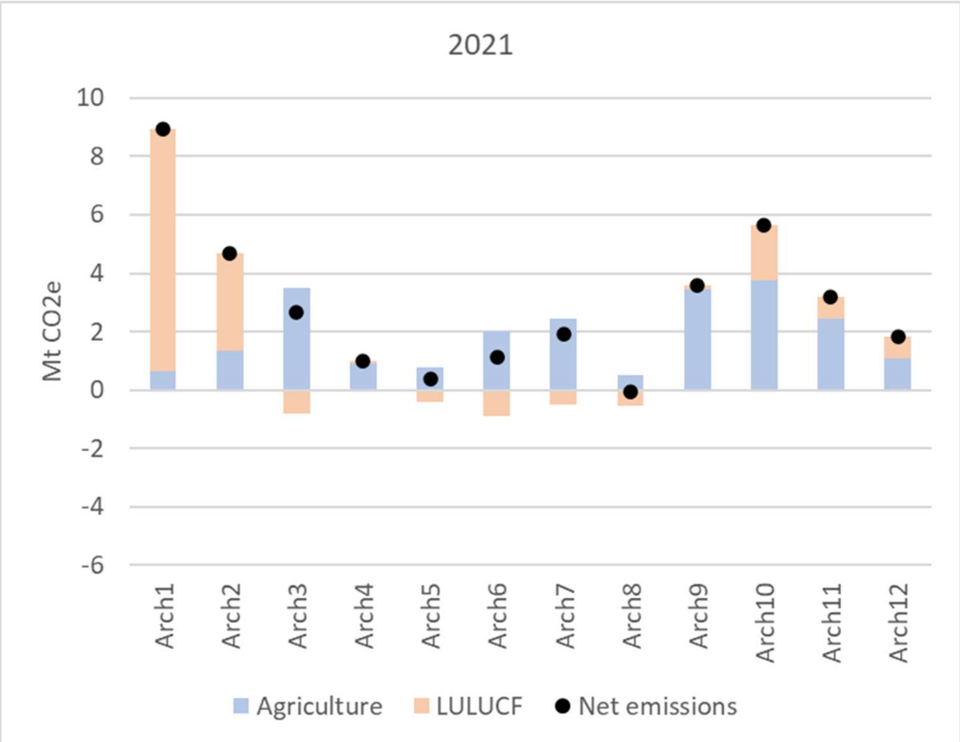


Figure 14 Combined Agriculture and LULUCF emissions in 2021

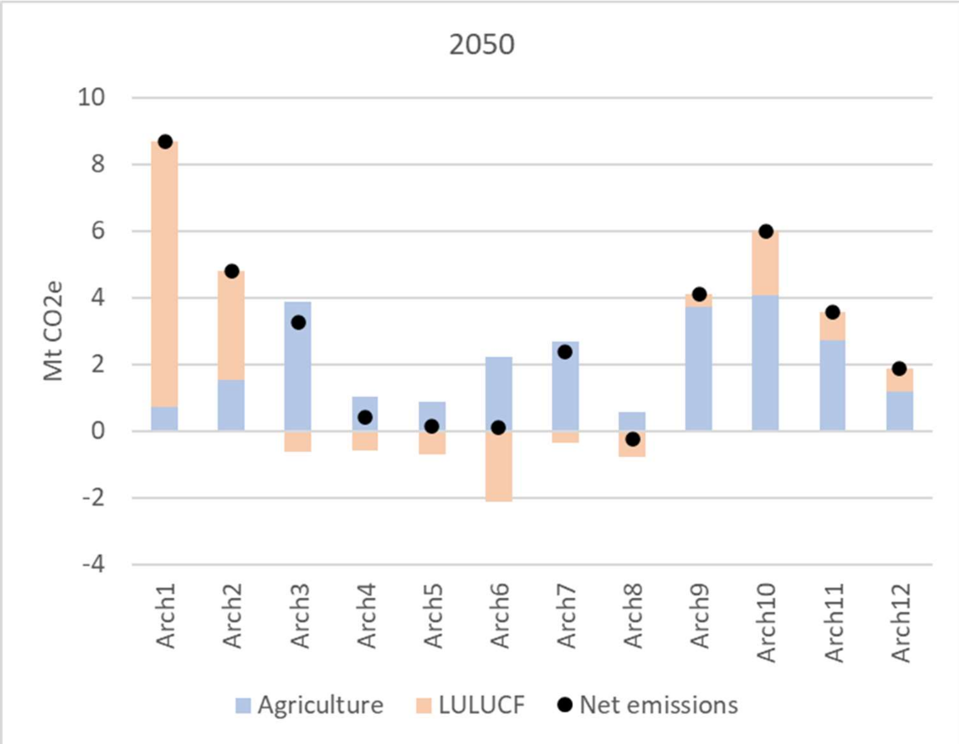


Figure 15 Combined Agriculture and LULUCF emissions in 2050

Archetypes: 1-Lowland organic soils; 2- Upland organic soils; 3- Intensive grassland; 4- Suburban fringe; 5- Hilly farmland; 6- Open pasture; 7- Enclosed pasture; 8- Acid upland grassland; 9- Arable on chalk/clay; 10- Arable on sandy soils; 11- Lowland agriculture in Northern Ireland; 12- Uplands in Northern Ireland.

4.5 Agricultural ammonia emissions

Ammonia (NH_3) gas can travel long distances, be damaging to the environment, and combine with other pollutants to form fine Particulate Matter pollution, which are harmful to human health. Agricultural animal waste is the main source of UK ammonia emissions[12]. Baseline agricultural ammonia emissions were estimated by Huw Woodward (Imperial College London) by overlaying NH_3 emissions maps at 5x5km^2 resolution from the Defra-funded Support for National Air Pollution Control Strategies (SNAPCS) project with the archetype locations. The emissions maps were generated using EDINA AgCensus data and provide emissions from beef, dairy, pigs, layers, other poultry, sheep, other livestock, and fertiliser as shown in Figure 16.

Emissions data was projected to 2035 and 2050 using on the proportional changes in livestock numbers for emissions from beef cattle, dairy cattle, sheep, pigs and poultry, and the proportional change in cropland and improved grassland for emissions from fertiliser application. Ammonia emissions increase with time across the archetypes (Figure 17), similarly to agricultural GHG emissions.

[12] https://naei.energysecurity.gov.uk/sites/default/files/2025-03/GB_IIR_2025_Submission.pdf

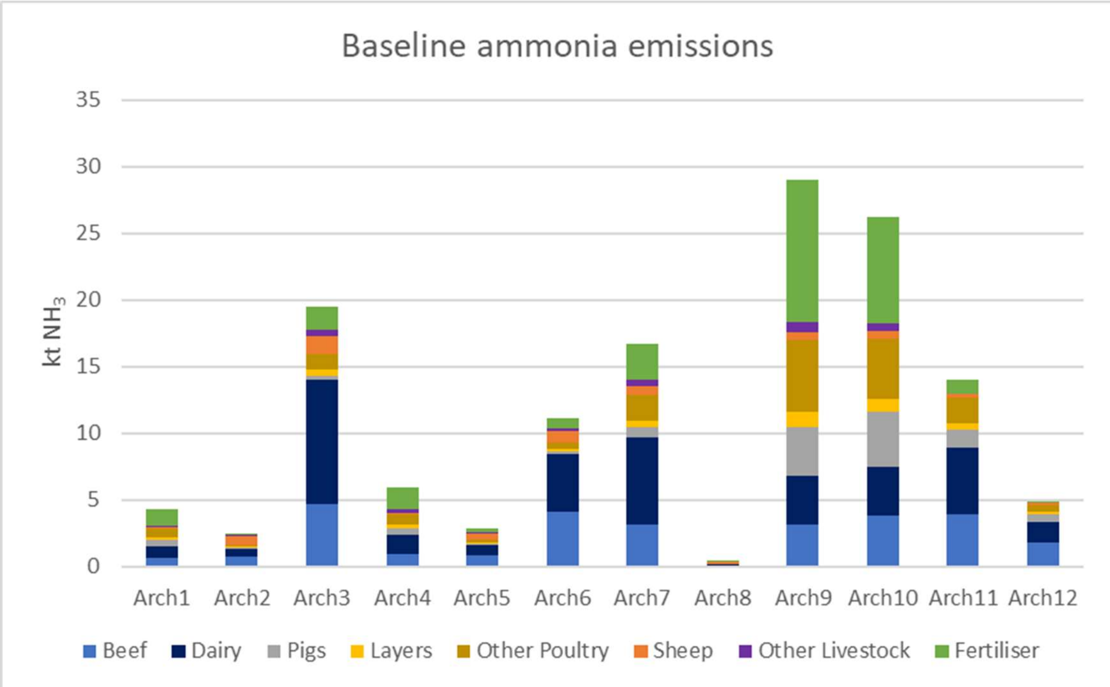


Figure 16 Sources of agricultural ammonia emissions per archetype

Archetypes: 1-Lowland organic soils; 2- Upland organic soils; 3- Intensive grassland; 4- Suburban fringe; 5- Hilly farmland; 6- Open pasture; 7- Enclosed pasture; 8- Acid upland grassland; 9- Arable on chalk/clay; 10- Arable on sandy soils; 11- Lowland agriculture in Northern Ireland; 12- Uplands in Northern Ireland.

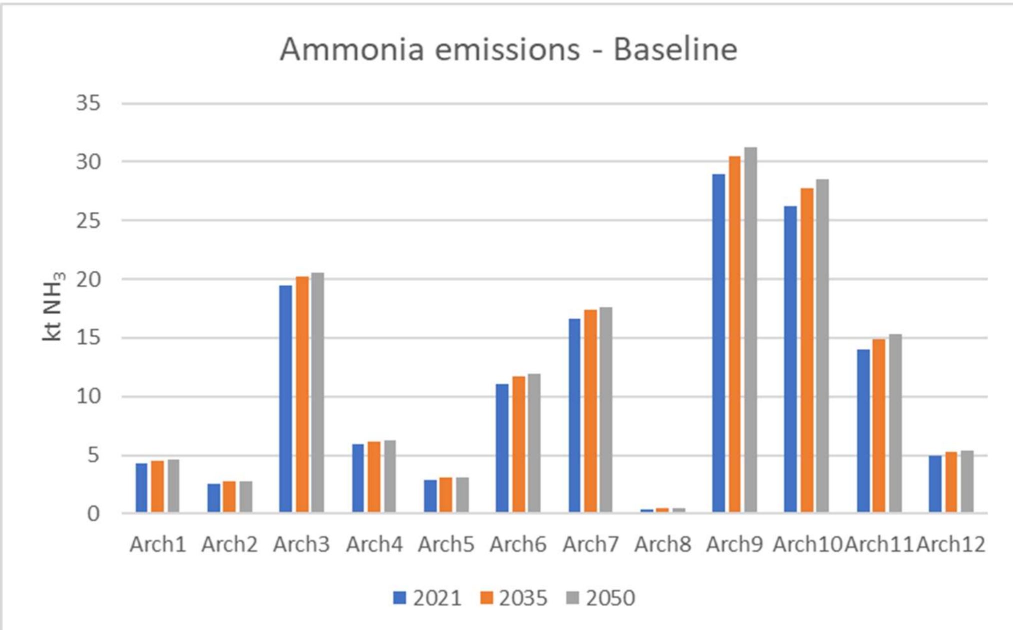


Figure 17 Agricultural ammonia emissions under Baseline projection

4.6 Ecosystem Service Metrics

Methodology

To examine differences in ecosystem service delivery across archetypes, as well as the environmental consequences of baseline changes and archetype transitions, we used spatial data on 23 ecosystem services, or proxies thereof, including richness and diversity metrics (hereafter referred to collectively as ecosystem service metrics). This data had been derived from modelling work conducted under a variety of other research projects, including the AgLand project (funded under NERC Landscape Decisions programme); the OpenClim project (funded under UKRI UK Climate Resilience Programme); DESNZ Net Zero Land Use Programme (Malcolm *et al.,* 2023); and the BRC Species Distribution Modelling library (Boyd *et al.,* 2022). All of these datasets are detailed in Table 6.

In order to assess the relationship between land cover, rural archetypes and ecosystem services, we first found the dominant land cover class (derived from LCM 2021; Marston *et al.,* 2022) associated with each 1km cell classified to a CCC rural archetype. We then extracted the ecosystem service values for all these 1km cells for each of the datasets in Table 6. We were then able to calculate the mean and standard deviation of the ecosystem service values for cells dominated by each LCM land cover class within each archetype.

Table 6: The ecosystem services and diversity measures assessed in the transition pathways, including the source project from which the data were derived.

Ecosystem service	Description	Units	Cover-age	Data source / citation
Carbon storage	Carbon stored in soils & aboveground biomass	t CO_2 / km^2	GB	Evans *et al.*, in prep; AgLand
Soil Carbon	Soil organic carbon stocks	t / km^2	UK	Henrys *et al.*, 2012; DESNZ Net Zero
GHG sequestration	Total sequestration of GHGs as CO_2 equivalents	t CO_2 / yr / km^2	GB	Evans *et al.*, in prep; AgLand
Erosion avoided	Sediment prevented from entering watercourses	t sediment / yr / km^2	GB	Hooftman *et al.*, 2023; AgLand
Nitrogen retained	Surface runoff of agricultural N prevented from entering watercourses	Kg N /yr / km^2	GB	Redhead *et al.*, 2018; AgLand
Water retention	Water from precipitation events retained on land	mm / km^2	GB	Evans *et al.*, in prep; AgLand
Water yield	Water reaching watercourse network	Millions m^3 / yr/ km^2	GB	Redhead *et al.*, 2016; AgLand

Ecosystem service	Description	Units	Cover-age	Data source / citation
Current cropping production index	Total potential calorific yield from eight crops	Index (weighted by arable)	UK	Redhead *et al.*, 2025; OpenClim
OSR potential production	Modelled oilseed rape potential yield	Mt (over total arable)	UK	Hayman *et al.*, 2024; OpenClim
Wheat potential production	Modelled winter wheat potential yield	Mt (over total arable)	UK	Hayman *et al.*, 2024; OpenClim
Grass potential production	Modelled perennial ryegrass yield	Mt (over total arable)	UK	Hayman *et al.*, 2024; OpenClim
Bee species richness	Index of Number of pollinating bee species	Index of no. of species / km^2	GB	Redhead *et al.*, 2020; DESNZ Net Zero
Natural enemy species richness	Index of number of pest-predatory carabid and coccinellid species	Index of no. of species / km^2	GB	Redhead *et al.*, 2020; AgLand
Bird species richness	Compiled species distribution modelled occurrence probability	Index of no. of species / km^2	UK	Boyd *et al.*, 2022; BRC SDM library
Wetland bird species richness	Compiled species distribution modelled occurrence probability	Index of no. of species / km^2	UK	Boyd *et al.*, 2022; BRC SDM library
Woodland bird species richness	Compiled species distribution modelled occurrence probability	Index of no. of species / km^2	UK	Boyd *et al.*, 2022; BRC SDM library
Farmland bird species richness	Compiled species distribution modelled occurrence probability	Index of no. of species / km^2	UK	Boyd *et al.*, 2022; BRC SDM library
Farmland bat species richness	Compiled species distribution modelled occurrence probability	Index of no. of species / km^2	UK	Boyd *et al.*, 2022; BRC SDM library
Mammal species richness	Compiled species distribution modelled occurrence probability	Index of no. of species / km^2	UK	Boyd *et al.*, 2022; BRC SDM library
Herptile species richness	Compiled species distribution modelled occurrence probability	Index of no. of species / km^2	UK	Boyd *et al.*, 2022; BRC SDM library
Vertebrate species group diversity	Shannon diversity index for results of 7 rows above	Shannon diversity index / km^2	UK	Boyd *et al.*, 2022; BRC SDM library
Pollinator visits	Estimated pollinator visitation	Average no. of visits per 10m^2 / yr	GB	Gardner *et al.*, 2020; AgLand
Land cover diversity	Shannon diversity index of dominant land covers	Shannon diversity index / km^2	UK	-

Ecosystem service	Description	Units	Cover-age	Data source / citation
Aesthetic appeal	Modelled aesthetic appeal	Occurrence of Flickr record / yr / km^2	GB	Evans *et al.*, in prep; AgLand

Figure 18 shows a schematic overview of the workflow used to explore current delivery, and the impact of baseline and transition changes in land use and land cover on ecosystem service metric. First, to calculate the baseline values for ecosystem services in 2021 we calculated a weighted mean for each archetype from the existing ecosystem service means of each land cover class for that archetype. We did this by using the number of cells dominated by each land cover class within the archetype to weight its ecosystem service mean value, ending up with an average value for each ecosystem service per archetype. With the aim of deriving a measure of variation in ecosystem service metrics for each archetype, we calculated a pooled standard deviation of all the variation values for each land cover class within an archetype.

Using this method allowed the number of cells dominated by different land cover classes to be adjusted within each archetype following baseline woodland creation and urbanisation land cover changes in 2035 and 2050. This was then reflected in a change in the weightings, and we were able to calculate adjusted ecosystem service values for each archetype (Fig 17).

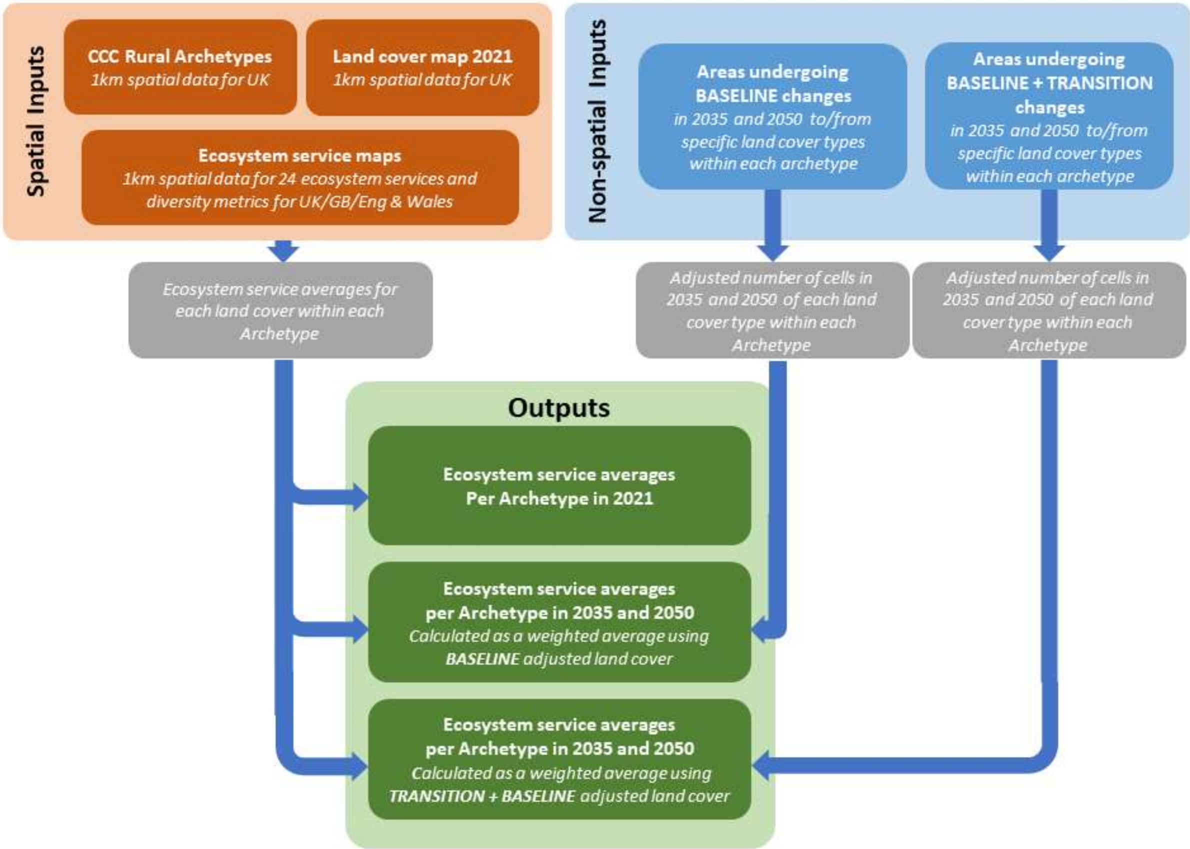


Figure 18 Diagram detailing methods for assessing ecosystem services across archetypes, and the impacts of baseline and transition land cover changes within archetypes.

This process was followed for most of the ecosystem service metrics listed in Table 6, apart from Land cover diversity and some land-cover specific ecosystem services. Land cover diversity was calculated directly from the distribution of land cover classes in each archetype. Ecosystem services which were specific to some land cover types, included yield data for wheat and oilseed and cropping suitability, which were only relevant for arable dominated land (and thus had only one mean land cover value, and a weighted mean could not be calculated); and grass yield, which was only considered for cells dominated by improved grassland. The values for these ecosystem services were instead weighted by the amount of available arable or grass land, respectively, to derive a production index.

To illustrate relative ecosystem service provision across archetypes, the values for each ecosystem service for each archetype were mean-centred and divided by their standard deviation. To examine relative change, the % change in the value of each ecosystem service was calculated, relative to a baseline value of 0 in 2021.

Results

Different archetypes have very different relative portfolios of ecosystem service provision in 2021 (Figure 19). The two upland archetypes degraded upland organic soils (Archetype 2) and acid grasslands on hilly uplands (Archetype 8), deliver more climate mitigation service than other archetypes in the form of GHG sequestration and higher levels of Soil Carbon, and Archetype 2 has the highest levels of carbon storage, most likely due to additional forestry in these landscapes. They also provide other soil-based services, although Archetype 2 has higher levels of nitrogen retained, whereas Archetype 8 is more specialised in erosion avoidance and water yield. While acid grasslands have the highest levels of recreation, both landscapes are quite species poor, and have lower than average levels of all the species richness measures. Other more mixed archetypes, such as farming on the suburban fringe (Archetype 4) and intensive grassland (Archetype 3), have higher species richness levels, and degraded lowland organic soils (Archetype 1) have higher than average bird and wetland bird species richness. The two arable-focused archetypes (Archetypes 9 and 10) unsurprisingly have high levels of production-based services with high potential production indices of OSR, wheat and current cropping.

Following baseline changes in land cover within each archetype from 2021 to 2035 (Figure A1) and 2050 (Figure 20) there are subtle percentage changes in ecosystem service provision of archetypes, as the overall proportion of land use that is changing is quite small. As all additional ecosystem service amounts represent increased environmental benefits, a positive change in ecosystem service provision (above 0), represents a greater provision of those benefits and a negative change represents a reduction in service provision.

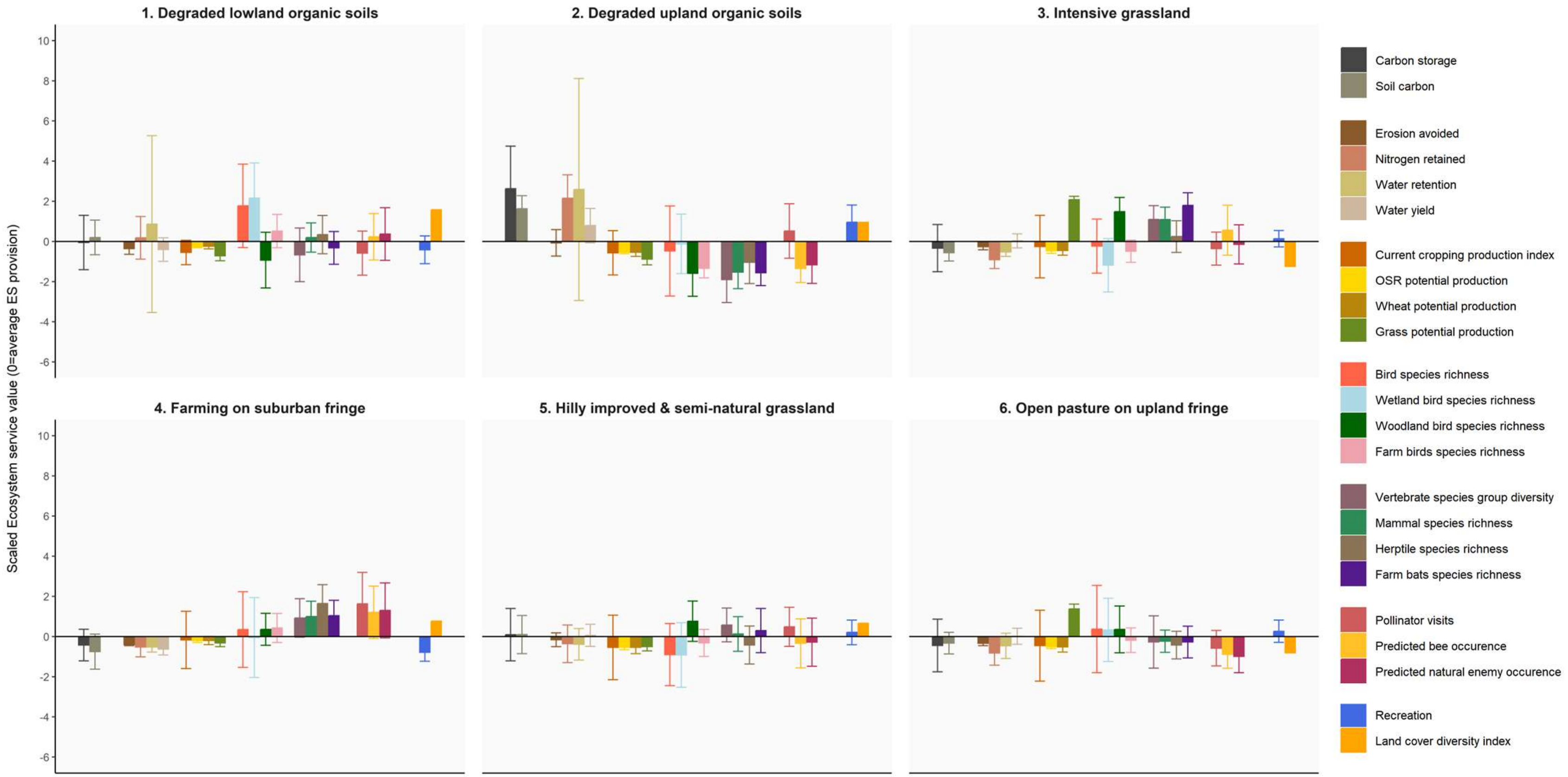


Figure 19. See below

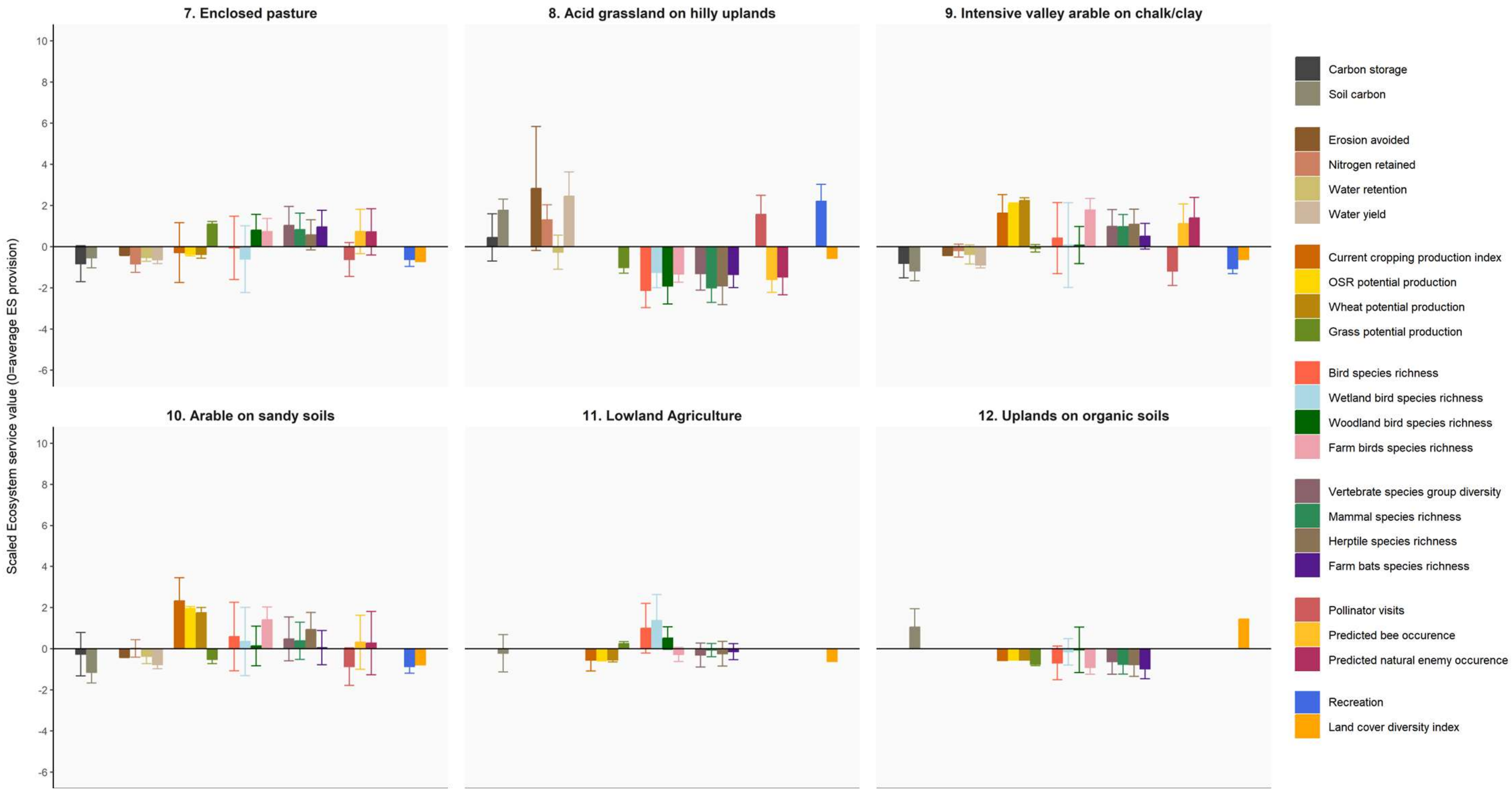
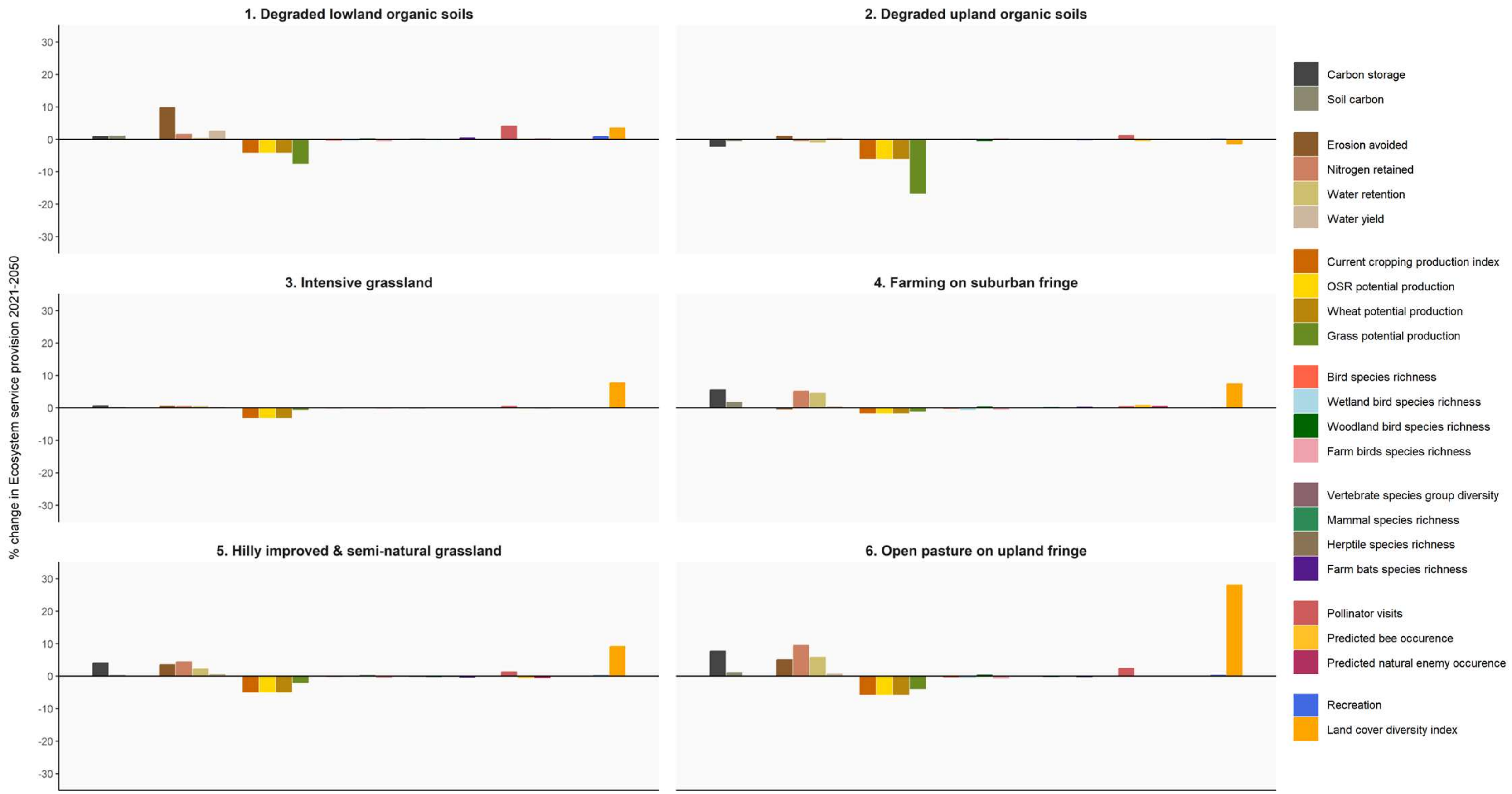


Figure 19. The relative mean, and pooled SD, ecosystem service values for each archetype in 2021.

These have been scaled so that each ecosystem service is relative across archetypes, i.e. the average for each ecosystem service across all archetypes is 0. Ecosystem services which have not been possible to calculate are not included i.e. all run-off and invertebrate species richness services, pollination and recreation for Northern Irish Archetypes 11 and 12, and arable production archetypes for Archetype 8 (as this archetype has no arable land).



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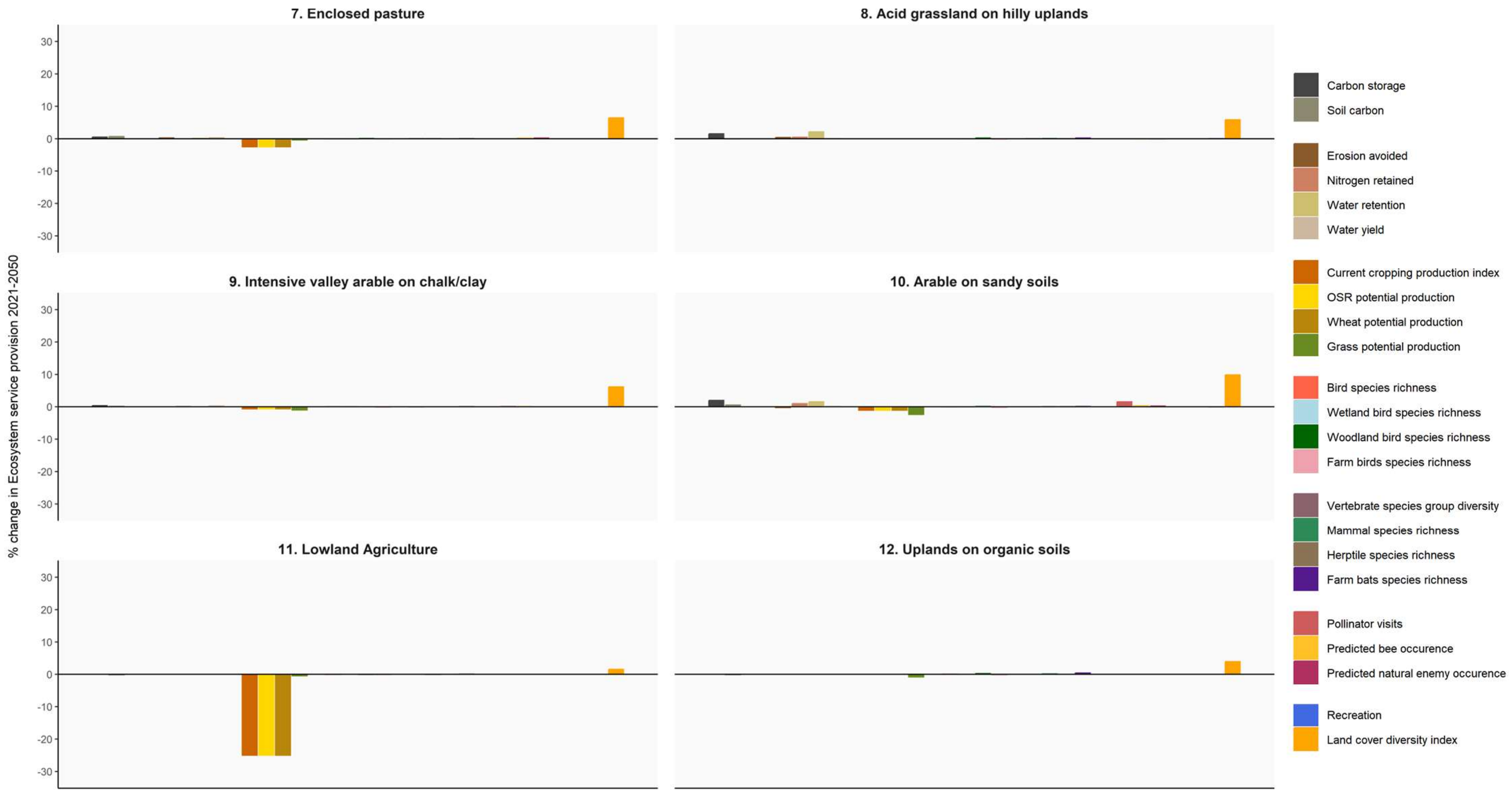

Figure 20 The relative percentage change in ecosystem services within each archetype between 2021 and 2050, under baseline change pathways.

As with Figure 19, Ecosystem services which have not been possible to calculate are not included i.e. all run-off and invertebrate species richness services, pollination and recreation for: Northern Irish Archetypes 11 and 12; arable production archetypes for archetype 8 (as this archetype has no arable land); and grass potential production for Archetype 8, as this archetype has <1 km^2 of improved grassland in 2050.

4.7 Soil Carbon

Methodology

In addition to the soil carbon (0 – 15 cm, based on Countryside Survey topsoil carbon data) evaluated above under the Ecosystem Service Metrics, soil organic carbon at 0 – 30 cm (based on SoilGrids data) were modelled separately to give a comprehensive and more detailed assessment on soil carbon.

The turnover of organic carbon in soil (0 – 30cm) was simulated using the Rothamsted Carbon (RothC) Model (Coleman and Jenkinson, 1996). This model was ordinarily used to model soil organic carbon (SOC) turnover at a single site over monthly timesteps, with monthly climate variation that is assumed to remain constant between years. For this project the RothC model was adapted to accept rasterised soil and climate data that is both spatially and temporally variable, allowing for the assessment of climate change and land use transition impacts on SOC stocks (Figure 21).

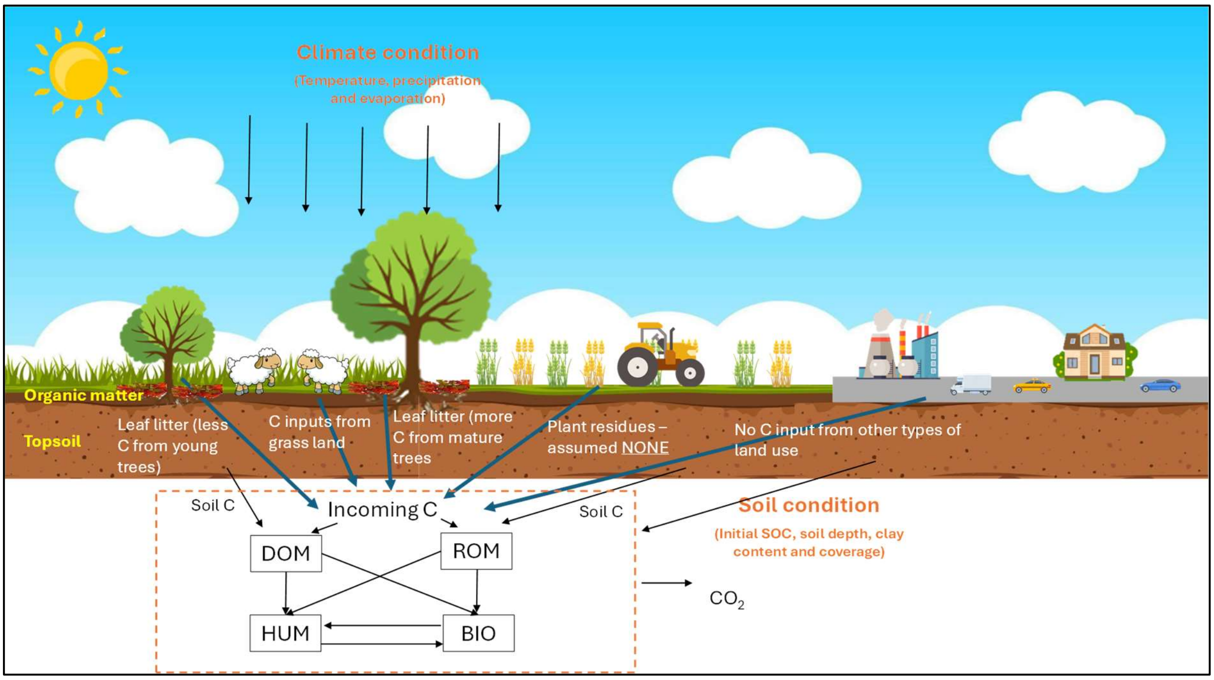

Figure 21 A demonstration of the soil carbon modelling process.

Initial SOC and incoming C from plants residues were both divided into a decomposable fraction (decomposable organic matter - DOM) and a resistant fraction (resistant organic matter - ROM). DOM and ROM decay to form microbial biomass (BIO), humified organic matter (HUM) and CO_2 over monthly timesteps. BIO and HUM decay to form more BIO, HUM and CO_2. The decay of each compartment is affected by the land use and the soil and climate conditions (Table 7).

Table 7: Soil organic carbon modelling input parameters

Input parameters		Data sources
Climate inputs	Average monthly air temperature (°C)	UKCP18 (processed by Robinson *et al.* (2017))
	Monthly rainfall (mm)	UKCP18 (processed by Robinson *et al.* (2017))
	Monthly potential evapotranspiration (mm)	UKCP18 (processed by Robinson *et al.* (2017)); Muller, 2012
Soil inputs	Initial SOC[a] (t ha^{-1})	ISRIC SoilGrids.org (retrieved 2024)
	Monthly OC[b] inputs (t ha^{-1})	IPCC GPG-LULUCF (2003); IPCC Guidance for NGGI (2006), Chapters 4 and 6
	DOM:ROM ratio[c] (initial SOC)	ESDAC LUCAS Survey (2021)
	DOM:ROM ratio (OC[b] inputs)	Coleman and Jenkinson (2014)
	Soil clay content (%)	ISRIC SoilGrids.org (retrieved 2024)

[a] SOC: soil organic carbon; [b] OC: organic carbon; [c] DOM:ROM ratio: decomposable organic matter: resistant organic matter ratio.

To simulate the soil organic carbon stocks following baseline pathway, the RothC model (Coleman and Jenkinson, 1996) was adapted and iterated over the 2-dimensional input raster datasets. Due to the dynamic nature of the model, the entire 720-month period from 2021 to 2080 was simulated month by month. Soil and climate inputs were retrieved from the data sources mentioned in Table 7. Initial SOC and clay content were down-scaled and snap aligned to match the 1 km resolution soil archetypes raster map. The DOM:ROM ratios and the monthly OC inputs were dependent on the land use type, and they were converted to archetype-associated data based on the land areas for each land use type under baseline pathway. A raster dataset was then generated by substituting the archetype averages into the grid cells of the archetypes' raster map. For the monthly OC inputs parameter for cropland, grassland and woodland, data was derived from the default carbon input values/factors in the IPCC Guidance (IPCC 2003; IPCC 2006). It was noted that for improved grassland two different factors (with low or high additional management inputs) were considered. For all other types of land use (e.g. urban, bog, inland rock, etc.), it was assumed that there were not additional OC inputs.

The general circulation model (GCM) outputs sourced from the UK Climate Projections 2018 (UKCP18) database span from January 1981 to December 2080 over daily timesteps and cover the UK at a 12 km spatial resolution. All data sourced from UKCP18 had been bias corrected by Robinson *et al.,* (2017). The GCMs numbered 4, 6, 7, 8, 12, and 13 in this dataset were downscaled to a monthly temporal resolution to be used in this project. For the baseline modelling, climate data between January 1981 and December 2020 was averaged into a single twelve-month climate timeseries. The potential evapotranspiration in Northern Ireland and the Shetland Islands was not available in this dataset, therefore, a twelve-month PET timeseries was generated from historical evapotranspiration data from Muller (2012).

With the low/high addition OC inputs and six climate models each pathway was run for 12 times and the average and standard deviation of SOC density (t ha^{-1}; SOC stock on a per hectare basis) and stocks (Mt; total SOC stock in a given archetype) were generated. The baseline SOC was simulated for years 2021, 2035 and 2050.

Results

Baseline SOC density was predicted to range from 62 t ha^{-1} (Archetype 4 - Farming on the suburban fringe in England) to 103 t ha^{-1} (Archetype 12 - Uplands with large extent on organic soils in Northern Ireland) (Figure 22).

Archetype 2 (Degraded upland grazing land and forest on organic soils in GB) was predicted to have the highest decomposable organic matter (DOM) fraction (36%) and the lowest resistant organic matter (ROM) fraction (64%) while Archetype 9 (Intensive and valley/floodplain arable on chalk/clay soils in England) was predicted to have the lowest DOM fraction (24%) and the highest ROM fraction (76%). DOM represents the carbon pool that decomposes easily while ROM represents the carbon pool that decomposes slowly. The SOC is likely to be more vulnerable to decomposition/decay when the DOM fraction is higher, despite other factors affecting the SOC decomposition. While SOC stocks are important to be obtained the factions of DOM and ROM significantly affect how the SOC will change over time.

Archetype 2 (Degraded upland grazing land and forest on organic soils in GB) was also predicted to have the highest SOC stocks (162 Mt) due to its high SOC density and large land area (Figure 23). Archetype 12 (Uplands with large extent on organic soils in Northern Ireland) was predicted to have the lowest SOC stocks (33 Mt) due to its small land area although the carbon density is high (Figure 23).

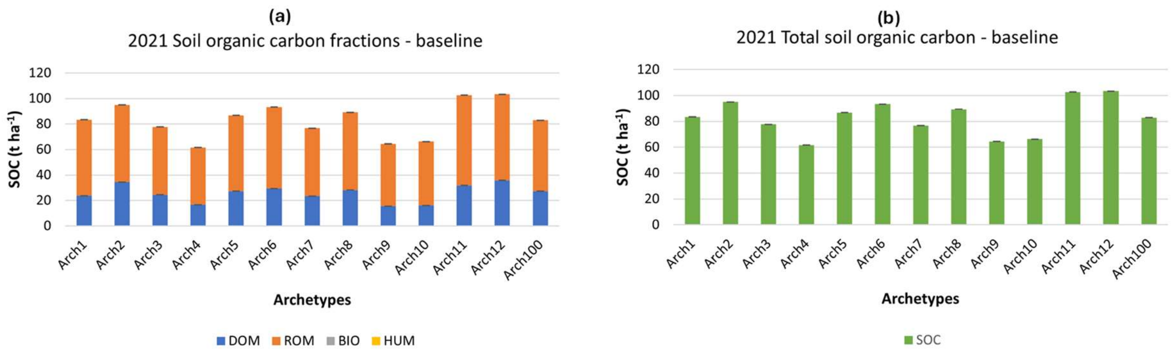

Figure 22 Baseline soil organic carbon fractions (t ha^{-1}; a) and total soil carbon stocks (t ha^{-1}; b) in all archetypes in year 2021. DOM: decomposable organic matter; ROM: resistant organic matter; BIO: microbial biomass; HUM: humified organic matter; SOC: soil organic carbon.

Archetypes: 1-Lowland organic soils; 2- Upland organic soils; 3- Intensive grassland; 4- Suburban fringe; 5- Hilly farmland; 6- Open pasture; 7- Enclosed pasture; 8- Acid upland grassland; 9- Arable *on chalk/clay; 10- Arable on sandy soils; 11- Lowland agriculture in Northern Ireland; 12- Uplands in Northern Ireland.*

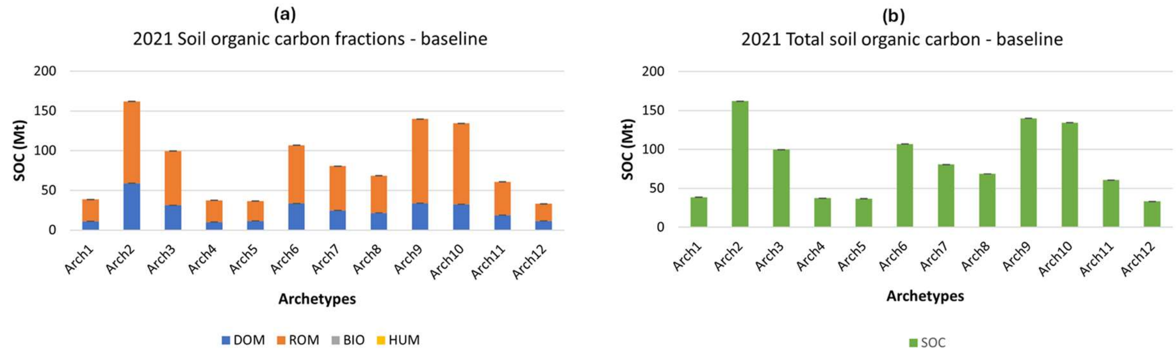

Figure 23 Baseline soil organic carbon fractions (Mt; a) and total soil carbon stocks (Mt; b) in all archetypes in year 2021. DOM: decomposable organic matter; ROM: resistant organic matter; BIO: microbial biomass; HUM: humified organic matter; SOC: soil organic carbon.

SOC naturally decays over time, however, when there is enough organic carbon (OC) entering the SOC pools it is possible to maintain or even enhance the SOC stocks. In this project, it was assumed that the OC inputs come from leaf litter in woodland and additional carbon inputs (e.g. manure) in improved grassland. All other types of land were assumed to have no additional OC inputs. In reality, there are other sources of OC inputs, for example, plant residues left on cropland, soil amendments added to soil, however, it was out of the scope of the project to consider these. The SOC stocks predicted are expected to be lower than they would be in reality. The baseline SOC stocks in 2035 and 2050 are used as reference values to evaluate the impacts of land use transition and climate change and should not be used to compare with real-world measured data.

Following baseline pathway, it was predicted that only a very small amount of DOM fraction and small amount of BIO fraction remained in the soil while ROM and HUM factions were more dominant in the soil (Figure 24). ROM and HUM carbon pools provide long term carbon storage potential for the soil.

In 2035, SOC density in all archetypes was predicted to range from 16 t ha^{-1} (Archetype 4 - Farming on the suburban fringe in England) to 25 t ha^{-1} (Archetype 11 - Lowland agriculture in Northern Ireland) (Figure 25). SOC stocks in the 12 Archetypes were predicted to range from 7 Mt (Archetype 12 - Uplands with large extent on organic soils in Northern Ireland) to 39 Mt (Archetype 9 - Intensive and valley/floodplain arable on chalk/clay soils in England). Archetype 2 (Degraded upland grazing land and forest on organic soils in GB), which had the highest SOC stocks in 2021) was predicted to have the third highest SOC stocks. This is because, out of all the archetypes, Archetype 2 had the largest proportion of DOM in its initial SOC, and as a result it was expected to lose more of its initial SOC in the first few months compared to other archetypes.

In 2050, SOC density in all archetypes was predicted to range from 9 t ha^{-1} (Archetype 8 - Acid grassland on hilly uplands in GB) to 17 t ha^{-1} (Archetype 11 - Lowland agriculture in Northern Ireland) (Figure 26). SOC stocks in the 12 archetypes were predicted to range from 4 Mt (Archetype 12 - Uplands with large extent on organic soils in Northern Ireland) to 22 Mt (Archetype 9 - Intensive and valley/floodplain arable on chalk/clay soils in England). Archetype 2 (Degraded upland grazing land and forest on organic soils in GB), which had the highest SOC stocks in 2021 was predicted to have the second highest SOC stocks. Although it dropped below Archetypes 9 (Intensive and valley/floodplain arable on chalk/clay soils in England) and 10 (Arable on sandy soils in England and Scotland) in 2035 due to its high DOM:ROM value, Archetype 2 was able to recover to comparable SOC levels because of its high OC input value (0.027 t ha^{-1} mth^{-1} for archetype 2 compared to 0.013 and 0.009 t ha^{-1} mth^{-1} for archetypes 9 and 10 respectively at the high OC input estimate).

The SOC decomposition is affected by many factors including the initial SOC stocks, the climate factors and the soil conditions. The archetypes that start with high carbon density will not necessarily remain the highest over time as the decomposition of SOC in these archetypes may be slower or faster depending on their land use, soil conditions and where they are in the landscape. In the case of Archetype 2 (Degraded upland grazing land and forest on organic soils in GB), SOC decomposability and OC input levels caused its SOC stocks to fluctuate relative to other archetypes. It is possible that climate factors also drove this behaviour, since Archetype 2 (Degraded upland grazing land and forest on organic soils in GB) occupies more of the UK's northern landmass compared to Archetypes 9 (Intensive and valley/floodplain arable on chalk/clay soils in England) and 10 (Arable on sandy soils in England and Scotland).

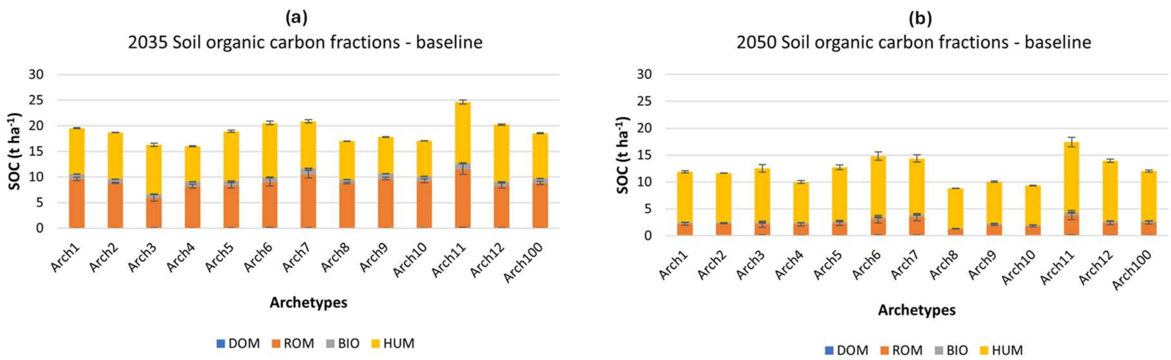

Figure 24 Baseline soil organic carbon fractions (t ha^{-1}) in all archetypes in year 2035 (a) and 2050 (b). DOM: decomposable organic matter; ROM: resistant organic matter; BIO: microbial biomass; HUM: humified organic matter.

Archetypes: 1-Lowland organic soils; 2- Upland organic soils; 3- Intensive grassland; 4- Suburban fringe; 5- Hilly farmland; 6- Open pasture; 7- Enclosed pasture; 8- Acid upland grassland; 9- Arable on chalk/clay; 10- Arable on sandy soils; 11- Lowland agriculture in Northern Ireland; 12- Uplands in Northern Ireland.

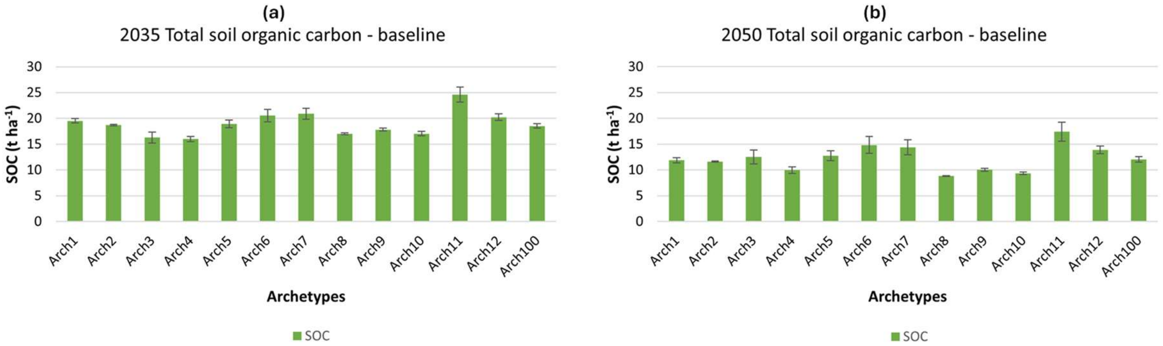

Figure 25 Baseline total soil organic carbon stocks (t ha^{-1}) in all archetypes in year 2035 (a) and 2050 (b).

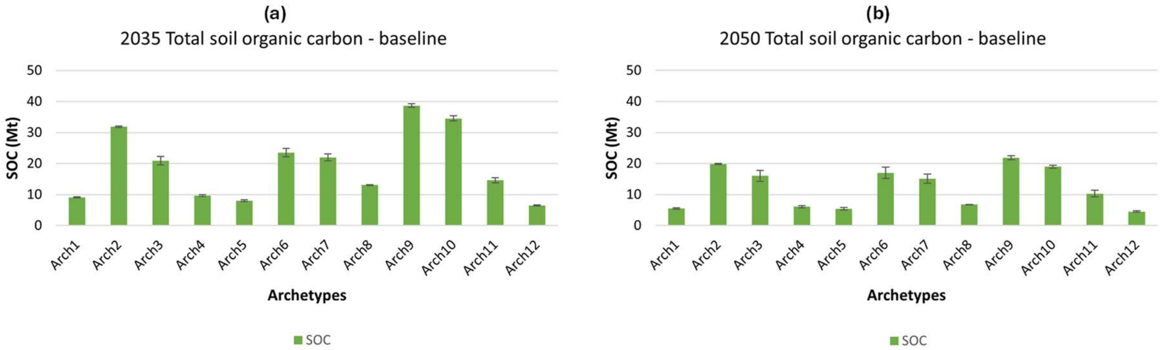

Figure 26 Baseline total soil organic carbon stocks (Mt) in all archetypes in year 2035 (a) and 2050 (b).

4.8 Costs and benefits

Methodology

Eunomia produced a Valuation Model to estimate the economic value of 24 social and private costs and benefits at the country level for the 12 archetypes for the baseline pathway. A summary of these costs and benefits, and the method used to derive their value are presented in Table 8**Error! Reference source not found.**.

Table 8: Methodology and data sources used to model economic costs and benefits

Cost/benefit type	Cost/Benefit	Methodology	Data source(s)	Notes for 2035 & 2050 baseline
Private costs	Woodland planting and establishment	Per hectare woodland planting and establishment costs applied to baseline land cover data and an assumption of the proportion under active restoration	Land cover data, Section 4.1); John Nix Pocketbook (Redman 2023)	2021 £/ha values applied to 2035 and 2050
	Peat restoration	Per hectare peatland restoration costs applied to baseline peatland habitat areas multiplied by proportion of peatland under active restoration	Land cover data, Section 4.1); Scottish Government (2023). Peatland restoration costs	2021 £/ha values applied to 2035 and 2050
	Other nature restoration	Per hectare nature restoration costs applied to baseline land cover data and an assumption of the proportion under active restoration	Land cover data, Section 4.1); Hawkins *et al.,* (2023). Nature recovery costs	2021 £/ha values applied to 2035 and 2050
	Maintenance	Per hectare habitat maintenance costs applied to baseline habitat data	Land cover data, Section 4.1); Hawkins *et al.,* (2023). Nature recovery costs	2021 £/ha values applied to 2035 and 2050
	Harvesting and production	Per hectare harvesting and production costs (for agriculture and timber) applied to apportioned area of arable and horticulture land. Per head livestock variable costs applied to UKCEH agricultural projections data	Land cover data, Section 4.1); Agricultural projections, Sections 4.1-4.3; John Nix Pocketbook (Redman 2023)	2021 £/ha values applied to 2035 and 2050
	Monitoring and management	Per hectare monitoring and management costs applied to baseline land cover data	Land cover data, Section 4.1); Ricardo (2020);	2021 £/ha values applied to 2035 and 2050

Cost/benefit type	Cost/Benefit	Methodology	Data source(s)	Notes for 2035 & 2050 baseline
			Hawkins *et al.,* (2023). Nature recovery costs	
	Solar PV installation and maintenance	UK solar PV generation apportioned to the area of land under each archetype	Land cover data, Section 4.1); ONS (2022). UK Natural Capital Accounts; CCC (2023). Delivering a Reliable Decarbonised Power System; DESNZ (2023). Electricity Generation Costs	2035 and 2050 £/kW values applied
Private benefits	Agricultural production	Arable and horticulture: Gross margins applied to apportioned area of arable and horticulture land. Livestock: Per head livestock variable costs applied to UKCEH baseline agricultural projections data	Agricultural projections, Sections 4.1-4.3; John Nix Pocketbook (Redman 2023)	Baseline agricultural production projections used for 2035 and 2050 (applying 2021 £/ha values)
	Timber production	Per hectare timber prices for softwood and popular applied to apportioned coniferous and broadleaf woodland under management per archetype	Land cover data, Section 4.1); Forestry Statistics (2022); John Nix Pocketbook (Redman 2023)	Baseline land use projections used for 2035 and 2050 (applying 2021 £/ha values)
	Wood fuel revenue	Per hectare wood fuel prices for softwood and popular applied to apportioned coniferous and broadleaf	Land cover data, Section 4.1);	Baseline land use projections used for 2035

Cost/benefit type	Cost/Benefit	Methodology	Data source(s)	Notes for 2035 & 2050 baseline
		woodland under management per archetype	John Nix Pocketbook (Redman 2023)	and 2050 (applying 2021 £/ha values)
	Solar PV	UK solar PV generation apportioned to the area of land under each archetype	Land cover data, Section 4.1); ONS (2022). UK Natural Capital Accounts; CCC (2023). Delivering a Reliable Decarbonised Power System; CCC (2023). CCC grid export price for CB7	2035 and 2050 p/kWh values applied
	Nature market revenue	Woodland Carbon Code and Peatland code transactions apportioned to archetypes based on proportion of total UK woodland and peatland. Expected size of BNG market apportioned to archetypes	Land cover data, Section 4.1); Woodland Carbon Code (2023); Defra (2021). BNG Market Assessment	Baseline land use projections used for 2035 and 2050 (applying current prices)
	Agri-environmental funding received as income	Countryside Stewardship data apportioned to archetypes based on baseline habitat data	Land cover data, Section 4.1); Defra (2024). Countryside Stewardship option uptake; JNCC (2022). Area under agri-environment schemes	2021 £/ha values applied to 2035 and 2050
Social costs	Greenhouse gas emissions from farming practices	UK carbon value applied to baseline agricultural emissions data (including emissions from livestock, livestock manure management, animal fertiliser	Agricultural emissions data, Section 4.3; DESNZ (2021). Valuation of greenhouse gas emissions	Substantial increase expected given the DESNZ

Cost/benefit type	Cost/Benefit	Methodology	Data source(s)	Notes for 2035 & 2050 baseline
		and grazing returns and synthetic fertiliser)		carbon values increase from £245/t CO_2e in 2021 to £302/t CO_2e in 2035 and £378/t CO_2e in 2050 (2020 prices)
	Air pollution from farming practices	Apply air quality damage costs to baseline ammonia emissions data	Ammonia emissions, Section 4.5; Defra (2023). Air quality appraisal	2021 £/ha values applied to 2035 and 2050
	Government support and resourcing	Per hectare agri-environment scheme payments to farmers applied to baseline land cover data, with a factor applied for overheads/administration	Land cover data, Section 4.1); John Nix Pocketbook (Redman 2023)	2021 £/ha values applied to 2035 and 2050
Social benefits	GHG sequestration	UK carbon value applied to baseline LULUCF emissions data	LULUCF emissions data, Section 4.4; DESNZ (2021). Valuation of greenhouse gas emissions	Substantial increase expected given the DESNZ carbon values increase from £245/t CO_2e in 2021 to £302/t CO_2e in 2035 and £378/t CO_2e in 2050 (2020 prices)

Cost/benefit type	Cost/Benefit	Methodology	Data source(s)	Notes for 2035 & 2050 baseline
	Recreation	Predicted recreational use and welfare values applied to baseline land cover data, with mental health valuation subtracted to avoid double counting	Land cover data, Section 4.1); University of Exeter (2018). Outdoor Recreation Valuation Tool (ORVal)	2021 £/ha values applied to 2035 and 2050
	Physical health	Per visit physical health benefit values applied to recreational use data (above)	Land cover data, Section 4.1); Defra (2023). Enabling a Natural Capital Approach	2021 £/ha values applied to 2035 and 2050
	Mental health	Per visit mental health benefit values to individual applied to recreational use data (above)	Land cover data, Section 4.1); Defra (2023). Enabling a Natural Capital Approach	2021 £/ha values applied to 2035 and 2050
	Air pollution removal	Air pollution removal rates per habitat and avoided damage costs applied to baseline land cover data	Land cover data, Section 4.1); Jones *et al.*, (2017). Valuation of Air Pollution Removal Valuation	2021 £/ha values applied to 2035 and 2050
	Flood risk reduction	Flood storage benefit of different habitats applied to baseline land cover data	Land cover data, Section 4.1); Broadmeadow *et al.*, (2023). Valuing flood regulation services of existing forest cover to inform natural capital accounts	2021 £/ha values applied to 2035 and 2050

Cost/benefit type	Cost/Benefit	Methodology	Data source(s)	Notes for 2035 & 2050 baseline
	Water quality	Water quality benefit of wetland habitats applied to baseline land cover data	Land cover data, Section 4.1); Morris and Camino (2011). Economic assessment of Freshwater, Wetland and Floodplain Ecosystem Services	2021 £/ha values applied to 2035 and 2050
	Biodiversity	Biodiversity value of baseline habitat data based on the cost of replacing existing habitats through habitat restoration or a market-based Biodiversity Unit	Land cover data, Section 4.1); Natural England (2023). Biodiversity Metric 4.0; Defra (2021). Biodiversity Net Gain: Market Analysis Study	2021 £/ha values applied to 2035 and 2050

With the exception of biodiversity, all costs and benefits were summed to calculate the net benefits per archetype. The rationale for excluding biodiversity from this calculation is that it is estimated using a proxy value for the stock of biodiversity (as opposed to an annual cost or benefit flow, like the other impacts), based on the price of biodiversity units as calculated by the Statutory Biodiversity Metric.

The 23 costs/benefits were further grouped into six impact categories for ease of interpretation:

- Arable and horticultural production;
- Livestock production;
- Other private benefits (including agri-environment funding as income to farmer, nature market revenue, solar PV, timber and wood fuel revenue);
- Net GHG emissions from LULUCF and farming (greenhouse gas sequestration and farming GHG emissions);
- Net social impacts (government support and resourcing, water quality improvement, recreation, physical and mental health, flood water storage, and air pollution removal); and
- Private costs (harvesting and production, solar PV installation and maintenance, maintenance, monitoring and management, peat restoration, woodland planting and establishment, and other nature restoration).

Results

This section presents the outputs from the baseline analysis. The overall picture is summarised under Net Benefits, with the sections that follow detailing the results for each of the six impact categories.

<u>Net Benefits</u>
As shown in Figure 27, all archetypes provide a net economic benefit in the 2021 Baseline pathway (as shown by the blue line running above the y-axis) except for Archetype 1 (Lowland organic soils), due to large LULUCF emissions. The archetypes with the highest overall net benefits are Archetypes 2 (Upland organic soils), 9 (Arable on chalk/clay soils) and 10 (Arable on sandy soils), with net benefits of £3.9, £2.9 and £2.3 billion per year respectively. In Archetype 2, the benefit is mainly driven by net social impacts, delivered due to its high coverage of woodland, heather grassland, bog, and acid grassland, which provide large recreational, mental and physical health benefits. Despite this, Archetype 2 delivers a relatively small agricultural production relative to other archetypes. In contrast, overall net benefits in Archetypes 9 and 10 are driven mainly by private benefits from agriculture given their large arable and horticultural land areas.

The same analysis was undertaken on a per-hectare basis, as seen in Figure 28. The net benefit values across archetypes follow a similar pattern to the absolute values, with all archetypes delivering around £1,000 of net benefits per hectare in 2021. However, the high values of Archetypes 9 and 10 relative to the others are reduced (though still relatively high), with Archetype 12 (Uplands in Northern Ireland) delivering the greatest per hectare benefits, driven by net social impacts.

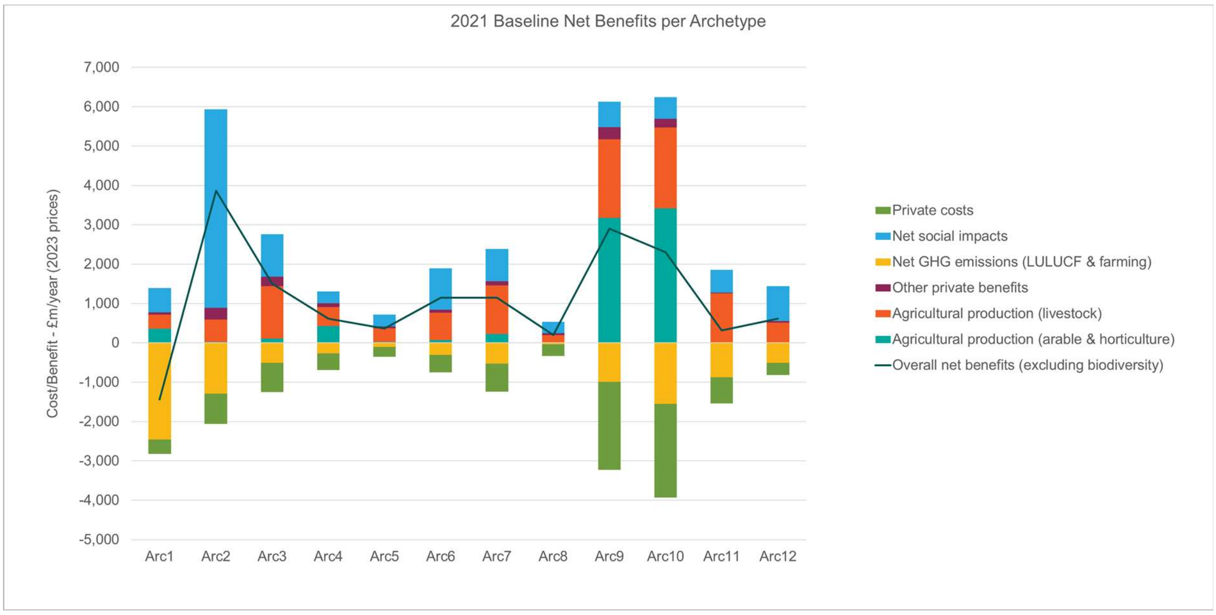

Figure 27 2021 Baseline Net Benefits per Archetype

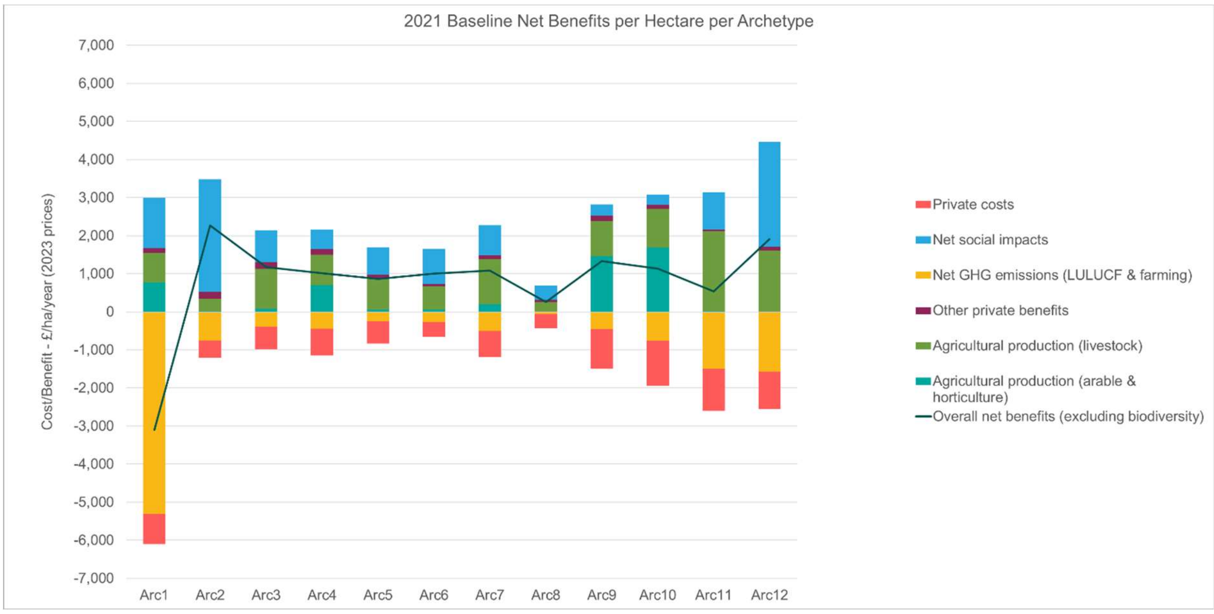

Figure 28 2021 Baseline Net Benefits per Hectare per Archetype

Archetypes: 1-Lowland organic soils; 2- Upland organic soils; 3- Intensive grassland; 4- Suburban fringe; 5- Hilly farmland; 6- Open pasture; 7- Enclosed pasture; 8- Acid upland grassland; 9- Arable on chalk/clay; 10- Arable on sandy soils; 11- Lowland agriculture in Northern Ireland; 12- Uplands in Northern Ireland.

Between the three time periods, 2021, 2035 and 2050, net benefits are expected to remain stable in the baseline at around £13bn per year, as shown in Figure 29, reflecting the limited ambition in this pathway. The distribution of costs and benefits is similarly expected to remain relatively stable over the time period, with an increase in net GHG emissions (by 20% in 2035 and 20% in 2050 relative to 2021) balanced by an increase in livestock production (by 9% in 2035 and 14% in 2050) and decrease in private costs (by 6% in 2035 and 9% in 2050 respectively).

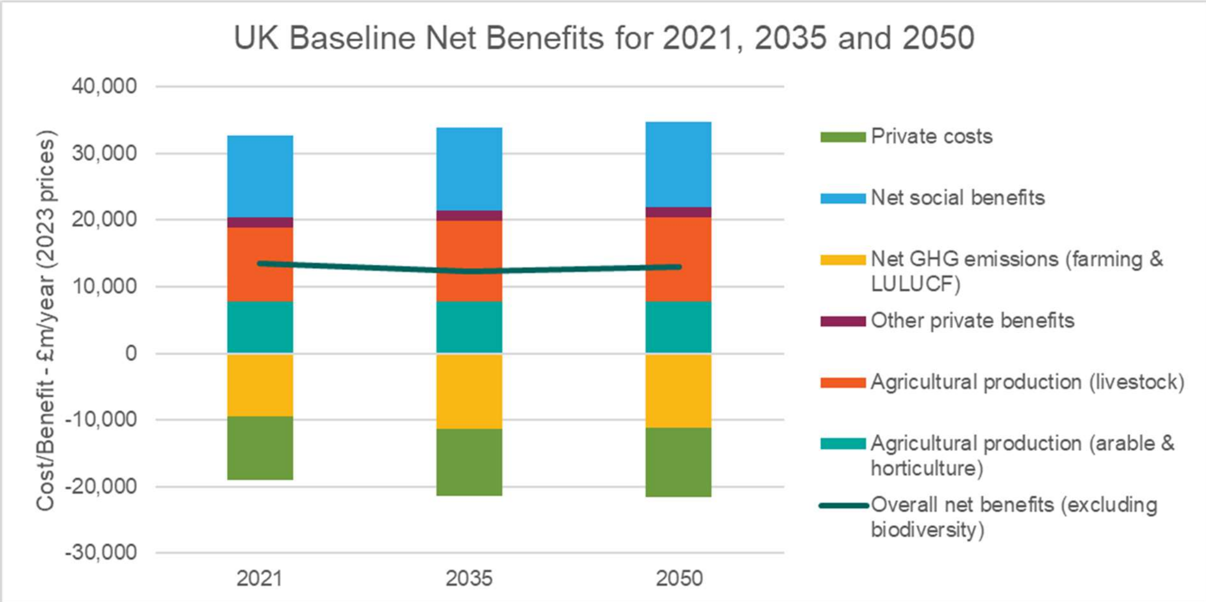

Figure 29 UK Baseline Net Benefits for 2021, 2035 and 2050

<u>Agricultural production (arable & horticulture)</u>
This section explores agricultural production for arable and horticulture in the baseline pathway for 2021, 2035 and 2050. As see in Figure 30production is concentrated in Archetypes 9 (Arable on chalk/clay soils) and 10 (Arable on sandy soils), accounting for 84% of all revenue across archetypes in 2021. Over the baseline time horizon, production remains relatively constant, reducing by just 0.7% in 2035 and 1.2% in 2050 relative to 2021 across all archetypes. It should be noted that for some archetypes, production falls more rapidly, notably for Archetype 11 (Lowland agriculture in Northern Ireland), reducing by 18.8% and 20.0% respectively. As shown in Figure 32 which shows the same analysis on a per hectare basis, a similar trend is predicted.

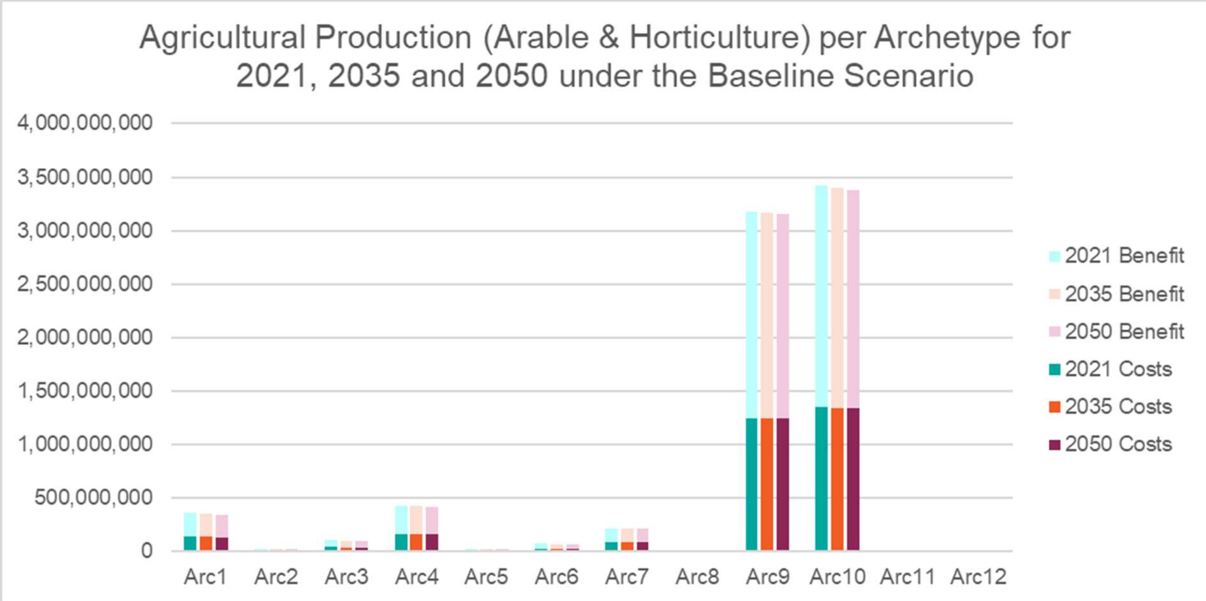

Figure 30 Agricultural Production (Arable & Horticulture) per Archetype for 2021, 2035 and 2050 under the Baseline pathway[13]

Archetypes: 1-Lowland organic soils; 2- Upland organic soils; 3- Intensive grassland; 4- Suburban fringe; 5- Hilly farmland; 6- Open pasture; 7- Enclosed pasture; 8- Acid upland grassland; 9- Arable on chalk/clay; 10- Arable on sandy soils; 11- Lowland agriculture in Northern Ireland; 12- Uplands in Northern Ireland.

[13] The private costs of arable and horticulture production (described further under Private Costs below) are shown as the darker shaded section of each column (for all archetypes, the private benefits - which exclude subsidies - are greater than the private costs).

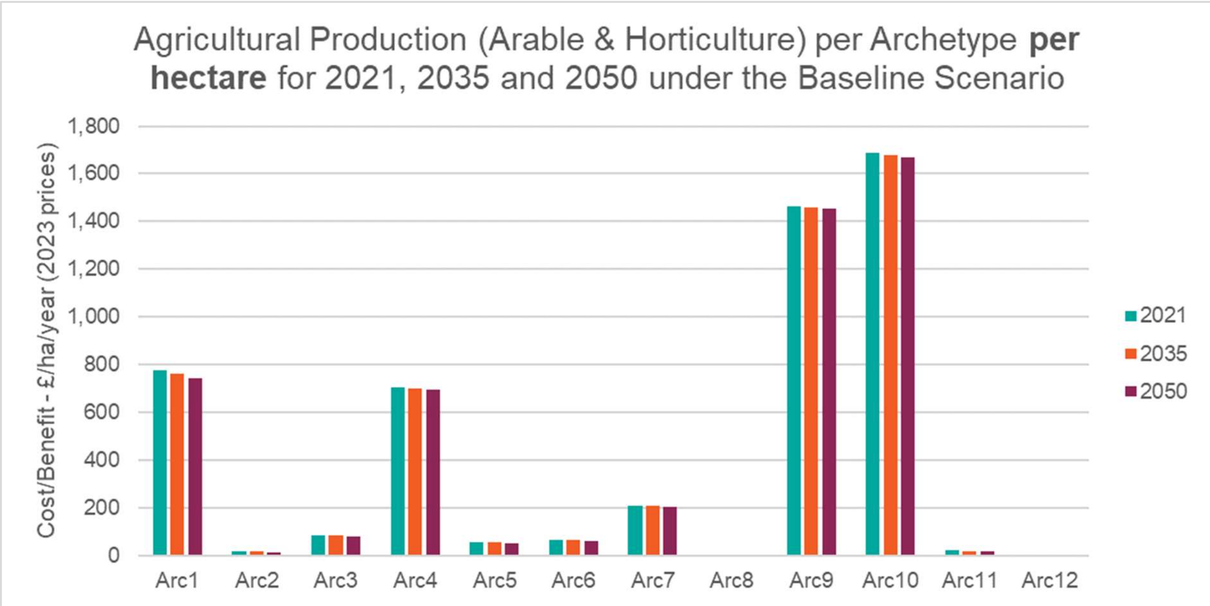

Figure 31 Agricultural Production (Arable & Horticulture) per Archetype per hectare for 2021, 2035 and 2050 under the Baseline pathway

Archetypes: 1-Lowland organic soils; 2- Upland organic soils; 3- Intensive grassland; 4- Suburban fringe; 5- Hilly farmland; 6- Open pasture; 7- Enclosed pasture; 8- Acid upland grassland; 9- Arable on chalk/clay; 10- Arable on sandy soils; 11- Lowland agriculture in Northern Ireland; 12- Uplands in Northern Ireland.

Agricultural production (livestock)

In contrast to arable and horticultural production, livestock production is more evenly distributed across the different archetypes, though still concentrated in Archetypes 9 (Arable on chalk/clay soils) and 10 (Arable on sandy soils), as seen in Figure 32, making up 18% and 19% of the 2021 total value respectively. When looking on a per hectare basis however, as shown in Figure 33, the picture is more balanced, notably with production in Archetypes 2 (Upland organic soils) and 8 (Acid upland grassland) remaining below average, and Archetypes 11 (Lowland agriculture in Northern Ireland) and 12 (Uplands in Northern Ireland) showing relatively high outputs. Production also varies more notably between the three time periods, increasing by 9% and in 2035 and 14% in 2050 relative to 2021 across all archetypes, with these growth rates expected to remain fairly consistent between archetypes. It should be noted that this overall value masks differences in livestock type which are expanded on in Section 4.2.

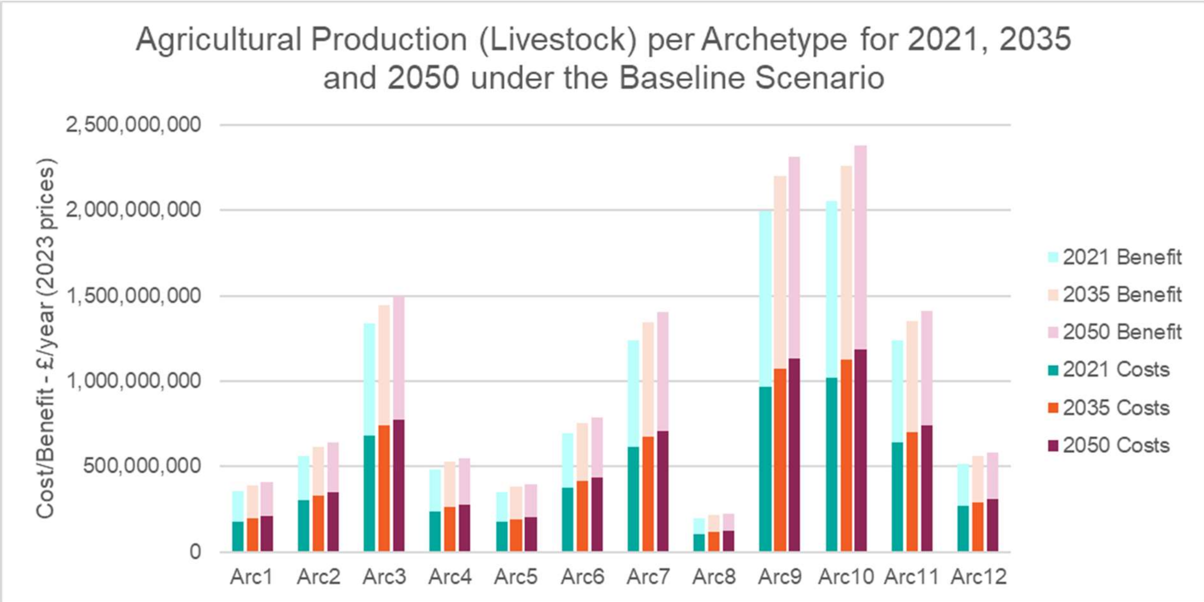

Figure 32 Agricultural Production (Livestock) per Archetype for 2021, 2035 and 2050 under the Baseline pathway[14]

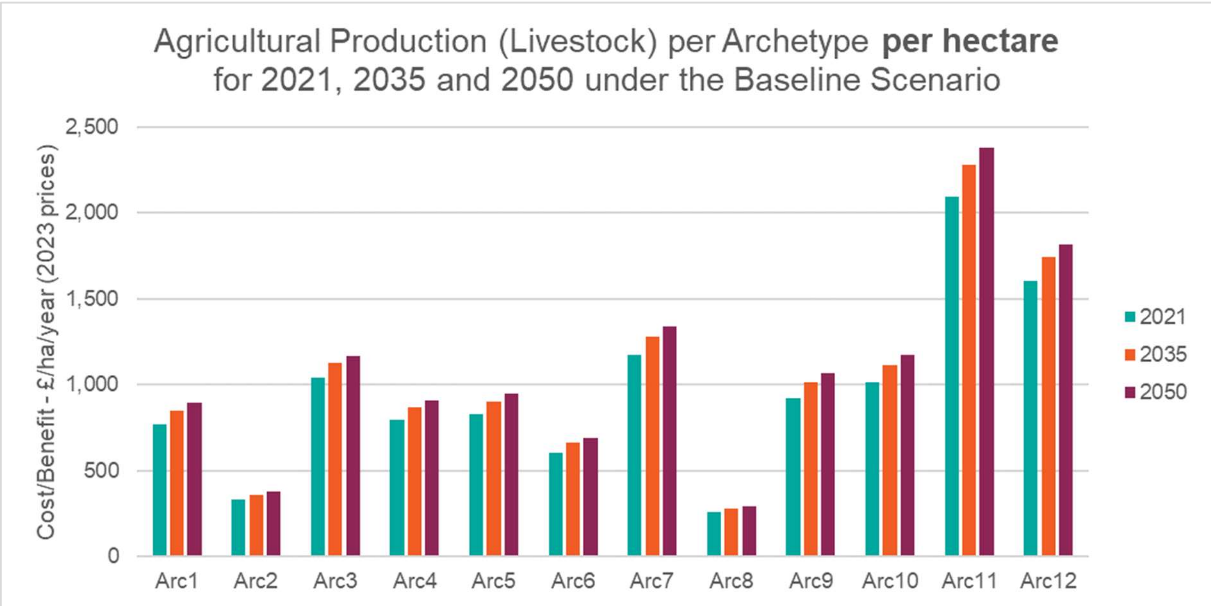

Figure 33 Agricultural Production (Livestock) per Archetype per hectare for 2021, 2035 and 2050 under the Baseline pathway

Archetypes: 1-Lowland organic soils; 2- Upland organic soils; 3- Intensive grassland; 4- Suburban fringe; 5- Hilly farmland; 6- Open pasture; 7- Enclosed pasture; 8- Acid upland grassland; 9- Arable on chalk/clay; 10- Arable on sandy soils; 11- Lowland agriculture in Northern Ireland; 12- Uplands in Northern Ireland.

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[14] The private costs of livestock production (described further under Private Costs below) are shown as the darker shaded section of each column (for all archetypes, the private benefits - which exclude subsidies - are greater than the private costs).

<u>Other private benefits</u>

Other private benefits (comprising agri-environment funding, nature market revenue, solar PV energy generation, timber and wood fuel revenue) are more evenly distributed across different archetypes in the baseline pathways, as shown in Figure 34. However, it is worth noting that these values are smaller in magnitude compared to agricultural production presented above, and are dominated by agri-environment funding income, which is not surprising given the archetypes are focused primarily on agricultural as opposed to forested land. The exceptions to this pattern are for Archetypes 2 (Upland organic soils) and 12 (Upland soils in Northern Ireland) where timber revenue contributes 45% and 54% of the total other private benefits, respectively. When looking on a per hectare basis however, as shown in Figure 35, the picture is more even. Over the baseline time horizon, other private benefits remains relatively constant, increasing by just 0.1% in 2035 and 0.2% in 2050 relative to 2021 across all archetypes.

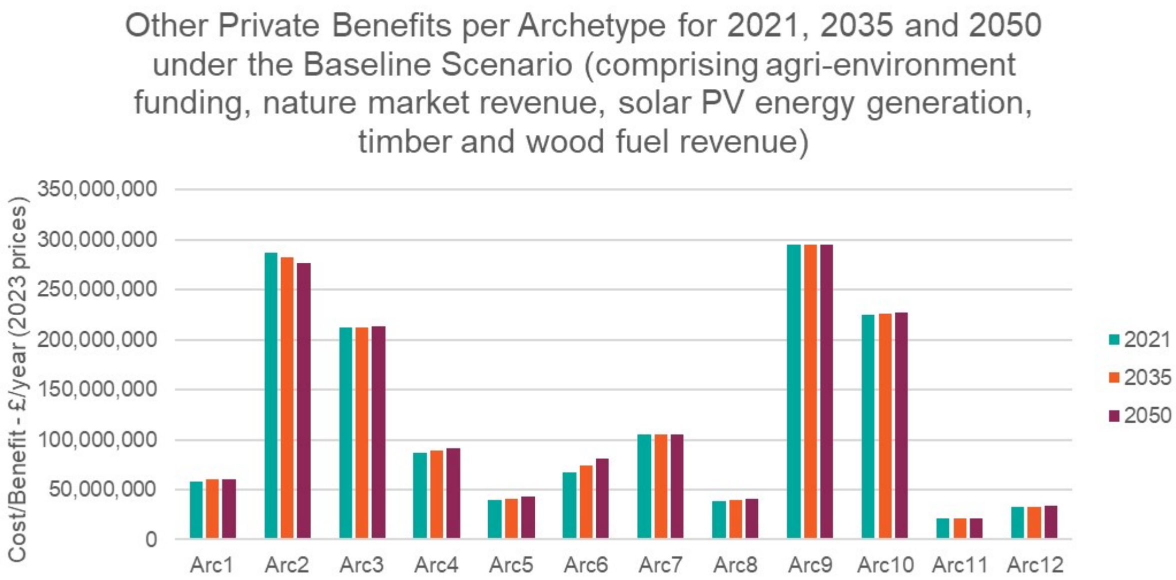

Figure 34 Other Private Benefits per Archetype for 2021, 2035 and 2050 under the Baseline pathway

Archetypes: 1-Lowland organic soils; 2- Upland organic soils; 3- Intensive grassland; 4- Suburban fringe; 5- Hilly farmland; 6- Open pasture; 7- Enclosed pasture; 8- Acid upland grassland; 9- Arable on chalk/clay; 10- Arable on sandy soils; 11- Lowland agriculture in Northern Ireland; 12- Uplands in Northern Ireland.

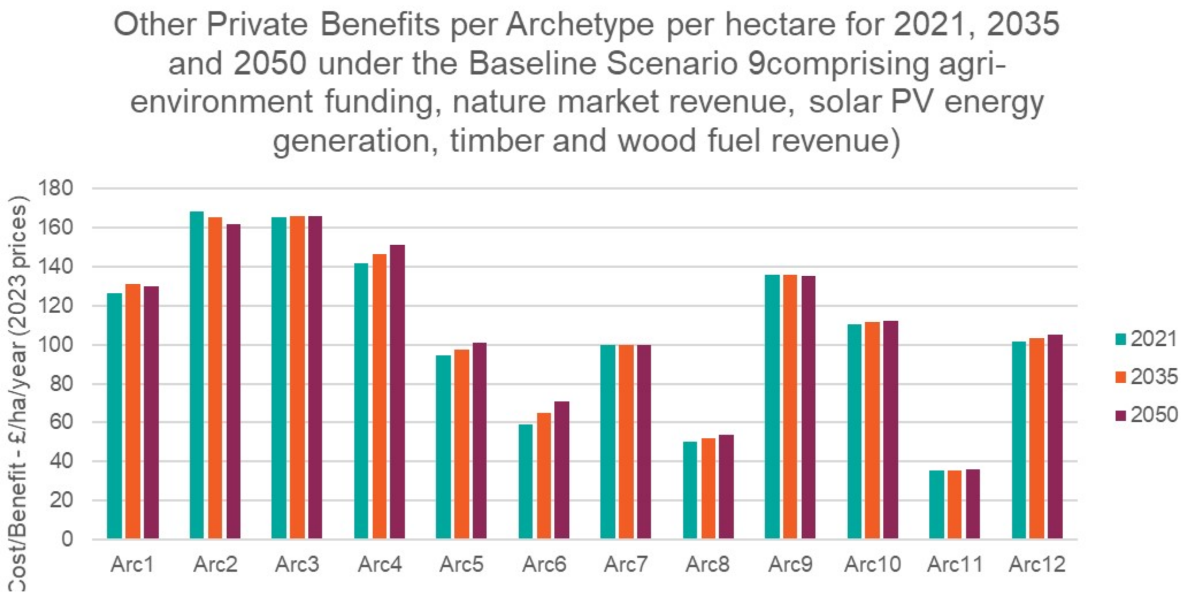

Figure 35 Other Private Benefits per Archetype per hectare for 2021, 2035 and 2050 under the Baseline pathway

<u>Private Costs</u>
Private costs (relating to farming, habitat restoration and solar PV installation and maintenance) are substantial across the archetypes though significantly larger in Archetypes 9 (Arable on chalk/clay soils) and 10 (Arable on sandy soils), as shown in Figure 36, mirroring the patten found for arable and horticultural production (above). It should be noted that farming costs (i.e. harvesting and production) are dominant across the archetypes, accounting for around 90% of the total cost. Over the baseline time horizon, private costs remain relatively constant, though increase for all archetypes – on average by 6.3% in 2035 and 9.4% in 2050 relative to 2021. When looking on a per hectare basis, as shown in Figure 37, private costs are more even between archetypes, with Archetypes 11 (Lowland agriculture in Northern Ireland) and 12 (Uplands in Northern Ireland) matching those in 9 and 10.

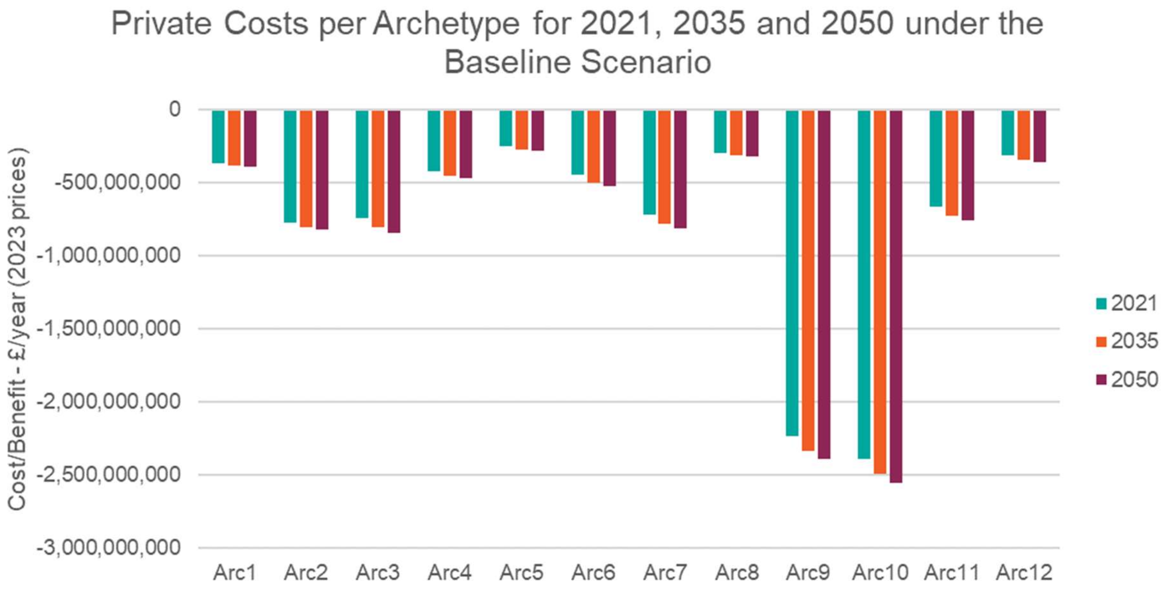

Figure 36 Private Costs per Archetype for 2021, 2035 and 2050 under the Baseline pathway

Archetypes: 1-Lowland organic soils; 2- Upland organic soils; 3- Intensive grassland; 4- Suburban fringe; 5- Hilly farmland; 6- Open pasture; 7- Enclosed pasture; 8- Acid upland grassland; 9- Arable on chalk/clay; 10- Arable on sandy soils; 11- Lowland agriculture in Northern Ireland; 12- Uplands in Northern Ireland.

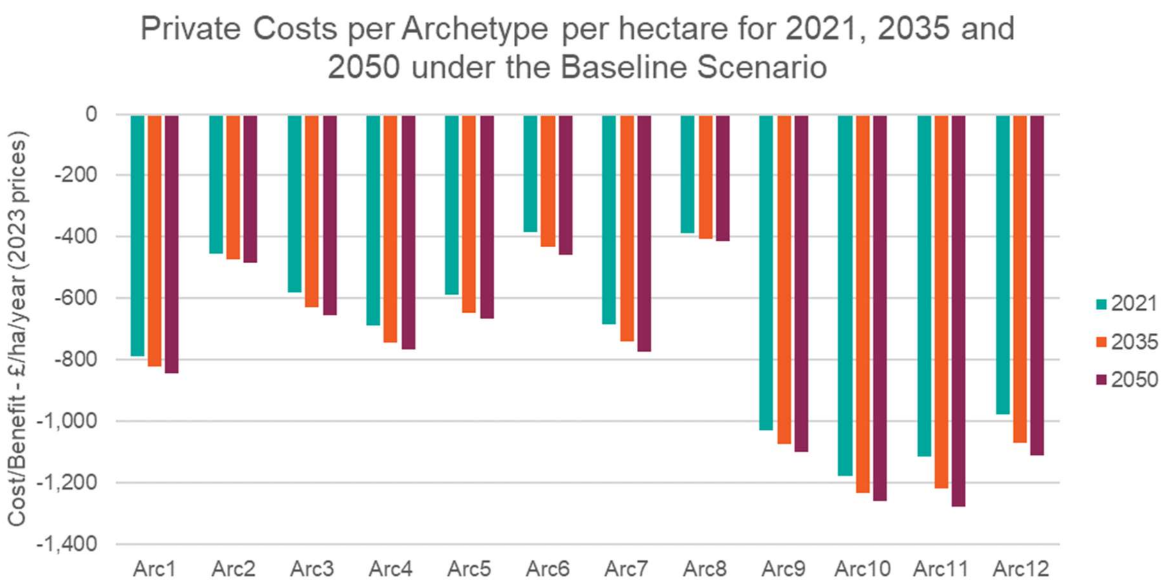

Figure 37 Private Costs per Archetype per hectare for 2021, 2035 and 2050 under the Baseline pathway

Net GHG emissions

This section looks at the monetised GHG emissions from both the land use, land-use change and forestry (LULUCF) and farming sectors. As can be seen in Figure 38, of the six impact categories, the differences between archetypes and over time are most stark for this impact. Of note is the large net emissions from Archetype 1 (Lowland organic soils), which increase significantly over time. In particular, the net emissions from this archetype account for 26% across all archetypes, increasing to 32% in 2050. The high emissions relative to the other archetypes is highlighted further when comparing on a per hectare emissions, as in Figure 39. Large net emissions over time are also present in Archetypes 2 (Upland organic soils), 9 (Arable on chalk/clay soils) and 10 (Arable on sandy soils). It should also be noted that while overall, net emissions are expected to increase by 18% between 2021 and 2050, some archetypes move from being a net source to a net sink, such as Archetypes 5 (Hilly farmland), 6 (Open pasture) and 8 (Acid upland grassland), driven by the LULUCF sector.

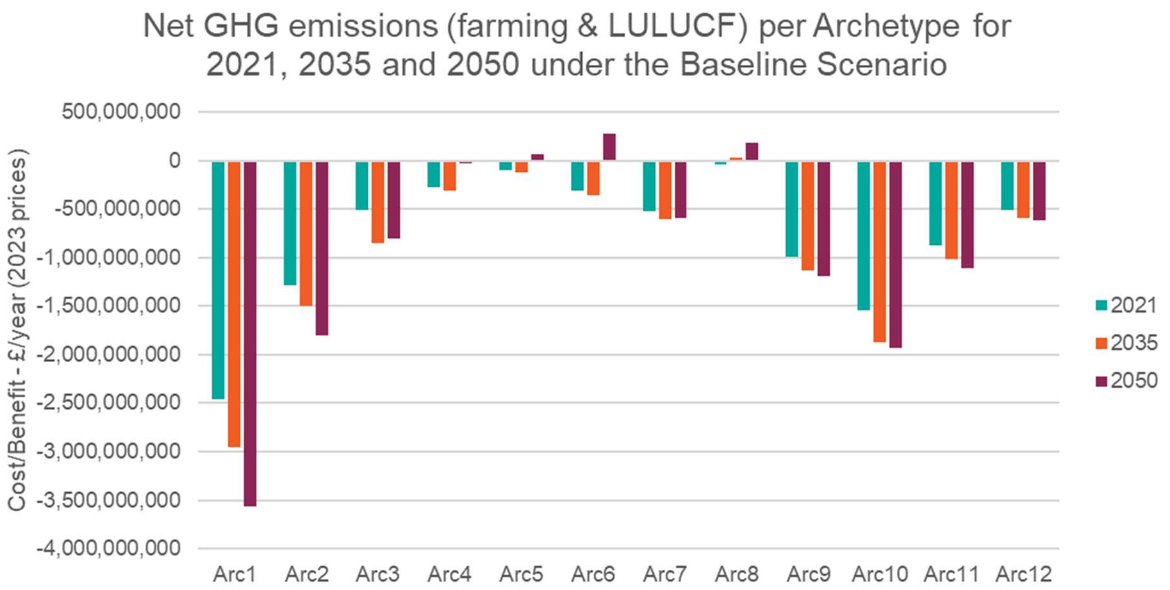

Figure 38 Net GHG Emissions per Archetype for 2021, 2035 and 2050 under the Baseline pathway

Archetypes: 1-Lowland organic soils; 2- Upland organic soils; 3- Intensive grassland; 4- Suburban fringe; 5- Hilly farmland; 6- Open pasture; 7- Enclosed pasture; 8- Acid upland grassland; 9- Arable on chalk/clay; 10- Arable on sandy soils; 11- Lowland agriculture in Northern Ireland; 12- Uplands in Northern Ireland.

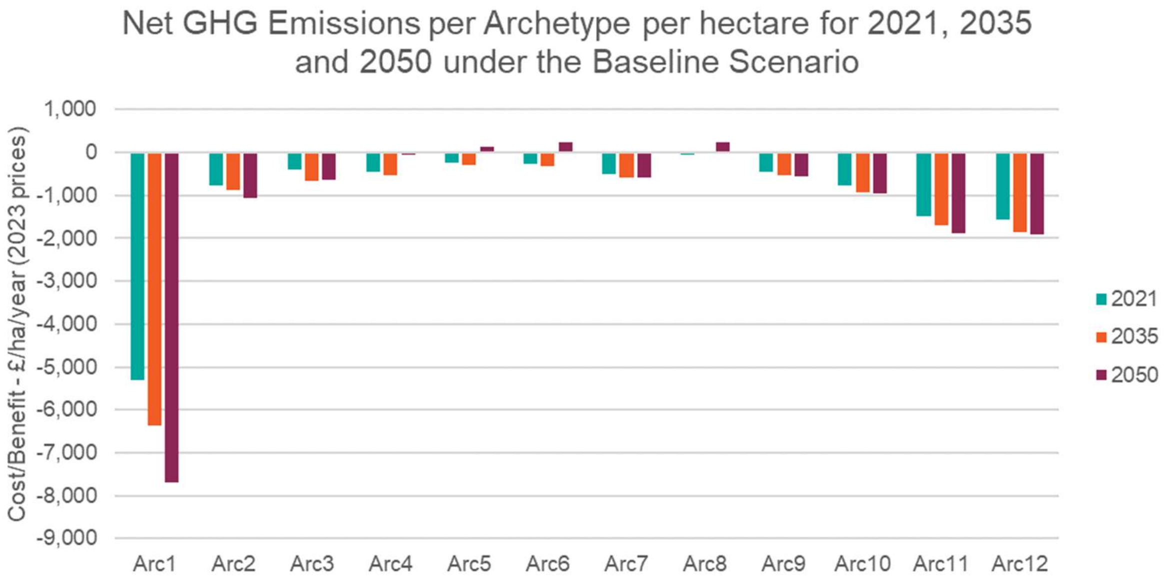

Figure 39 Net GHG Emissions per Archetype per hectare for 2021, 2035 and 2050 under the Baseline pathway

<u>Net social impacts</u>

Net social impacts (including environmental benefits such as recreation, air and water quality, as well as the public cost of providing and administrating agri-environmental funding) is positive across all archetypes, as shown in Figure 40. These impacts are concentrated in Archetype 2 (Upland organic soils), accounting for around 41% of the total, driven largely by recreation, physical and mental health benefits. In fact, recreation alone accounts for 43% of the total benefits within this category[15]. When looking on a per hectare basis, as shown in Figure 41, net social impacts remain highest in Archetype 2, with high values also found for Archetypes 1 (Lowland organic soils) and 12 (Uplands in Northern Ireland). Over time, there is only a minor increase in these impacts, with overall values increasing by just 2% in 2035 and 5% in 2050, relative to 2021.

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[15] For the 2021 baseline, recreation accounts for 43% of the total benefit, followed by mental health (29%), flood storage (20%), physical health (12%), air pollution removal (3%) and water quality improvement (3%). These percentages remain relatively consistent across 2035 and 2050.

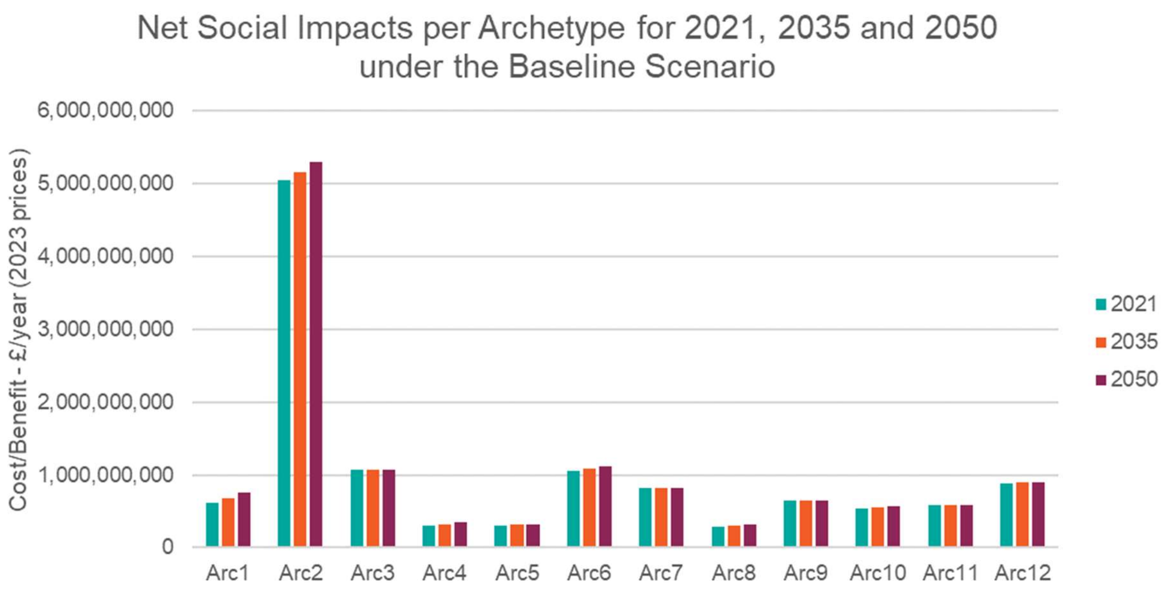


Figure 40 Net Social Impacts per Archetype for 2021, 2035 and 2050 under the Baseline pathway

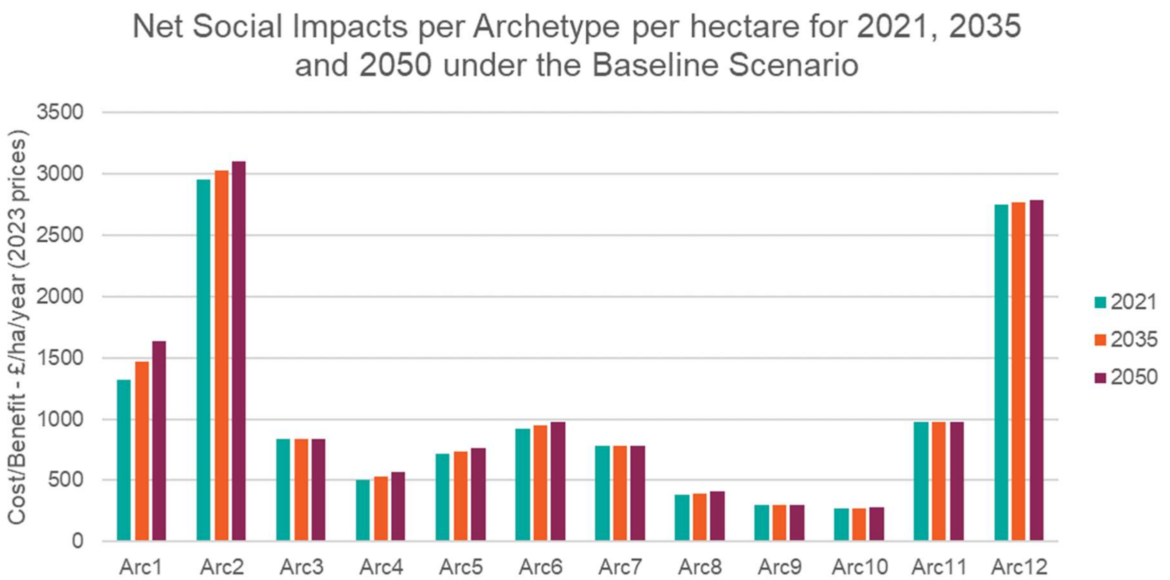


Figure 41 Net Social Impacts per Archetype per hectare for 2021, 2035 and 2050 under the Baseline pathway

Archetypes: 1-Lowland organic soils; 2- Upland organic soils; 3- Intensive grassland; 4- Suburban fringe; 5- Hilly farmland; 6- Open pasture; 7- Enclosed pasture; 8- Acid upland grassland; 9- Arable on chalk/clay; 10- Arable on sandy soils; 11- Lowland agriculture in Northern Ireland; 12- Uplands in Northern Ireland.

5. Archetype transition pathways

Metrics are quantified for 2035 and 2050 under the transition pathways (2021 metrics are considered unchanged from the Baseline pathway).

The transition pathways were defined by the CCC and include at least one transition pathway per archetype, with 2 transitions for some archetypes. Transition pathways explored different combinations of land-based mitigation options, livestock stocking densities and solar panel uptake (Table 9). Existing agricultural incomes (e.g. £/hectare) and ALC grade of land were two of the key factors in determining the type and scale of the transition per archetype, such that highly productive land (e.g. ALC grade 1 cropland) had more land ‘sharing’ type measures deployed (e.g. hedges and agroforestry), while less productive land (such as upland grazing) underwent more extensive land use change out of agriculture, with consequent reductions in livestock numbers.

For transitions involving tree planting and conversion to bioenergy crops, the areas suitable for planting were assessed based on the Agricultural Land Classification (ALC) grade areas in each archetype (for England, Scotland and Wales). These were calculated by intersecting ALC maps for each DA (Soil Survey of Scotland Staff, 1981; MAFF, 1988; Natural England 2012; Welsh Government, 2017) with the land use areas within each archetype. This enabled planting to be focussed on the most appropriate ALC grade areas in each archetype according to the transition definition, e.g. planting on one grade of land (e.g. woodland creation on Grade 5 grassland in Archetype 6 transition 2) or planting on successively better agricultural land in order to reach the required area (e.g. woodland creation on grade 5 arable and grassland, then grade 4, then grade 3, as required to reach the total areas required in the archetype).

Archetypes 2 and 8 were predominantly lowest grade agricultural land (grade 5), whereas Archetypes 1, 4, 6, 7, 9 and 10 had at least 50% Grade 3 and above land (Figure 42).

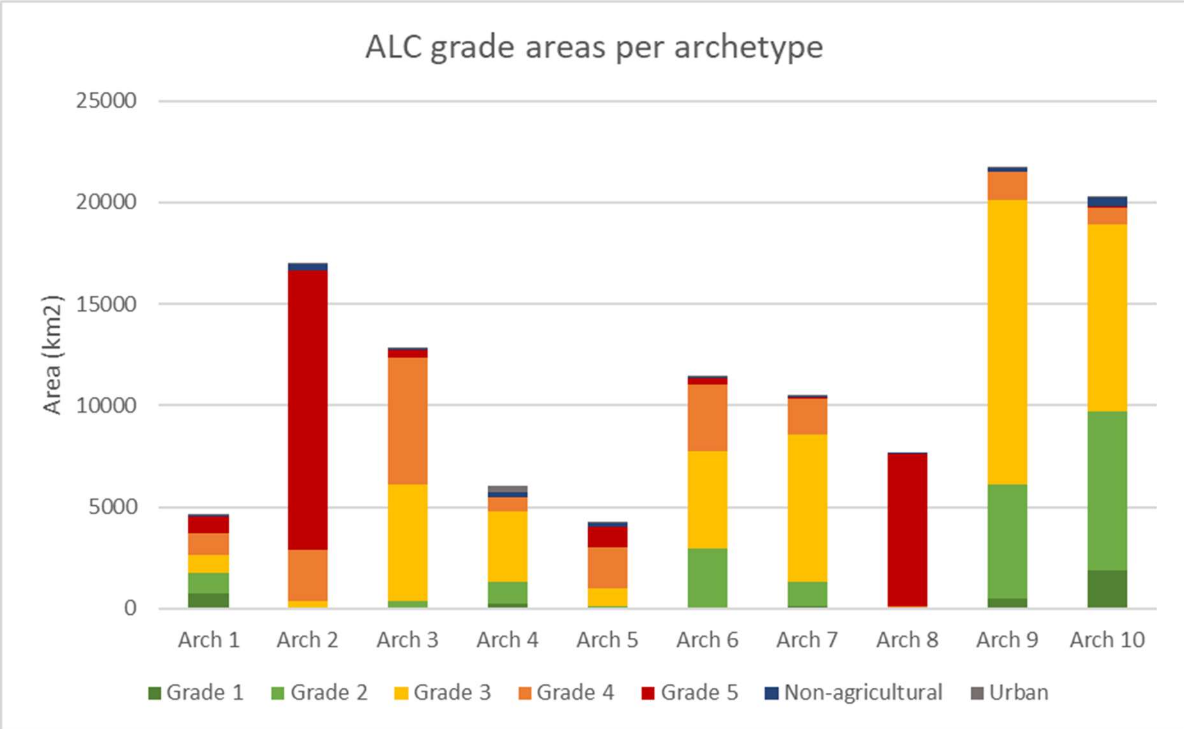


Figure 42 Areas per ALC grade in each archetype

Archetypes: 1-Lowland organic soils; 2- Upland organic soils; 3- Intensive grassland; 4- Suburban fringe; 5- Hilly farmland; 6- Open pasture; 7- Enclosed pasture; 8- Acid upland grassland; 9- Arable on chalk/clay; 10- Arable on sandy soils; 11- Lowland agriculture in Northern Ireland; 12- Uplands in Northern Ireland.

The total area of new woodland plantation/habitat creation, agroforestry planting and short rotation forestry planting is reported as the total potential woodland creation area that has been taken up.

In some archetypes there were changes in the assumed livestock stocking rates to either reduce the impact of reduced pasture area on overall livestock production of meat and dairy products, or to reduce livestock GHG emissions.

5.1 Archetype 1- Highly degraded lowland organic soils in Great Britain

Restoration and sustainable management of lowland organic soils

- Restoration and sustainable management of lowland organic soils by 2050 aligned to 7th Carbon Budget assumptions (75% of cropland restored or brought into sustainable management, 50% of lowland grassland restored, 100% of peat extraction sites restored by 2042).
- 0% of woodland creation potential is taken up (no woodland creation, agroforestry or Short Rotation Forestry) and woodland cover reduces from 3.9% to 3.8% by 2050.
- No additional solar PV energy generation.

5.2 Archetype 2- Degraded upland grazing land and forest on organic soils in Great Britain

Restoration of upland organic soils.

- Restoration of upland organic soils by 2050 aligned to 7th Carbon Budget assumptions (90% of upland grassland, 100% of forests on peat under yield class 8 restored to peatland habitat)
- 0% of woodland creation potential is taken up (no woodland creation, agroforestry or Short Rotation Forestry) and woodland cover falls from 22.5% to 17.6% by 2050.
- No additional solar PV energy generation.

5.3 Archetype 3- Intensive grassland in Wales and south-west England, pathway 1

Plantation woodland creation and expansion of on-farm tree cover, increased stocking

- Woodland creation (planting of productive plantations): 133,200 ha planted 2021-2050 (80% broadleaves). Planted on ALC grade 5 and 4 land. Productive conifers assumed to be Sitka spruce YC16 with standard management, productive broadleaves assumed to be Birch YC6 with continuous cover management.
- Agroforestry: 10% of permanent pasture and rough grassland converted to agroforestry system, 10% of arable and temporary grassland converted to agroforestry system.
- Hedgerow creation: aligned to 7th Carbon Budget Balanced Pathway assumptions, 40% increase by 2050.
- Stocking rates of cattle and sheep increase by 5% in 2035 and 10% in 2050.
- 100% of woodland creation potential is taken up and woodland cover increases from 1.0% to 12.7% by 2050.
- No additional solar PV energy generation.

5.4 Archetype 3- Intensive grassland in Wales and south-west England, pathway 2

Expansion of on-farm tree cover, bioenergy crops and solar power generation, increased stocking

- Agroforestry: 15% of permanent pasture and rough grassland converted to agroforestry system, 15% of arable and temporary grassland converted to agroforestry system.

- Hedgerow creation: aligned to 7th Carbon Budget contingency assumptions, 40% increase in Scotland, Wales and Northern Ireland, 60% increase in England by 2050
- Bioenergy crops: 4% of agricultural land converted to energy crops by 2050, on ALC Grade 4 land or above.
- Stocking rates of cattle and sheep increase by 5% in 2035 and 10% in 2050.
- An increase in land area for solar PV energy generation of 674% has been modelled for 2035 and 1,096% for 2050.
- Other semi-natural habitat restoration: 15,600 ha restored to achieve 5% of agricultural land converted to mitigation
- No additional woodland creation beyond baseline pathway where woodland cover increases from 1% to 4.1% by 2050.

5.5 Archetype 4- Farming on the suburban fringe in England, pathway 1

Tree planting for habitat creation and hedgerow expansion

- Tree planting for habitat creation: 45,203 ha planted 2021-2050 (78% broadleaves) , focussed on ALC Grade 4 and 5 agricultural land. Planting for habitat creation assumed to be Scots pine YC8 with standard management and Birch YC6 with continuous cover management.
- Hedgerow creation: aligned to 7th Carbon Budget Balanced Pathway assumptions, 40% increase by 2050.
- 100% of woodland creation potential is taken up and woodland cover increases from 0.6% to 7.9% by 2050.
- No additional solar PV energy generation.

5.6 Archetype 4- Farming on the suburban fringe in England, pathway 2

Expansion of on-farm tree cover, bioenergy crops and solar power generation

- Agroforestry: 10% of permanent pasture and rough grassland converted to agroforestry system, 10% of arable and temporary grassland converted to agroforestry system.
- Hedgerow creation: aligned to 7th Carbon Budget Balanced Pathway assumptions, 40% increase by 2050
- Bioenergy crops: 4% of agricultural land converted to energy crops by 2050, on ALC Grade 4 land or above.
- An increase in land area for solar PV energy generation of 1,283% has been modelled for 2035 and 2,085% for 2050.
- No additional woodland creation beyond baseline pathway where woodland cover increases from 0.6% to 2.7% by 2050.

5.7 Archetype 5- Hilly farmland on improved and semi-natural grassland on non-organic soils in Great Britain

Plantation woodland creation and expansion of on-farm tree cover, reduced stocking

- Planting of productive plantations: 40,305 ha planted 2021-2050 (72% broadleaves). Planted on ALC grade 5 land. Productive conifers assumed to be Sitka spruce YC16 with standard management, productive broadleaves assumed to be Birch YC6 with continuous cover management.
- Agroforestry: 10% of permanent pasture and rough grassland converted to agroforestry system
- Hedgerow creation: aligned to 7th Carbon Budget Balanced Pathway assumptions, 40% increase by 2050
- Stocking rates of cattle and sheep decrease by 5% in 2035 and 10% in 2050.
- 100% of woodland creation potential is taken up and woodland cover increases from 2.9% to 13.6% by 2050.
- No additional solar PV energy generation.

5.8 Archetype 6- Open pasture on the upland fringe in England and Scotland, pathway 1

Plantation woodland creation and expansion of on-farm tree cover

- Planting of productive plantations: 259,301 ha planted 2021-2050 (59% broadleaves). Planted on ALC grade 5 and 4 land. Productive conifers assumed to be Sitka spruce YC16 with standard management, productive broadleaves assumed to be Birch YC6 with continuous cover management.
- Agroforestry: 10% of permanent pasture and rough grassland converted to agroforestry system.
- Hedgerow creation: aligned to 7th Carbon Budget Balanced Pathway assumptions, 40% increase by 2050.
- 100% of woodland creation potential is taken up and woodland cover increases from 1.8% to 25.5% by 2050.
- No additional solar PV energy generation.

5.9 Archetype 6- Open pasture on the upland fringe in England and Scotland, pathway 2

Tree planting for habitat creation and on-farm tree cover expansion, increased stocking

- Tree planting for habitat creation: 32,901 ha planted 2021-2050 (60% broadleaves) focussed on ALC Grade 5 grassland. Planting for habitat creation assumed to be Scots pine YC8 with standard management and Birch YC6 with continuous cover management.
- Agroforestry: 10% of permanent pasture and rough grassland converted to agroforestry system.
- Hedgerow creation: aligned to 7th Carbon Budget Balanced Pathway assumptions, 40% increase by 2050.
- Other semi-natural habitat restoration: 5% of agricultural land converted to mitigation.
- There is no change in livestock numbers in 2035 and 2050, thereby increasing stocking rates by 5% for dairy cattle, and 21% in 2050 for sheep and non-dairy cattle.
- 17% of woodland creation potential is taken up and woodland cover increases from 1.8% to 5.8% by 2050.
- No additional solar PV energy generation.

5.10 Archetype 7- Enclosed pasture in England and Wales

Plantation woodland creation, expansion of on-farm tree cover and bioenergy crops

- Planting of productive plantations: 92,601 ha planted 2021-2050 (80% broadleaves). Planted on ALC grade 5 and 4 land. Productive conifers assumed to be Sitka spruce YC16 with standard management, productive broadleaves assumed to be Birch YC6 with continuous cover management.
- Agroforestry: 15% of permanent pasture and rough grassland converted to agroforestry system, 15% of arable and temporary grassland converted to agroforestry system.
- Hedgerow creation: aligned to 7th Carbon Budget Balanced Pathway assumptions, 40% increase by 2050.
- Bioenergy crops: 4% of agricultural land converted to energy crops by 2050, on ALC Grade 4 land or above.
- 92% of woodland creation potential is taken up and woodland cover increases from 0.2% to 12.2% by 2050.
- No additional solar PV energy generation.

5.11 Archetype 8- Acid grassland on hilly uplands in Great Britain

Tree planting for habitat creation, reduced stocking

- 50% tree planting for habitat creation, 50% woodland natural regeneration: 13,000 ha planted by 2050 (52% broadleaves). Planted on ALC grade 5

land. Planting for habitat creation assumed to be Scots pine YC8 with standard management. Planting for natural regeneration assumed to be Scots pineYC2 and Birch YC2 with no thinning management.
- Sheep numbers are reduced to achieve a sheep: cattle ratio of 30:70 in livestock units (equivalent to a 21% reduction in sheep stocking rate by 2050).
- 100% of woodland creation potential is taken up and woodland cover increase from 2.1% to 3.7% by 2050.
- No additional solar PV energy generation.

5.12 Archetype 9- Intensive and valley/floodplain arable on chalk/clay soils in England, pathway 1

Expansion of on-farm tree cover and bioenergy crops

- Agroforestry: 10% of permanent pasture and rough grassland converted to agroforestry system, 10% of arable and temporary grassland converted to agroforestry system.
- Hedgerow creation: aligned to 7th Carbon Budget Balanced Pathway assumptions, 40% increase by 2050.
- Bioenergy crops: aligned to 7th Carbon Budget assumptions (1691 ha by 2050), on ALC Grade 4 land or above.
- No additional woodland creation beyond baseline pathway where woodland cover increases from 0.2% to 2.5% by 2050.
- No additional solar PV energy generation.

5.13 Archetype 9- Intensive and valley/floodplain arable on chalk/clay soils in England, pathway 2

Tree planting for habitat creation, expansion of on-farm tree cover and solar power generation

- Tree planting for habitat creation: 67,005 ha planted 2021-2050 (80% broadleaves). Planted on ALC grade 5 and 4 land. Planting for habitat creation assumed to be Scots pine YC8 with standard management and Birch YC 6 with continuous cover management.
- Agroforestry: 10% of permanent pasture and rough grassland converted to agroforestry system, 10% of arable and temporary grassland converted to agroforestry system.
- Hedgerow creation: aligned to 7th Carbon Budget Balanced Pathway assumptions, 40% increase by 2050.
- An increase in land area for solar PV energy generation of 3,374% has been modelled for 2035 and 5,483% for 2050.

- 100% of woodland creation potential is taken up and woodland cover increases from 0.2% to 3.2% by 2050.

5.14 Archetype 10- Arable on sandy soils in England and Scotland

Expansion of on-farm tree cover and bioenergy crops

- Agroforestry: 15% of permanent pasture and rough grassland converted to agroforestry system, 15% of arable and temporary grassland converted to agroforestry system
- Hedgerow creation: aligned to 7th Carbon Budget Balanced Pathway assumptions, 40% increase by 2050
- Bioenergy crops: aligned to 7th Carbon Budget assumptions (1674 ha by 2050), on ALC Grade 4 land or above.
- No additional woodland creation beyond baseline pathway where woodland cover increases from 1.5% to 3.2% by 2050.
- No additional solar PV energy generation.

5.15 Archetype 11- Lowland agriculture in Northern Ireland

Tree planting for production and habitat creation, expansion of on-farm tree cover, restoration of degraded organic soils.

- Tree planting: 9,840 ha of productive conifers planted 2021-2050; 88,560 ha of planting for woodland habitat creation by 2050 (80% broadleaves overall). There is no digital ALC information for Northern Ireland to inform targeting of woodland creation to lower grade agricultural land. Productive conifers assumed to be Sitka spruce YC16 with standard management. Planting for habitat creation assumed to be Scots pine YC8 with standard management and Birch YC6 with continuous cover management.
- Agroforestry: 10% of permanent pasture and rough grassland converted to agroforestry system
- Hedgerow creation: aligned to 7th Carbon Budget Balanced Pathway assumptions, 40% increase by 2050
- Restoration and sustainable management of lowland organic soils by 2050 aligned to 7th Carbon Budget assumptions (75% of cropland restored or brought into sustainable management, 50% of lowland grassland restored, 100% of peat extraction sites restored by 2042)
- Restoration of upland organic soils aligned to 7th Carbon Budget assumptions (90% of upland grassland)
- 62% of woodland creation potential is taken up and woodland cover increases from 1.4% to 19.0% by 2050.

- No additional solar PV energy generation.

5.16 Archetype 12- Uplands with large extent on organic soils in Northern Ireland

Restoration of degraded organic soils, reduced stocking and hedgerow expansion

- Hedgerow creation: aligned to 7th Carbon Budget Balanced Pathway assumptions, 40% increase by 2050
- Restoration and sustainable management of lowland organic soils aligned to 7th Carbon Budget assumptions (50% of lowland grassland restored, 100% of peat extraction sites restored by 2042)
- Restoration of upland organic soils by 2050 aligned to 7th Carbon Budget assumptions (90% of upland grassland, 100% of forests on peat under yield class 8 restored to peatland habitat)
- Livestock are removed from grazing on upland organic soils (48% of rough grazing land).
  No additional woodland creation beyond baseline pathway and woodland cover reduces slightly from 15.4% to 13.8% by 2050.
- No additional solar PV energy generation.

Table 9: Summary of mitigation measures applied in archetype transition pathway

Archetype /Pathway	Livestock densities	Woodland creation – productive plantations		Woodland creation – habitat creation	Agroforestry on grassland	Agroforestry on cropland	Hedgerow creation	Energy crop production	Peatland restoration – upland	Peatland restoration – lowland	Semi-natural habitat restoration	Sustainable management of lowland peat	Solar PV
1										■		■	
2									■				
3/1	■	■			■	■	■						
3/2	■				■	■	■	■			■		■
4/1			■	■			■						
4/2					■	■	■	■					■
5	■	■			■		■						
6/1		■			■		■						
6/2	■		■	■	■		■				■		
7		■			■	■	■	■					
8	■		■	■									
9/1					■	■	■	■					
9/2			■	■	■	■	■						■
10					■	■	■	■					
11		■	■	■	■		■		■	■		■	
12	■						■		■	■		■	

Archetypes: 1-Lowland organic soils; 2- Upland organic soils; 3- Intensive grassland; 4- Suburban fringe; 5- Hilly farmland; 6- Open pasture; 7- Enclosed pasture; 8- Acid upland grassland; 9- Arable on chalk/clay; 10- Arable on sandy soils; 11- Lowland agriculture in Northern Ireland; 12- Uplands in Northern Ireland

6. Transition pathway metrics

6.1 Land Use Areas

Woodland creation

Woodland creation rates were set before the 7th Carbon Budget assumptions for the Balanced pathway for the UK but are similar. This ramps annual planting rates up to 13,500 ha in 2025 (15,005 ha yr^{-1} in the 7thCB), 50,000 ha by 2038 (52,500 ha yr^{-1} by 2036 and constant rate thereafter in the 7th CB) and 61,000 ha by 2043 to reach a total of 1,208,000 ha of new forest planted between 2020 and 2050. Broadleaf planting was assumed as 80% of the planted area in England, Wales and Northern Ireland, and 50% in Scotland. The UK area was distributed between archetypes based on the available suitable habitat, as described in Section 4.1. Land was transitioned from Grade 5 and Grade 4 ALC land in order of preference (Grade 3 land was not required).

Agroforestry

The baseline area of agroforestry in 2021 was assumed to be zero. Silvo-arable agroforestry is planted on cropland and temporary pasture (all on the Arable and Horticulture habitat type) and silvo-pastoral agroforestry is planted on permanent pasture (Improved grassland habitat) and rough grazing land (semi-natural grassland habitats). The area required for conversion to agroforestry was calculated based on the individual archetype pathways and assumed a constant rate of planting 2023-2050. Areas converted by 2050 are shown in Figure 43.

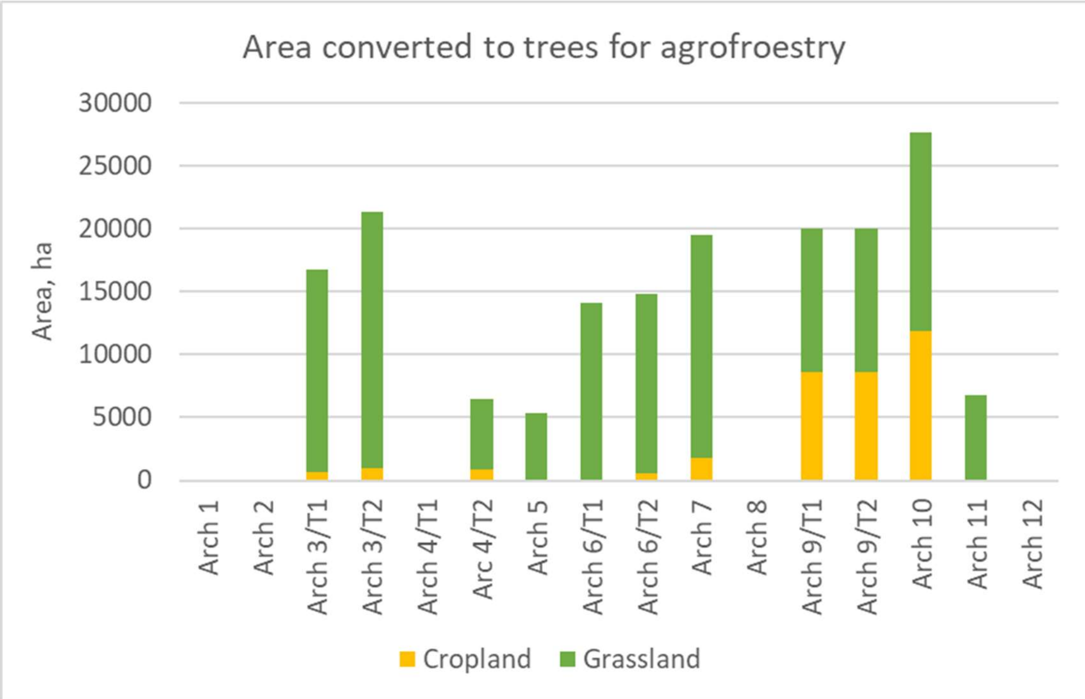


Figure 43 Areas of each archetype converted to agroforestry by 2050, on cropland and improved & seminatural grasslands

Archetypes: 1-Lowland organic soils; 2- Upland organic soils; 3- Intensive grassland; 4- Suburban fringe; 5- Hilly farmland; 6- Open pasture; 7- Enclosed pasture; 8- Acid upland grassland; 9- Arable on chalk/clay; 10- Arable on sandy soils; 11- Lowland agriculture in Northern Ireland; 12- Uplands in Northern Ireland.

Hedgerow creation

For current hedgerow lengths in each archetype, lengths per archetype (for England only) were calculated using the new UKCEH hedgerows dataset (Broughton *et al.,* 2024). These lengths were extended to the Scotland and Wales area in each archetype using the same average length per km^2 as in England in each archetype. In NI, Archetype 11 uses same hedgerow average length per km^2 as Archetype 7 (Enclosed pasture) as a proxy, and Archetype 12 is assumed to have no hedgerows as it is in the uplands. For the transitions, increased hedgerow lengths match CB7 rates (40% increase by 2050 applied in Archetypes 3 transition 1, 4, 5, 6, 7, 9, 10, 11 and 12 (noting assumption of zero hedgerow length in 2021 in Archetype 12), additional pathway with 60% increase in England and 40% elsewhere (Archetype 3 transition 2) (Figure 44). Hedgerow creation does not affect the land use areas reported for each archetype.

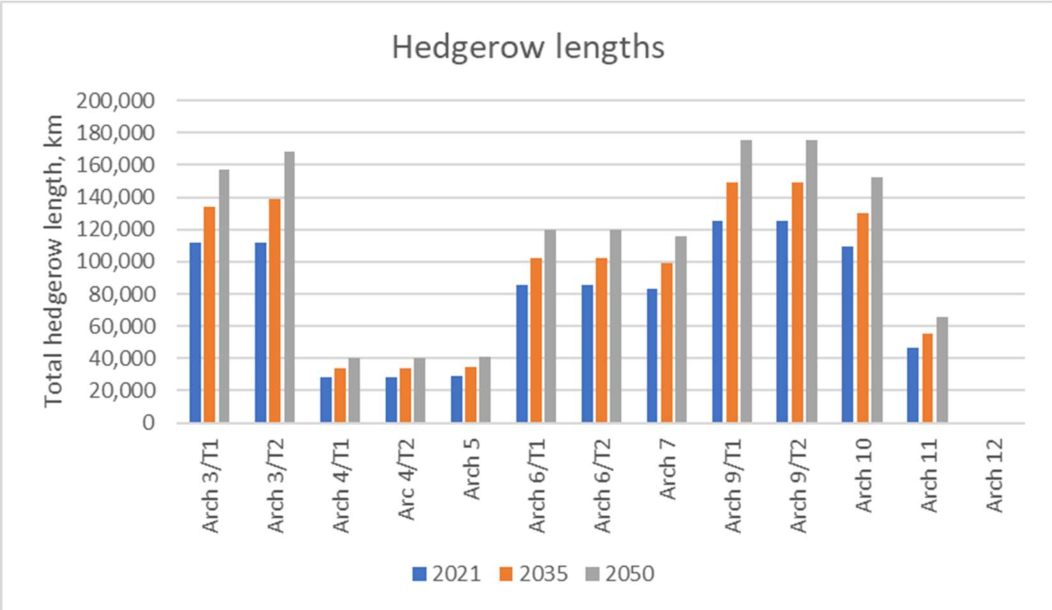


Figure 44 Total hedgerow length per archetype under the transitions

Archetypes: 1-Lowland organic soils; 2- Upland organic soils; 3- Intensive grassland; 4- Suburban fringe; 5- Hilly farmland; 6- Open pasture; 7- Enclosed pasture; 8- Acid upland grassland; 9- Arable on chalk/clay; 10- Arable on sandy soils; 11- Lowland agriculture in Northern Ireland; 12- Uplands in Northern Ireland.

Bioenergy crops

Proportions of archetype land were converted to bioenergy crops to reach either a percentage of the archetype area (4% of agricultural land in Archetypes 3 (transition 2), 4 (transition 2) and 7), or according to CB7 increase rates for the UK disaggregated out to the archetypes. The area was divided up between Miscanthus, SRC and SRF according to the proportions of each crop by 2050 under CB7 increases for the UK. SRC and Miscanthus are assumed to be grown on existing arable land, so there is no land use change. SRF is assumed to be grown on both cropland and grassland suitable for tree planting, apportioned according to the Grade 4 land available in each archetype. Figure 45 shows the areas used for bioenergy crops in 2035 and 2050, and Figure 46the production of bioenergy crops.

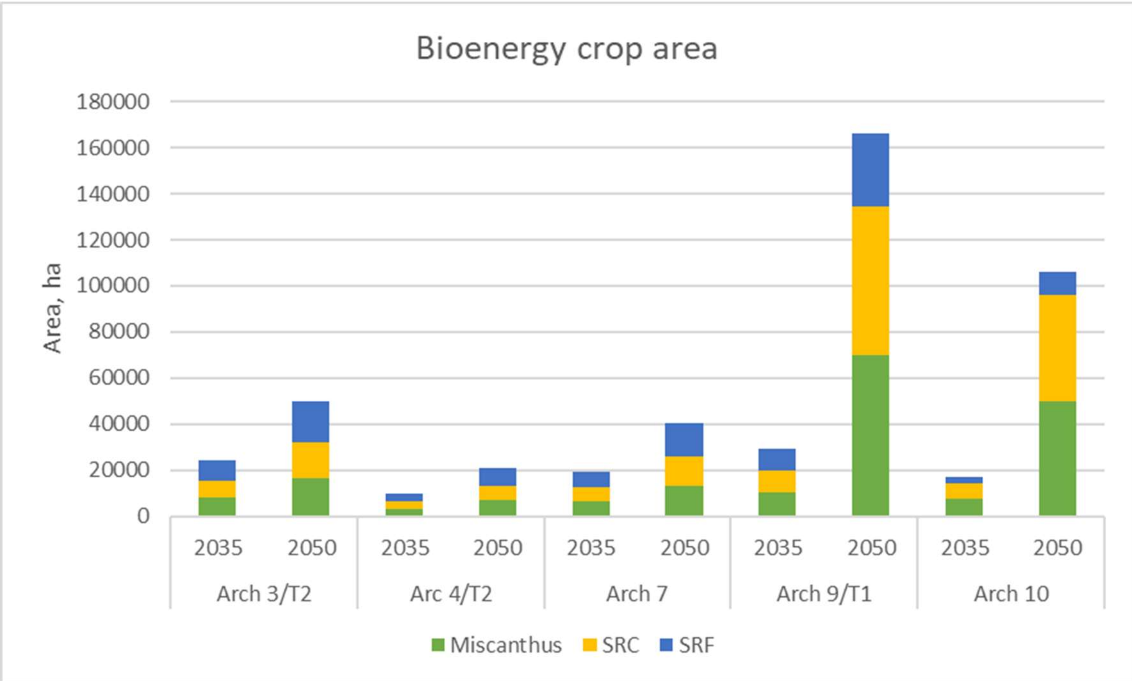


Figure 45 Bioenergy crop areas in archetypes where transitions include bioenergy crops in 2035 and 2050, split by crop type.

Archetypes: 1-Lowland organic soils; 2- Upland organic soils; 3- Intensive grassland; 4- Suburban fringe; 5- Hilly farmland; 6- Open pasture; 7- Enclosed pasture; 8- Acid upland grassland; 9- Arable on chalk/clay; 10- Arable on sandy soils; 11- Lowland agriculture in Northern Ireland; 12- Uplands in Northern Ireland.

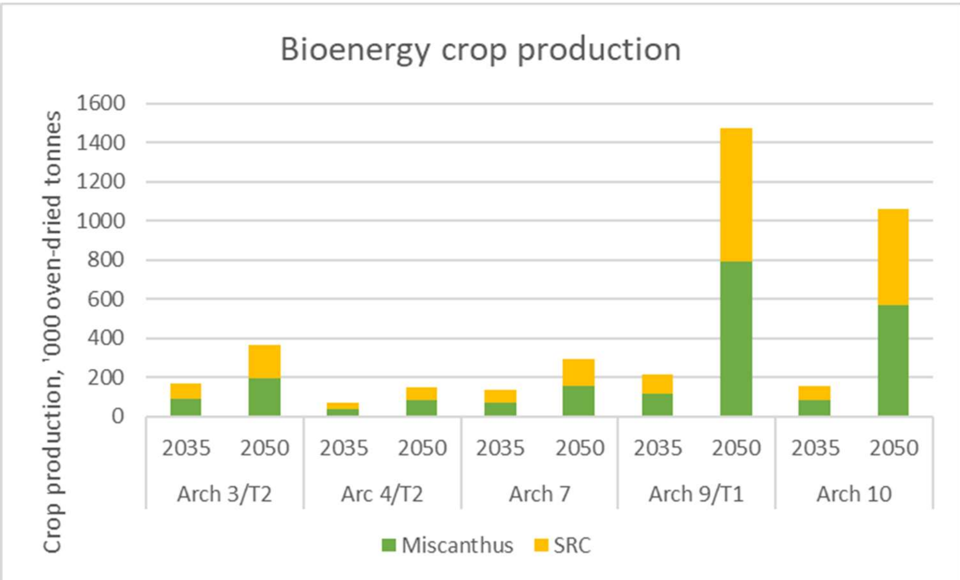


Figure 46 Bioenergy crop production in archetypes where transitions include bioenergy crops in 2035 and 2050 for Miscanthus and Short Rotation Coppice.

Note there is no Short Rotation Forestry production before 2050.

Peatland restoration

Applies to Archetypes 1, 2, 11 and 12 only. CB7 rates of peatland restoration are used, which in summary are:

- 90% upland grassland restored by 2050
- 50% lowland grassland restored by 2050
- 75% lowland cropland under restoration or sustainable management by 2050 (15% restored to paludiculture, 25% restored to near-natural condition, 20% under dynamic water level management, 15% under continuous raised water level management)
- 100% extraction sites restored by 2042
- 100% of forest sites <YC8 restored by 2050 (20% of forest area assumed to be <YC8)
- These rates are applied to the archetypes according to the peatland categories in each:
- Arch 1: lowland grassland, lowland cropland, extraction
- Arch 2: forest, upland grassland
- Arch 11: upland grassland, lowland grassland, extraction, lowland cropland
- Arch 12: forest, upland grassland, lowland grassland, extraction

Restoration of semi-natural habitats

Restoration of semi-natural habitats (conversion to semi-natural grassland; as creation of other semi-natural habitats was covered by other measures) was estimated for two archetype pathways (Archetype 3 pathway 2, and Archetype 6 pathway 2) to ensure that at least 5% of intensive agricultural land (Arable and Horticulture, and Improved Grassland) was converted to mitigation purposes in archetypes with >1500 ha of Grade 4 and 5 agricultural land (after other mitigation conversion has been accounted for). A constant rate of conversion was assumed 2023-2050.

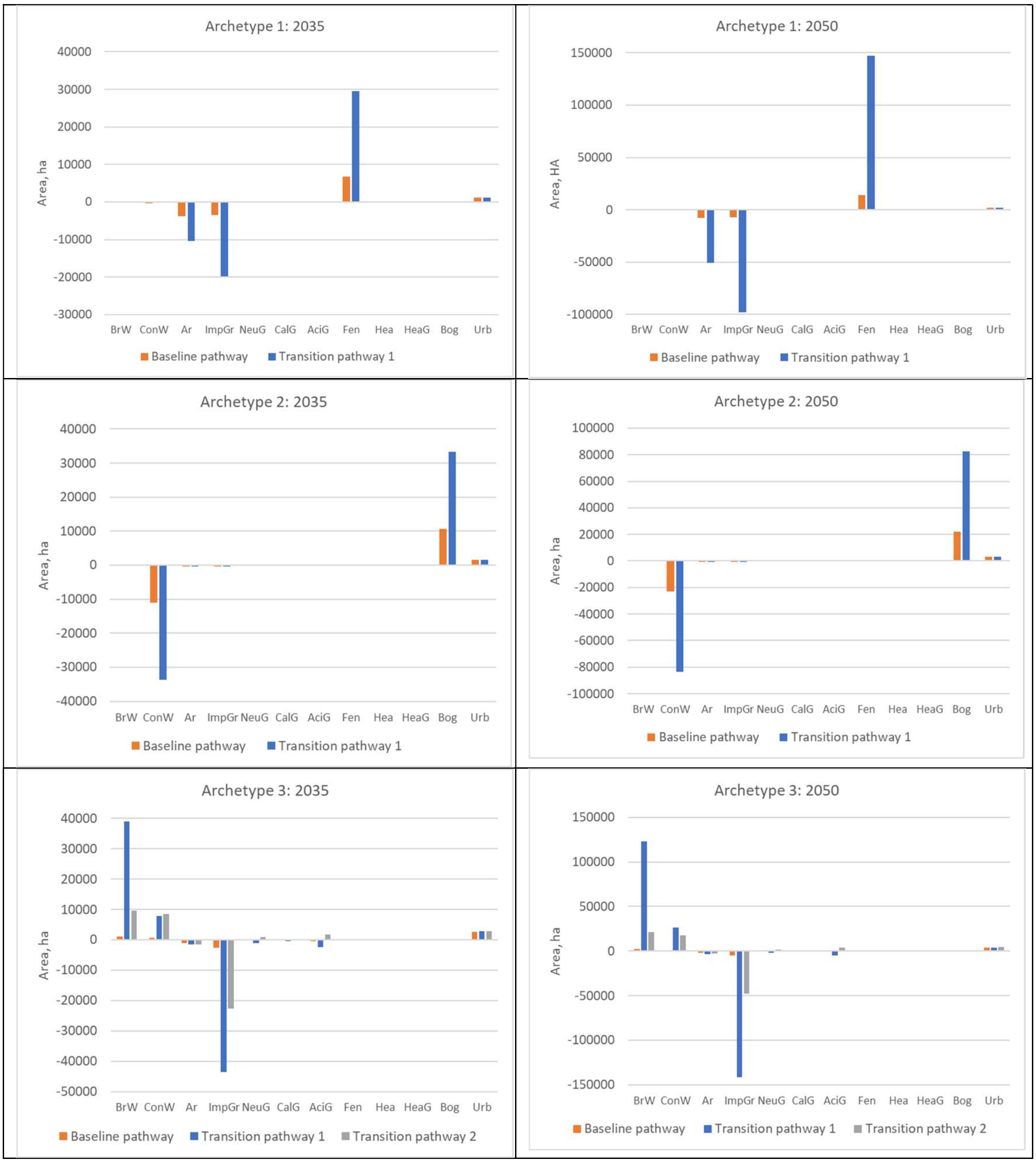
Change in agricultural land

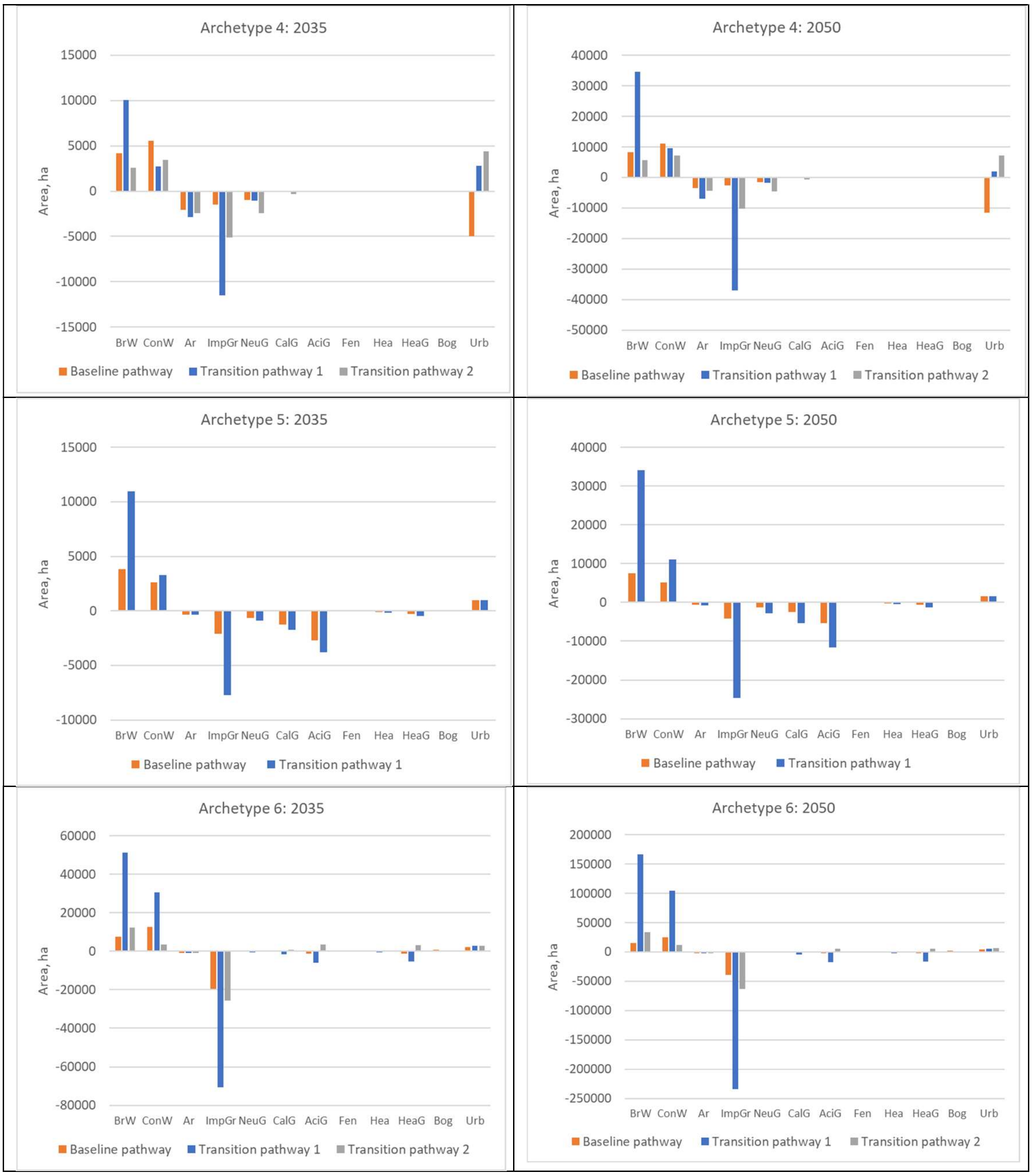
The change in agricultural land categories under the different pathways is covered in section 6.3 below.

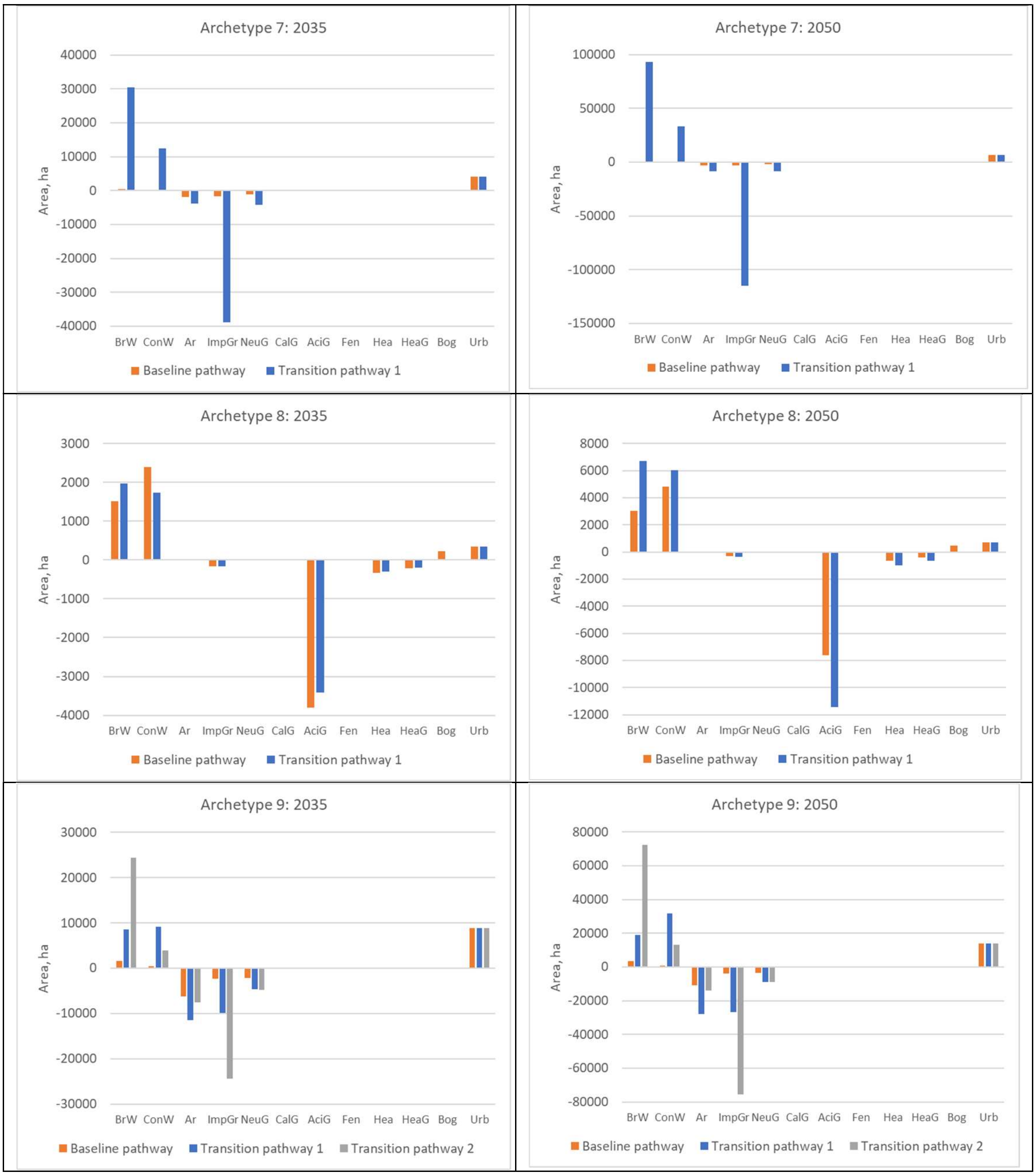
Overall land use change under the transitions

The land use change under the transition pathways for 2035 and 2050 is shown in Figure 47. The area of new woodland (both woodland creation, agroforestry and short rotation forestry) compared with the potential woodland creation area is shown in Figure 48. In Archetype pathways 3/1, 4/1, 5, 6/1, 8 and 9/2 100% of the potential woodland creation area is converted to tree cover. This is an additional 3,863 - 9,716 km^2 of additional woodland in 2050 compared to 2021, or 32-80% of the UK's 12,080 km^2 target. In order to achieve this UK target, the additional woodland planted on non-archetype rural land (Archetype 100 in the Baseline) would be 2,364-8,217 km2, or 31-109% of the woodland potential in Archetype 100, with planting on less suitable land being required at the upper end of that range.

Semi-natural habitats (excluding LCM categories Coniferous woodland, Arable and horticulture, Improved Grassland and Urban and suburban land) increased by 1,758-2,092 km^2 by 2035 (23.6-23.8% of the archetype area), and 7,132-7,681 km^2 by 2050 (27.9-28.3% of the archetype area).


Archetype 1: 2035
Area, ha
40000
30000
20000
10000
0
-10000
-20000
-30000
BrW ConW Ar ImpGr NeuG CalG AciG Fen Hea HeaG Bog Urb
Baseline pathway
Transition pathway 1
Archetype 1: 2050
Area, HA
150000
100000
50000
0
-50000
-100000
BrW ConW Ar ImpGr NeuG CalG AciG Fen Hea HeaG Bog Urb
Baseline pathway
Transition pathway 1
Archetype 2: 2035
Area, ha
40000
30000
20000
10000
0
-10000
-20000
-30000
-40000
BrW ConW Ar ImpGr NeuG CalG AciG Fen Hea HeaG Bog Urb
Baseline pathway
Transition pathway 1
Archetype 2: 2050
Area, ha
100000
80000
60000
40000
20000
0
-20000
-40000
-60000
-80000
-100000
BrW ConW Ar ImpGr NeuG CalG AciG Fen Hea HeaG Bog Urb
Baseline pathway
Transition pathway 1
Archetype 3: 2035
Area, ha
40000
30000
20000
10000
0
-10000
-20000
-30000
-40000
-50000
BrW ConW Ar ImpGr NeuG CalG AciG Fen Hea HeaG Bog Urb
Baseline pathway
Transition pathway 1
Transition pathway 2
Archetype 3: 2050
Area, ha
150000
100000
50000
0
-50000
-100000
-150000
BrW ConW Ar ImpGr NeuG CalG AciG Fen Hea HeaG Bog Urb
Baseline pathway
Transition pathway 1
Transition pathway 2


Archetype 4: 2035
Area, ha
15000
10000
5000
0
-5000
-10000
-15000
BrW ConW Ar ImpGr NeuG CalG AciG Fen Hea HeaG Bog Urb
Baseline pathway
Transition pathway 1
Transition pathway 2
Archetype 4: 2050
Area, ha
40000
30000
20000
10000
0
-10000
-20000
-30000
-40000
-50000
BrW ConW Ar ImpGr NeuG CalG AciG Fen Hea HeaG Bog Urb
Baseline pathway
Transition pathway 1
Transition pathway 2
Archetype 5: 2035
Area, ha
15000
10000
5000
0
-5000
-10000
BrW ConW Ar ImpGr NeuG CalG AciG Fen Hea HeaG Bog Urb
Baseline pathway
Transition pathway 1
Archetype 5: 2050
Area, ha
40000
30000
20000
10000
0
-10000
-20000
-30000
BrW ConW Ar ImpGr NeuG CalG AciG Fen Hea HeaG Bog Urb
Baseline pathway
Transition pathway 1
Archetype 6: 2035
Area, ha
60000
40000
20000
0
-20000
-40000
-60000
-80000
BrW ConW Ar ImpGr NeuG CalG AciG Fen Hea HeaG Bog Urb
Baseline pathway
Transition pathway 1
Transition pathway 2
Archetype 6: 2050
Area, ha
200000
150000
100000
50000
0
-50000
-100000
-150000
-200000
-250000
BrW ConW Ar ImpGr NeuG CalG AciG Fen Hea HeaG Bog Urb
Baseline pathway
Transition pathway 1
Transition pathway 2


Archetype 7: 2035
Area, ha
40000
30000
20000
10000
0
-10000
-20000
-30000
-40000
BrW ConW Ar ImpGr NeuG CalG AciG Fen Hea HeaG Bog Urb
Baseline pathway
Transition pathway 1
Archetype 7: 2050
Area, ha
100000
50000
0
-50000
-100000
-150000
BrW ConW Ar ImpGr NeuG CalG AciG Fen Hea HeaG Bog Urb
Baseline pathway
Transition pathway 1
Archetype 8: 2035
Area, ha
3000
2000
1000
0
-1000
-2000
-3000
-4000
BrW ConW Ar ImpGr NeuG CalG AciG Fen Hea HeaG Bog Urb
Baseline pathway
Transition pathway 1
Archetype 8: 2050
Area, ha
8000
6000
4000
2000
0
-2000
-4000
-6000
-8000
-10000
-12000
BrW ConW Ar ImpGr NeuG CalG AciG Fen Hea HeaG Bog Urb
Baseline pathway
Transition pathway 1
Archetype 9: 2035
Area, ha
30000
20000
10000
0
-10000
-20000
-30000
BrW ConW Ar ImpGr NeuG CalG AciG Fen Hea HeaG Bog Urb
Baseline pathway
Transition pathway 1
Transition pathway 2
Archetype 9: 2050
Area, ha
80000
60000
40000
20000
0
-20000
-40000
-60000
-80000
BrW ConW Ar ImpGr NeuG CalG AciG Fen Hea HeaG Bog Urb
Baseline pathway
Transition pathway 1
Transition pathway 2

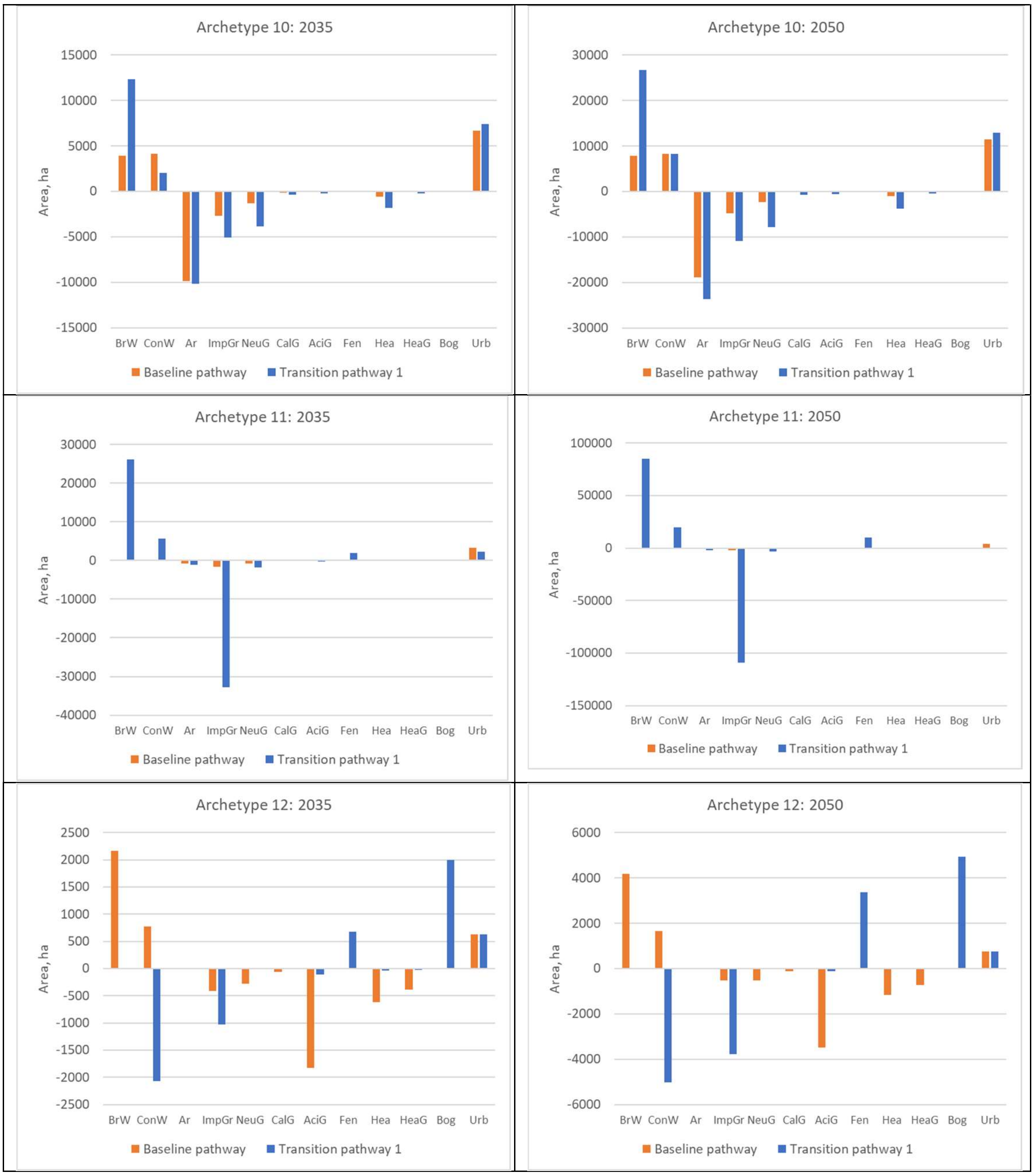


Figure 47 Land use change comparison by archetype

(BrW: Broadleaved woodland; ConW: Coniferous woodland; Ar: Arable and Horticulture; ImpG: Improved grassland; NeuG: Neutral grassland; CalG: Calcareous grassland; AciG: Acid Grassland; Fen: Fen, marsh and swamp; Hea: Heather; HeaG: Heather grassland; Bog: Bog; Urb: Urban and suburban)

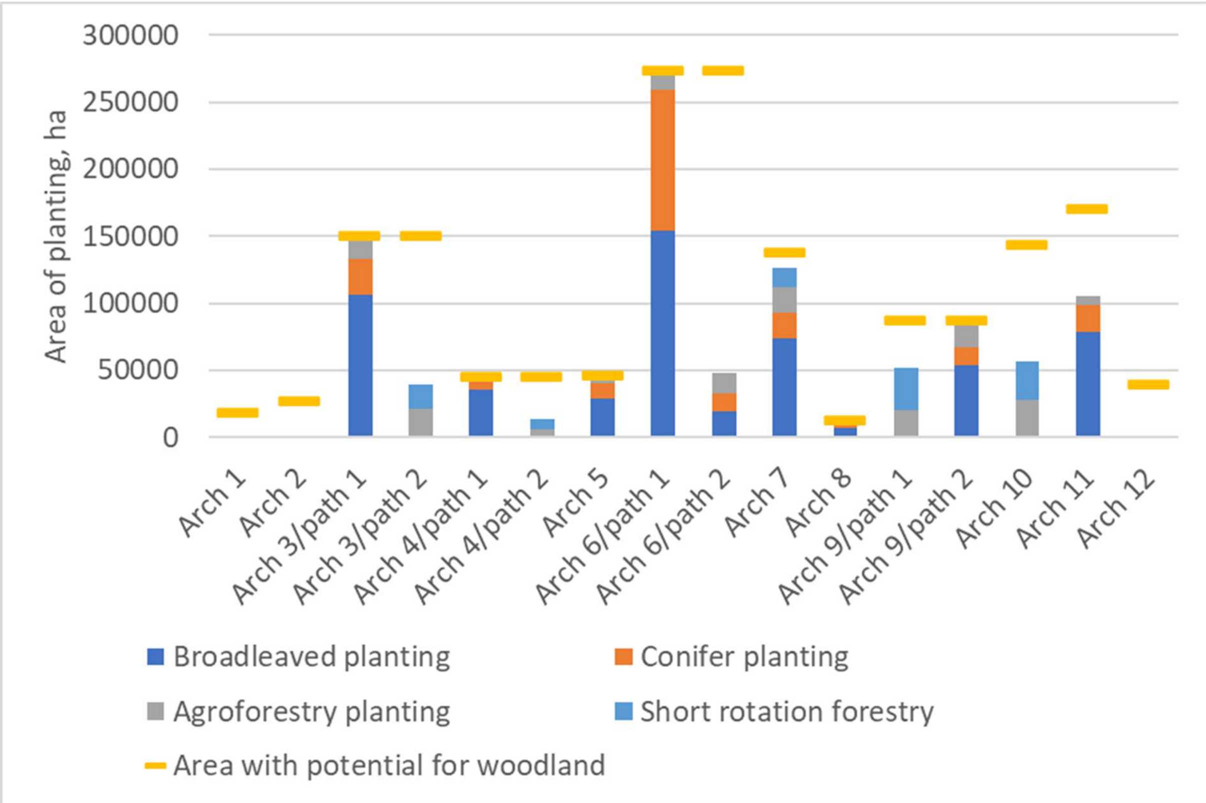


Figure 48 Comparison of Transition pathways projected vs. potential woodland creation area

Archetypes: 1-Lowland organic soils; 2- Upland organic soils; 3- Intensive grassland; 4- Suburban fringe; 5- Hilly farmland; 6- Open pasture; 7- Enclosed pasture; 8- Acid upland grassland; 9- Arable on chalk/clay; 10- Arable on sandy soils; 11- Lowland agriculture in Northern Ireland; 12- Uplands in Northern Ireland.

6.2 Livestock numbers and production

Livestock numbers in 2021 remained the same as in the Baseline pathway. Under the transition, 2035 and 2050 cattle and sheep numbers by archetype were adjusted using the projected agricultural areas of pasture and rough grazing (Figure 49) and stocking densities by livestock type. Numbers of dairy cattle fell by 6-22% in all archetypes except 6/pathway 2 which remained stable, and Archetypes 1,2 and 11 which fell by >30% (through conversion of pasture land to restored peatland). Numbers of beef dairy cattle in general declined more steeply (average of 30%) across all archetypes except Archetypes 6/pathway 2 and Archetype 8 which remained stable. Numbers of sheep declined (average of 30%) in all pathways except Archetype 6/pathway 2.

The projected areas took account of land-use change to mitigation activities, reducing the land available for grazing. Stocking densities were calculated for sheep, beef and other dairy cattle, and dairy cows were calculated for each archetype by country using the 2021 areas and livestock numbers. Assumptions on stocking density for some archetypes (see Section 5) were also applied. Dairy cows were assumed to use permanent pasture and temporary grassland only, but the other livestock also used rough grazing. Pig and poultry numbers were assumed to remain unchanged under the transition from the Baseline pathway, as they are not dependent on grazing area for production.

Livestock production (Figure 50) was calculated from livestock numbers using the same production factors as the baseline pathway. In general, there is an increase in milk production, although it falls steeply in Archetype 1 (Lowland organic soils) (as pasture land is lost to grazing by rewetting and livestock numbers are assumed to decline). Meat production from cattle and sheep is projected to fall under all archetypes, although with the maintenance of pig and poultry numbers this is less obvious when all meat production is considered.

Figure 49 Livestock numbers in 2021, 2035 and 2050 by archetype and pathway

Archetypes: 1-Lowland organic soils; 2- Upland organic soils; 3- Intensive grassland; 4- Suburban fringe; 5- Hilly farmland; 6- Open pasture; 7- Enclosed pasture; 8- Acid upland grassland; 9- Arable on chalk/clay; 10- Arable on sandy soils; 11- Lowland agriculture in Northern Ireland; 12- Uplands in Northern Ireland.

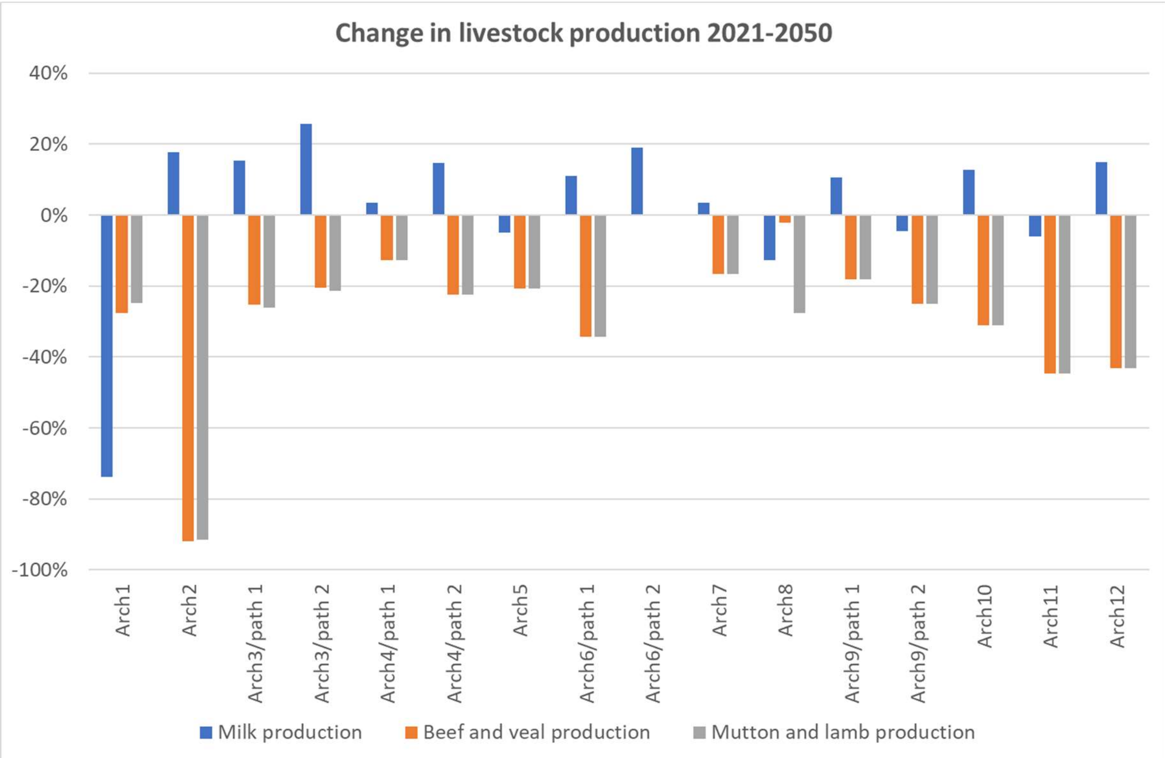


Figure 50 Livestock production changes 2021-2050

Archetypes: 1-Lowland organic soils; 2- Upland organic soils; 3- Intensive grassland; 4- Suburban fringe; 5- Hilly farmland; 6- Open pasture; 7- Enclosed pasture; 8- Acid upland grassland; 9- Arable on chalk/clay; 10- Arable on sandy soils; 11- Lowland agriculture in Northern Ireland; 12- Uplands in Northern Ireland.

6.3 Agriculture GHG Emissions

Agricultural GHG emissions are calculated using the approach in the Baseline pathway. The change in agricultural areas between the Baseline and the Transition pathways is shown in Figure 51. The 'unrestored rough grazing' refers to rough grazing land that has not undergone any peatland restoration or conversion to semi-natural grassland habitat.

The change in agricultural emissions in the transition pathways compared to the Baseline pathway is shown in Figure 52. The change in emissions comes from the change in livestock numbers and the reduction of agricultural land receiving synthetic fertilizer, rather than agricultural mitigation technologies such as feed additives or agroecological practices. All transitions have reduced GHG emissions, with half of the pathways having >20% reductions by 2050. Most of these changes arise from reductions in livestock numbers. There was a 14-16% reduction in total agricultural emissions 3.7-4.3 Mt CO_2e 2021-2050. The Balanced pathway in the 7th Carbon Budget has greater abatement (46%) as this includes additional agricultural emissions mitigation activities.

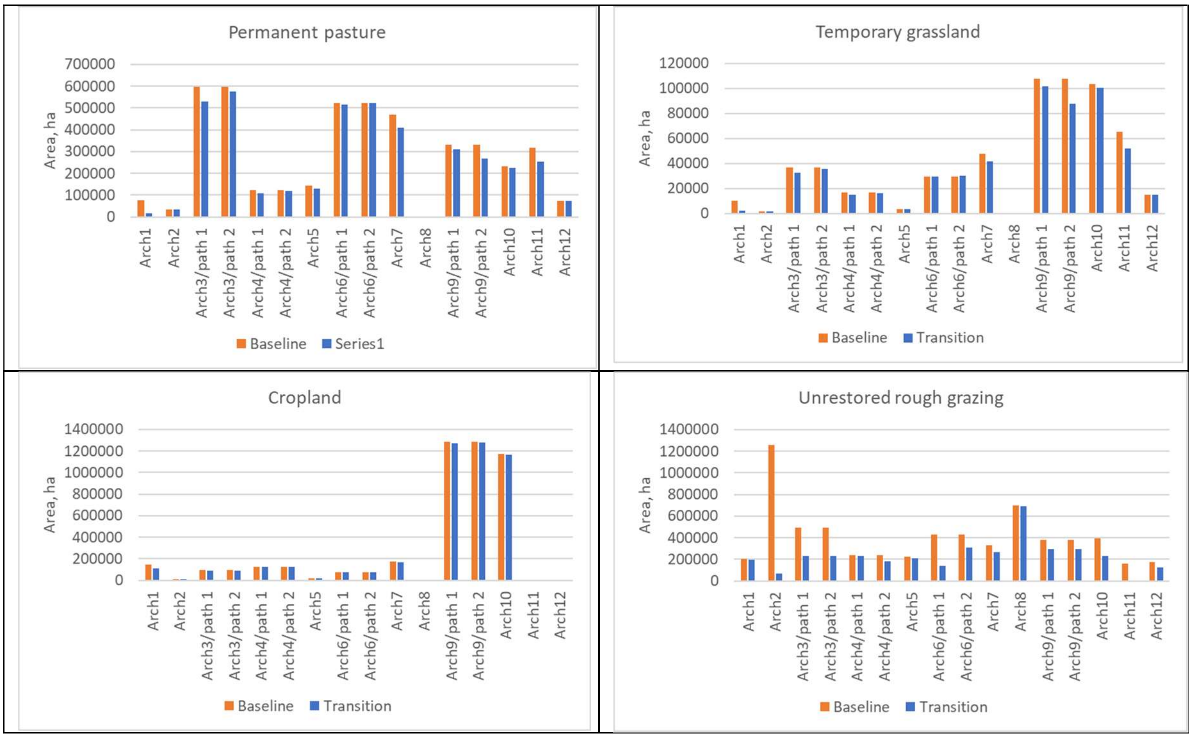


Figure 51 Change in agricultural areas between pathways and archetypes

Archetypes: 1-Lowland organic soils; 2- Upland organic soils; 3- Intensive grassland; 4- Suburban fringe; 5- Hilly farmland; 6- Open pasture; 7- Enclosed pasture; 8- Acid upland grassland; 9- Arable on chalk/clay; 10- Arable on sandy soils; 11- Lowland agriculture in Northern Ireland; 12- Uplands in Northern Ireland.

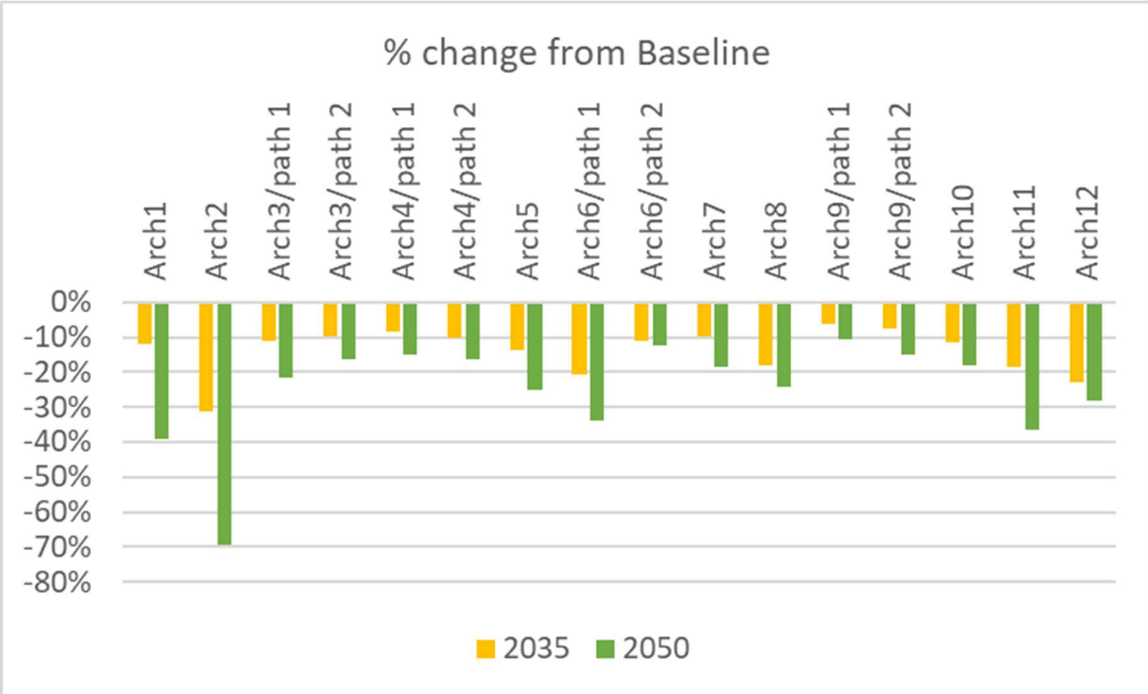


Figure 52 Percentage change in agricultural emissions between the Baseline and Transition pathways.

Archetypes: 1-Lowland organic soils; 2- Upland organic soils; 3- Intensive grassland; 4- Suburban fringe; 5- Hilly farmland; 6- Open pasture; 7- Enclosed pasture; 8- Acid upland grassland; 9- Arable on chalk/clay; 10- Arable on sandy soils; 11- Lowland agriculture in Northern Ireland; 12- Uplands in Northern Ireland.

6.4 LULUCF Emissions

LULUCF emissions in 2035 and 2050 were estimated using the same approach as in the Baseline pathway, with the following changes in assumptions:

- Woodland creation – Rates of woodland creation are calculated as described in Section 6.1, with emissions calculated in the same way as for the Baseline pathway. Assumptions about the planted species and yield classes are described in Section 5 on the archetype transition pathways. Results were scaled so that the 2021 net carbon stock change matched the GHG inventory 2021 value.
- Agroforestry – Emissions are calculated as for woodland creation, using the area of trees planted in each archetype. The species used for agroforestry are variable and trees may be managed for different purposes, e.g. for timber production in silvo-arable systems. Beech YC12[16] was assumed for

[16] In previous work for the CCC, poplar YC12 was used for silvo-arable planting but there are no yield tables for poplar in the QFORC database, so a similarly high-yielding broadleaf species was substituted.

silvo-arable planting, and Birch YC6 for silvo-pastoral, both with standard management.

- Forest wildfires – as Baseline.
- Deforestation – to Cropland, Grassland, Settlement - as Baseline.
- Deforestation to Wetland – Baseline projection emissions and areas used to calculate an average value for emissions per ha for deforestation to wetland emissions. This was then applied to the annual forest to bog restoration rates in each archetype under the transitions (calculated in the peatland restoration areas).
- Bioenergy crops – Miscanthus and SRC emissions savings are calculated using the same models as for the 7th Carbon Budget, using the planting areas calculated in the land use change areas for the transitions. SRF emissions calculated using the same approach for woodland creation. A wide variety of species and yield classes have been proposed for SRF in the UK and Beech YC12 was assumed for this project (see footnote to Agroforestry).
- Hedgerows – Emissions are calculated using the same model as for the 7th Carbon Budget, with areas calculated as described in Section 6.1. Biomass carbon stock changes are calculated assuming the change is from shrubby grassland to hedgerow. Soil carbon stock changes use the value from Biffi *et al.*, (2022) for annual SOC sequestration rates beneath hedgerows for a 37-year-old hedge.
- Peatland restoration – The areas of peatland restoration calculated for the land use change areas are based on the 1km rasterised organic soils data used in defining the archetype locations. To calculate the emissions, the more detailed organic soil map shapefiles and rewetting data are used to determine the peatland condition category areas in each archetype in 2021 (consistent with the approach used in the Baseline to disaggregate the DA emissions to archetypes). As for the land use change areas, areas of peatland restoration are calculated for each condition category, based on the CB7 restoration rates. This was applied to Archetypes 1, 2, 11 and 12 only (other archetypes include very minimal organic soil areas by definition). As for the Baseline projection, the areas of restoration of each condition category are used to calculate the changes in emissions from the 2021 values, for each archetype.
- Other cropland, grassland, settlement emissions – The same approach is used as in the Baseline pathway – i.e. the DESNZ Central scenario is used to calculate average per km^2 emissions for cropland, grassland and settlement per DA, which are used to adjust the 2021 emissions in each archetype according to how much land has changed to/from those land uses.
- Indirect N_2O – as Baseline.

Figure 53 shows the LULUCF emissions as totals and per area for each archetype under the transition pathways. Archetypes 1 and 2 show much greater reductions in emissions by 2050 compared to the Baseline due to the higher rates of peatland restoration under the transitions. Archetypes 3 and 4 are similar to their Baseline projections but still show greater increases in sequestration by 2050 under both transitions for Archetype 3, and transition 2 for Archetype 4. Archetypes 5, 6 and 7 have much higher sequestration rates under the transitions (particularly transition 1 for Archetype 6) due to the increased rates of woodland creation, agroforestry and bioenergy crop planting. Archetype 9 changes from a net emitter under the Baseline pathway to net sequestration by 2050 under both transition pathways, due to bioenergy crop planting in transition 1 and increased woodland creation rates in transition 2, as well as the addition of agroforestry and increased hedgerow lengths in both transitions. The two NI Archetypes, 11 and 12, both see substantial reductions in emissions under the transition pathways, with Archetype 11 becoming a net sink by 2050, and Archetype 12 close to zero emissions.

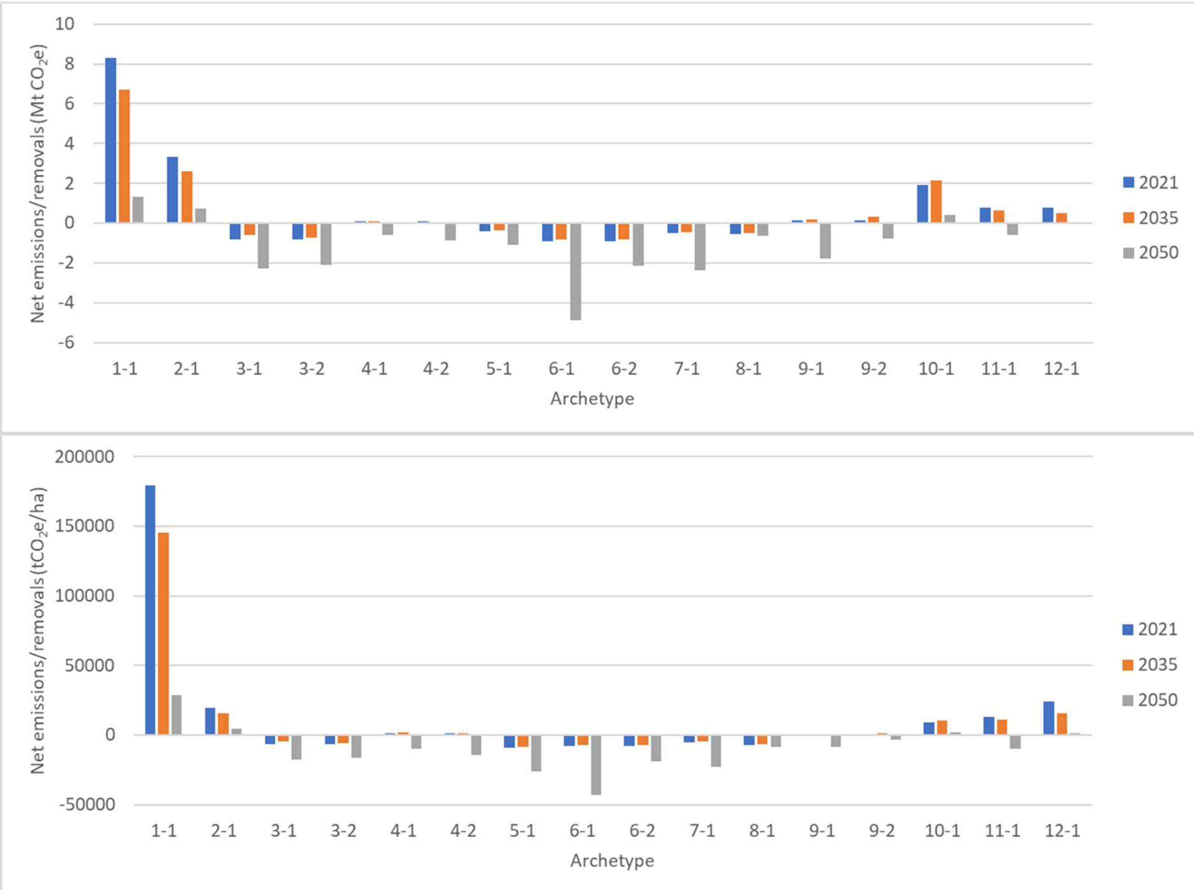


Figure 53 (a) Total GHG emissions by archetype and (b) GHG emissions per km^2 by archetype in 2021, 2035 and 2050

Archetypes: 1-Lowland organic soils; 2- Upland organic soils; 3- Intensive grassland; 4- Suburban fringe; 5- Hilly farmland; 6- Open pasture; 7- Enclosed pasture; 8- Acid upland grassland; 9- Arable on chalk/clay; 10- Arable on sandy soils; 11- Lowland agriculture in Northern Ireland; 12- Uplands in Northern Ireland.

Different measures drive these changes in emissions. Figure 54 shows the change in emissions at 2050 under the transitions compared to the Baseline, split by measures causing these changes, for Archetypes 3, 6 and 9. This highlights that in Archetype 3, while the two transition pathways lead to similar impacts on LULUCF emissions, in pathway 1 this is driven primarily by woodland creation, whereas in transition 2 this is due to the increase in bioenergy crop production. In Archetype 6 there is a large reduction in emissions by 2050 under transition 1 due to increased woodland creation rates, whereas under transition 2 the net change is minimal as the increased sequestration due to agroforestry is balanced out by a reduction in sequestration from woodland creation, due to a change in tree species planted compared to the Baseline. In Archetype 9, transition 1 reductions in emissions are mainly due to the increase in bioenergy crops, and there is a smaller reduction in emissions under transition 2.

There was a 20.2-23.9 Mt CO_2e reduction in net LULUCF emissions 2021-2050. This is close to the net LULUCF emissions reduction of 30.4 Mt CO_2e estimated under the Balanced pathway in the 7th Carbon Budget, with the differences explained by the different assumptions.

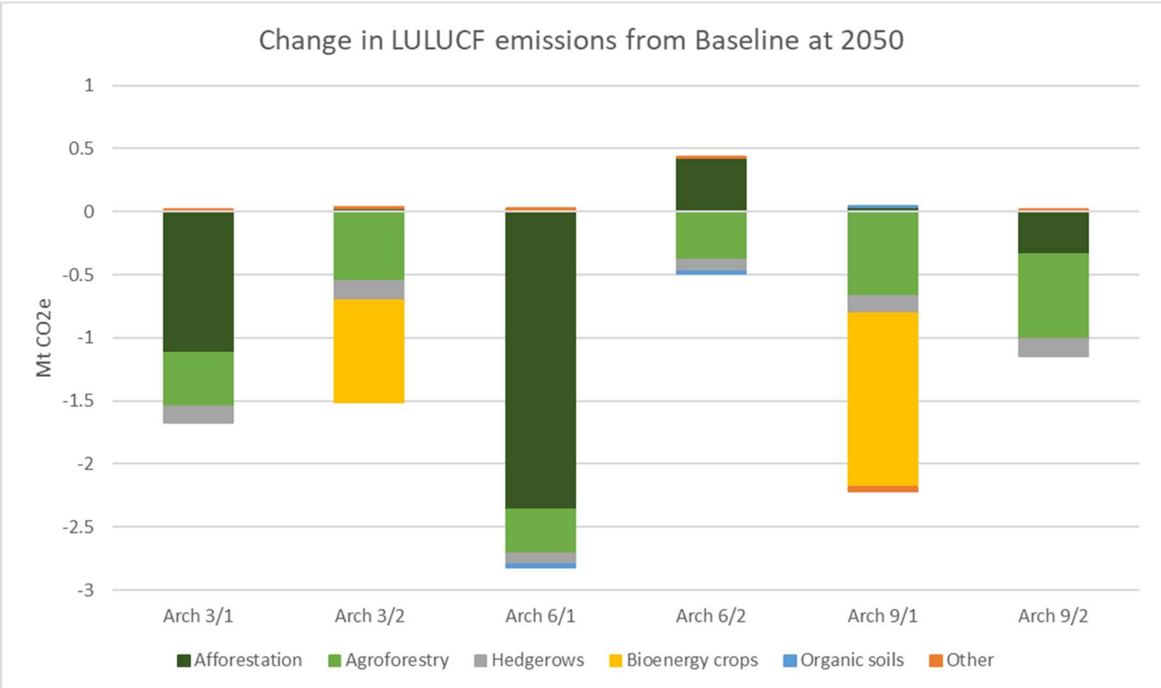


Figure 54 Changes in LULUCF emissions in 2050 compared to the Baseline emissions at 2050 split by measure.

When the Agriculture and LULUCF GHG emissions are combined into a net total, the archetype pathways show a reduction in emissions of between 0.2 and 7 Mt CO_2e each, with five pathways moving from a net source to a net sink (Archetypes 4/pathway 2, 5, 6/pathway 1, 6/pathway 2, 7) (Figure 55). There was a 23.8-28.1 Mt

CO_2e reduction in net emissions in total. This is 45-53% of the net emissions reduction estimated under the Balanced Pathway in the 7th Carbon Budget.

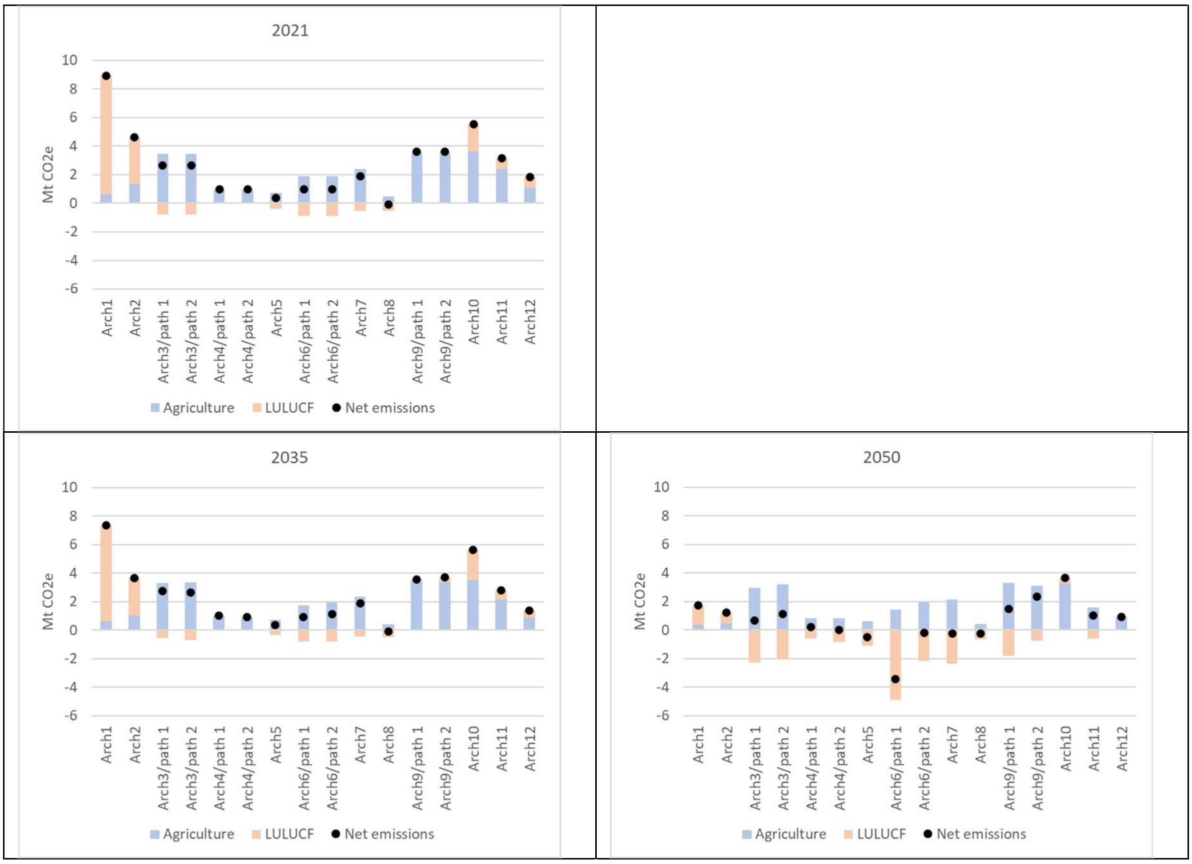


Figure 55 Combined LULUCF and Agriculture emissions under transition pathways in 2021, 2035 and 2050.

Archetypes: 1-Lowland organic soils; 2- Upland organic soils; 3- Intensive grassland; 4- Suburban fringe; 5- Hilly farmland; 6- Open pasture; 7- Enclosed pasture; 8- Acid upland grassland; 9- Arable on chalk/clay; 10- Arable on sandy soils; 11- Lowland agriculture in Northern Ireland; 12- Uplands in Northern Ireland.

6.5 Agricultural ammonia emissions

Agricultural ammonia emissions for the transition pathways were calculated in the same way as for the Baseline.

Ammonia emissions reduce by 2050 across the archetype transitions (Figure 56), with the exceptions of Archetype 6/ pathway 2 and Archetype 9/ pathway 1 which show small increases in emissions (although lower increases than under the Baseline projection).

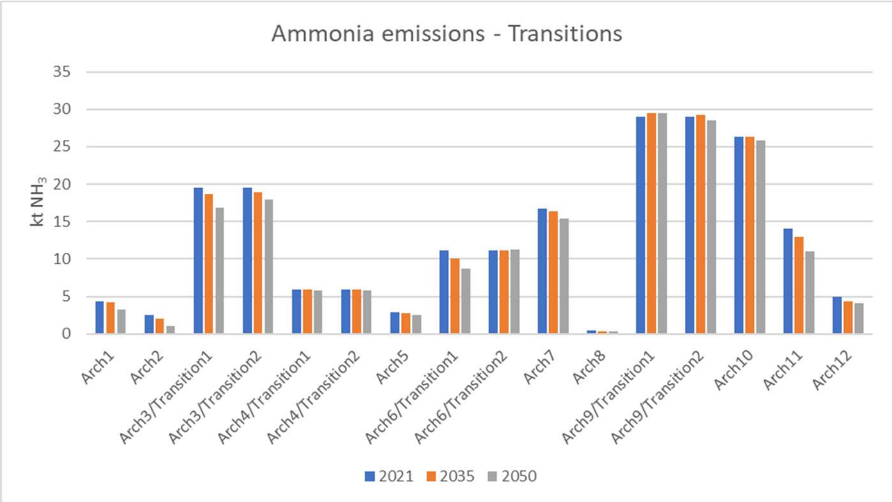


Figure 56 Agricultural ammonia emissions in 2021, 2035 and 2050 under Transition pathways

Archetypes: 1-Lowland organic soils; 2- Upland organic soils; 3- Intensive grassland; 4- Suburban fringe; 5- Hilly farmland; 6- Open pasture; 7- Enclosed pasture; 8- Acid upland grassland; 9- Arable on chalk/clay; 10- Arable on sandy soils; 11- Lowland agriculture in Northern Ireland; 12- Uplands in Northern Ireland.

6.6 Ecosystem Service Metrics

Methodology

We built on the conversion of transition pathway activities into land cover changes described above to derive new dominant land cover amounts for each archetype. Most of these are described in Section 4.6, but in addition we assumed that both upland and lowland peat restoration activities would create land similar to the 'Mountain, heath and bog' land cover class in terms of ecosystem services. 'Bioenergy – short rotation forestry' class was assumed to be equivalent to 80% coniferous woodland and 20% of the land cover class from which it was changing (improved grassland, arable or semi-natural grassland). Additionally, as short rotation coppice and *Miscanthus* for bioenergy are managed perennial crops they are assumed to remain as cropland. Whilst this potentially underestimates their impact on ecosystem services, this is the most reasonable assumption to make in terms of assignment to an existing land cover class, in the absence of equivalent spatial data on their current distribution.

To examine the ecosystem service consequences of archetype transitions, the same method was followed as for baseline land changes in 2035 and 2050 (Section 4.6): the land cover changes prompted by actions within each transition were then used to adjust the number of cells dominated by each land cover, and these were used to weight averages for each ecosystem service for each archetype. Results were similarly scaled to assess ecosystem service delivery between archetypes.

Results

Transition pathways resulted in larger percentage changes in ecosystem service provisions from 2021 to 2035 (Figure A2) and 2050 (Figure 57) compared to the baseline pathway, with some change evident across most archetypes. Land cover diversity tends to increase within archetypes, and this is specially marked in open and enclosed pasture landscapes (Archetypes 6 and 7) and lowland agriculture (Archetype 11). Changes in ecosystem service profile are most marked for carbon storage and soil-based services, e.g. nitrogen and water retention, in degraded lowland organic soils (Archetype 1), and open pasture on the upland fringe (Archetype 6/1), most likely due to peat restoration activities in degraded organic soils, and tree planting on the upland fringe. In many pathways there is a shift from productive land uses to a more multifunctional landscape, and one which can deliver more carbon storage; therefore, productive ecosystem services decrease over quite a few archetypes, including degraded lowland organic soils (Archetype 1), acid grassland on hilly uplands (Archetype 8), and lowland agriculture (Archetype 11). These plots also show that the relative change in species richness services tends to be very small (<5%) across all archetypes, apart from pollination service which is more closely tied to certain land uses and can be seen to increase across a few archetype transitions, including degraded lowland organic soils (Archetype 1), intensive grassland (Archetype 3/1), and open pasture of the upland fringe (Archetype 6/2).

The directional baseline and transitional change for each ecosystem service between 2021-2035-2050 is shown in Figure 58 across all archetypes, and for an example for an archetype which has two alternative transitions in Figure 59. The baseline and directional % change for each ecosystem service for each individual archetype are shown in figures A3-A13 in the Appendix. It should be noted that the scales on the plots for each ecosystem service are very variable, and therefore these plots do not clearly show magnitudes of change.

Over all archetypes, transitions lead to increases in carbon storage and soil ecosystem services over and above baseline changes, with the significant proportion of this change occurring between 2035 and 2050. For instance, carbon storage increases by 12.5% between 2021 and 2050 and avoided erosion by around 8%, whereas they increase by a much smaller extent under the baseline pathway. Recreation also increases more under transition pathways, but only by a relatively small 1%. Production services decrease between 8.4 and 15.4% by 2050 under transitions, in line with a reduction in arable and improved grassland area. Most species richness measures decrease to a very small extent under transition pathways between 2021 and 2050, with most declining between 0.03 and 0.4%. Species richness changes are usually small, as they are averaged across the group's constituent species, which may have varied or contrasting responses to land use change. Small changes are also to be expected given the formulation of this metric – changes of absolute values of one or more would be equivalent to local extirpation of one species across all 1km squares within the archetype, which is unlikely. The only group where average species richness increases as a consequence of transitions is woodland bird species richness, by 0.15%, however this is similar to the increase under baseline woodland creation. Average farm bird species richness decreases to the largest extent under transition pathways, however this is only by 1.3%, commensurate with decreases in agricultural area. The responses of species richness measures were more variable under the baseline, either decreasing to a lesser extent, or in the case of vertebrate species group diversity, mammal, herptile and farm bat species richness very slightly increasing. Predicted bee and natural enemy occurrence similarly decrease to a greater extent under transition pathways, but by a relatively small 1.2 and 0.9% respectively, however pollination increases by 5%, around 5x as much under transition pathways compared to the baseline.

The direction of change for individual transitions and archetypes is quite variable (Figures A3-A13), however, most show increases for carbon and soil related services to a greater extent than the baseline, with the exception of Archetype 2 (Upland organic soils) which sees reductions in all under transitions, and Archetypes 7, 8, 10 and 12 have reductions in one or two of these services. Similarly to the national level, productions services tend to decrease and species richness responses are quite variable.

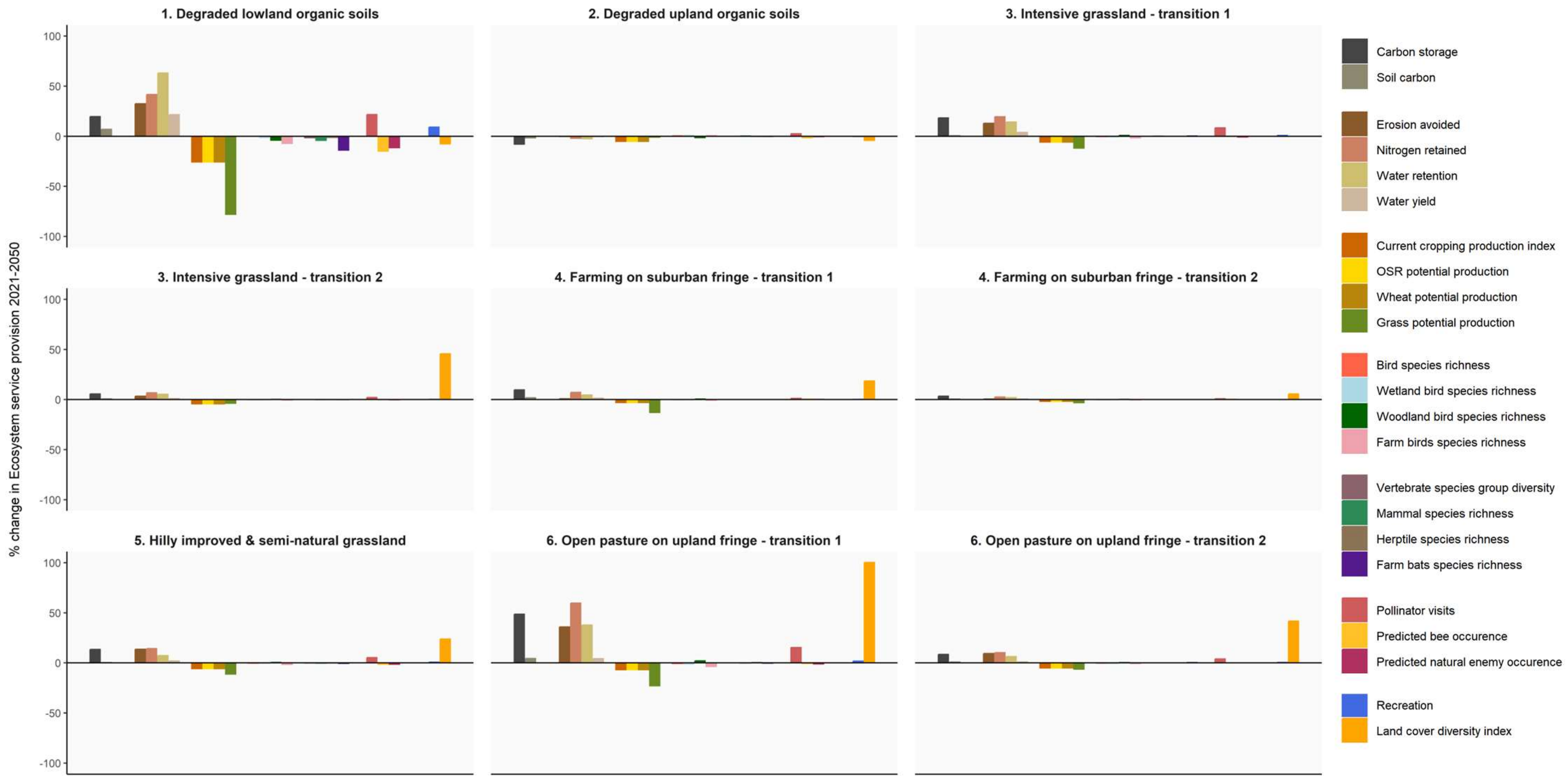


Figure 57 See Below

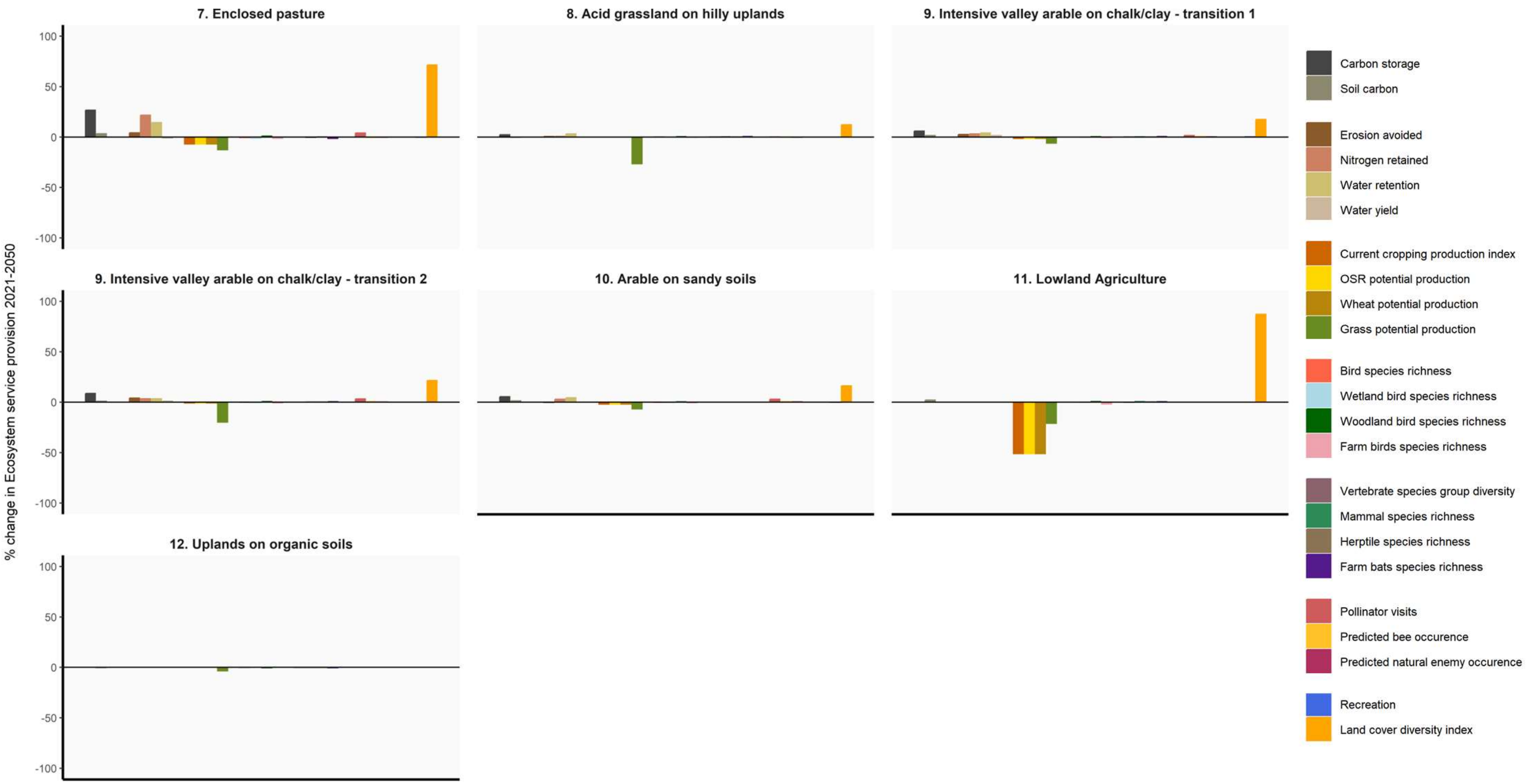


Figure 57 The relative percentage change in ecosystem services within each archetype between 2021 and 2050, under transition pathways (encompassing baseline change).

As with Figure 19, ecosystem services which have not been possible to calculate are not included i.e. all run-off and invertebrate species richness services, pollination and recreation for: Northern Irish archetypes 11 and 12; arable production for archetype 8 (as this archetype has no arable land); and grass potential production for archetype 8, as this archetype has <1 km^2 of improved grassland in 2050.

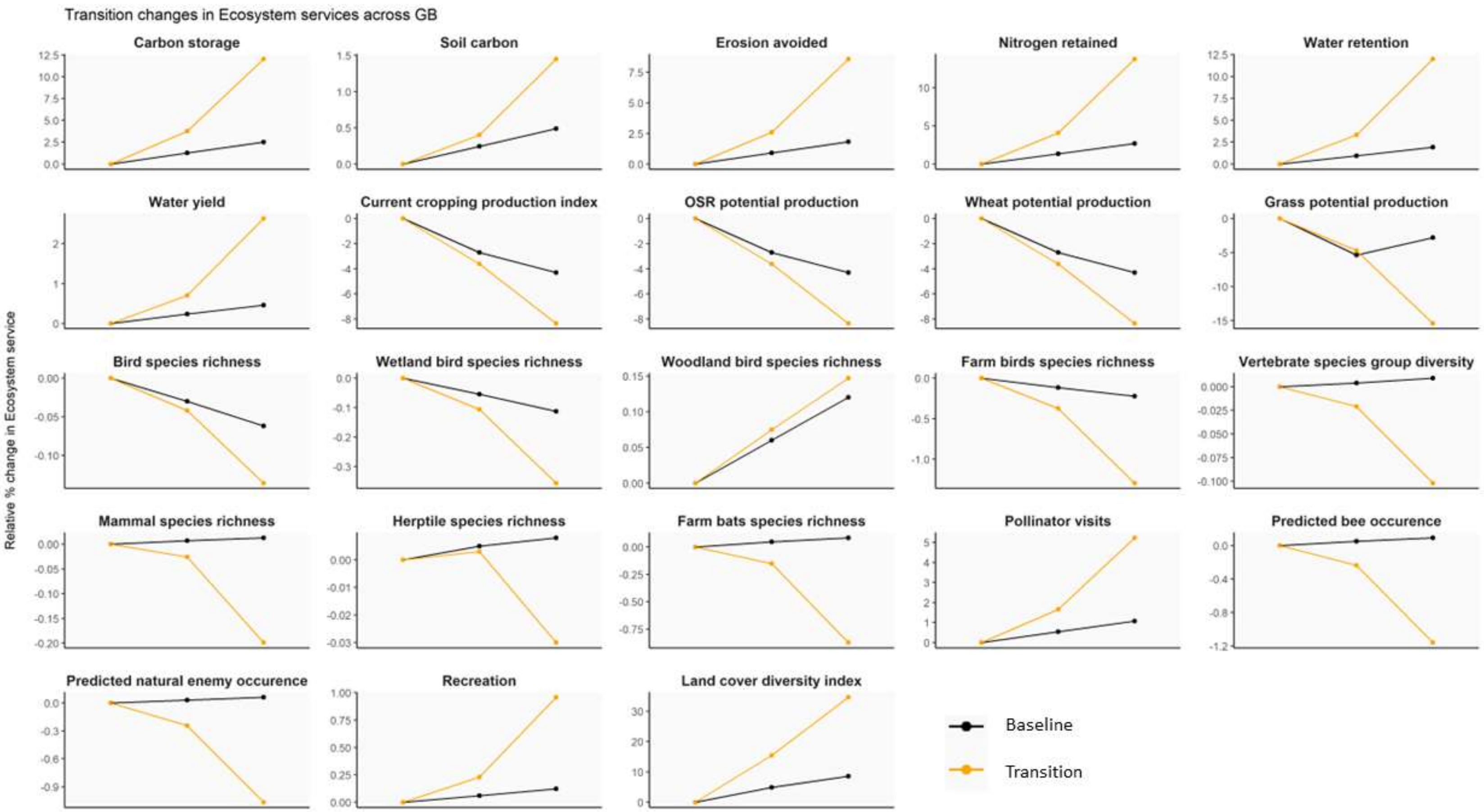


Figure 58 Relative percentage change in ecosystem service provision across all archetypes under baseline (black) and transition (orange) pathways, from 2021 to 2035 and 2050.

All transition pathways across all archetypes have been averaged, including transition pathways of the same archetype, to represent an averaged transition outcome.

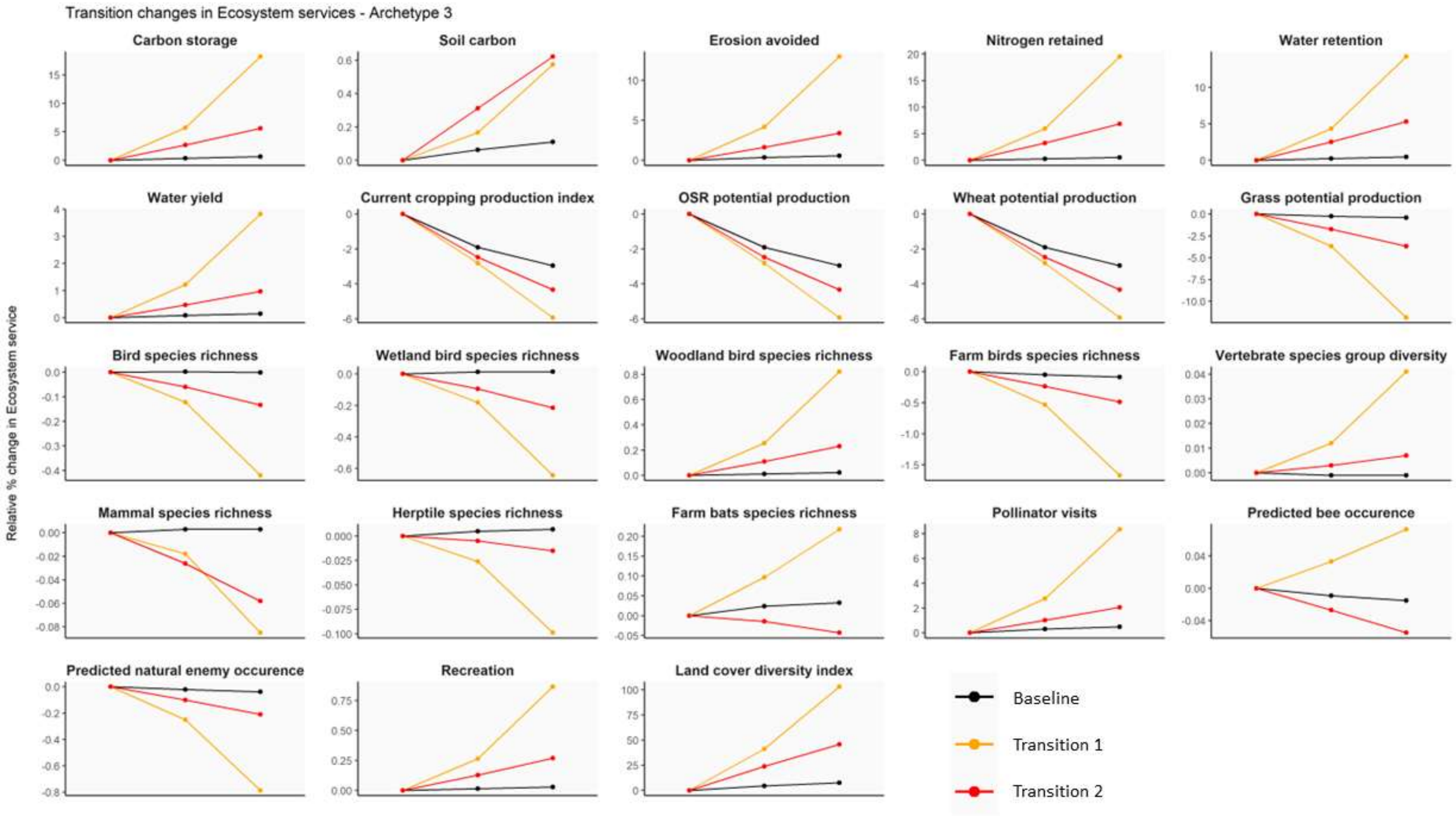


Figure 59 Relative percentage change in ecosystem service provision across all archetypes under baseline (black) and transition (orange and red) pathways, from 2021 to 2035 and 2050, for Archetype 3.

Archetype 3 was used to illustrate the changes over the timepoints for an individual archetype as it has two possible transition pathways, and is a major archetype, representing a large proportion of the rural UK.

6.7 Soil Carbon

Methodology

The impacts of land use transition on SOC were assessed and results were generated for years 2021, 2035 and 2050. Most of the modelling processes were the same as above in Section 4.7. The DOM:ROM ratios and the monthly OC inputs were recalculated at 2035 and 2050 based on the land use transition pathways, with a linear transition slope implemented over the intervening years. Climate inputs remained the same.

Results

The impacts of land use transition on SOC density (t ha^{-1}) were very small. In 2035, following land use transition pathway 1, three of 12 archetypes were predicted to increase in SOC density compared with the Baseline pathway, including Acid grassland on hilly uplands in GB (Archetype 8), Intensive and valley/floodplain arable on chalk/clay soils in England (Archetype 9/1) and Arable on sandy soils in England and Scotland (Archetype 10). All the other archetypes were predicted to decrease in SOC density compared with the baseline pathway. However, the changes in SOC density were very small (< ±0.1 t ha^{-1}) (Figure 60a). The largest increase in SOC density (0.006 t ha^{-1}) was predicted in Archetype 10 (arable on sandy soils in England and Scotland). The largest decrease (0.08 t ha^{-1}) in SOC density was predicted in Archetype 1 (Degraded lowland organic soils) and Archetype 2 (Degraded lowland organic soils), which was mainly due to the reduced intensive grassland or coniferous woodland.

In 2050, the changes were predicted to become greater but still less than ±0.6 t ha^{-1} (Figure 60b). Four of 12 archetypes were predicted to increase in SOC density compared with the baseline pathway, including Farming on suburban fringe in England (Archetype 4/2), Acid grassland on hilly uplands in GB (Archetype 8), Intensive and valley/floodplain arable on chalk/clay soils in England (Archetype 9/1) and Arable on sandy soils in England and Scotland (Archetype 10). All the other archetypes were predicted to decrease in SOC density compared with the baseline pathway. The largest increase in SOC density (0.03 t ha^{-1}) was predicted in Archetype 10 (arable on sandy soils in England and Scotland). The largest decrease (0.6 t ha^{-1}) in SOC density was predicted in Archetype 1 (Highly degraded lowland organic soils in GB), which was mainly due to the vastly reduced intensive grassland.

Small changes in SOC density could lead to great changes in the total SOC stocks in the archetypes when the land area is taken into account. The changes in SOC stocks were predicted to be less than ±0.14 Mt and ±0.5 Mt in 2035 and 2050, respectively (Figure 61). The trends in SOC carbon stocks changes were the same as predicted in SOC density. The largest increase in SOC stocks (0.01 Mt in 2035 and 0.05 Mt in 2050) was predicted in Archetype 10 (Arable on sandy soils in England and Scotland). The largest decrease in SOC stocks (0.1 Mt in 2035 and 0.5 Mt in 2050) was predicted in Archetype 2 (Degraded upland grazing land and forest on organic soils in GB) due to the decrease in SOC density and the large land area in Archetype 2.

The modelling results showed negative impacts on SOC stocks in most archetypes, especially when pasture is reduced or transferred to woodland when a decrease in SOC was predicted in the short term. However, it is likely that an increase in SOC will start to occur when the woodland is well established (Garnett *et al.,* 2017). It would have been beneficial to model the SOC changes for a longer term to account for the full benefits of the land use transition pathways. It is also highlighted that the changes in the SOC pools following land use transition were based on many assumptions: for future research it would be good to compare these results with measured data based on field experiments to adjust the model input parameters.

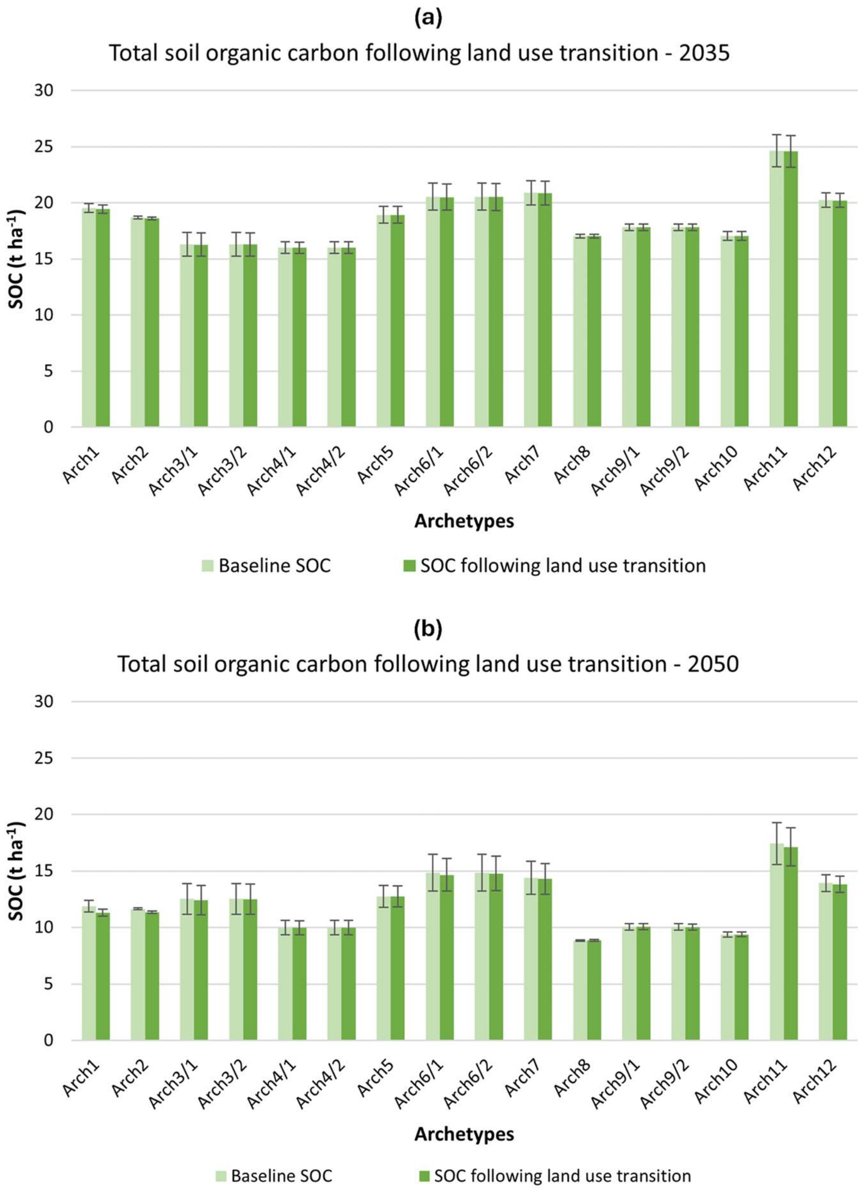


Figure 60 Baseline (*light green*) total soil organic carbon stocks (t ha^{-1}) compared with the total soil organic carbon stocks (t ha^{-1}) following land use transition (*dark green*) in 12 archetypes in year 2035 (a) and 2050 (b).

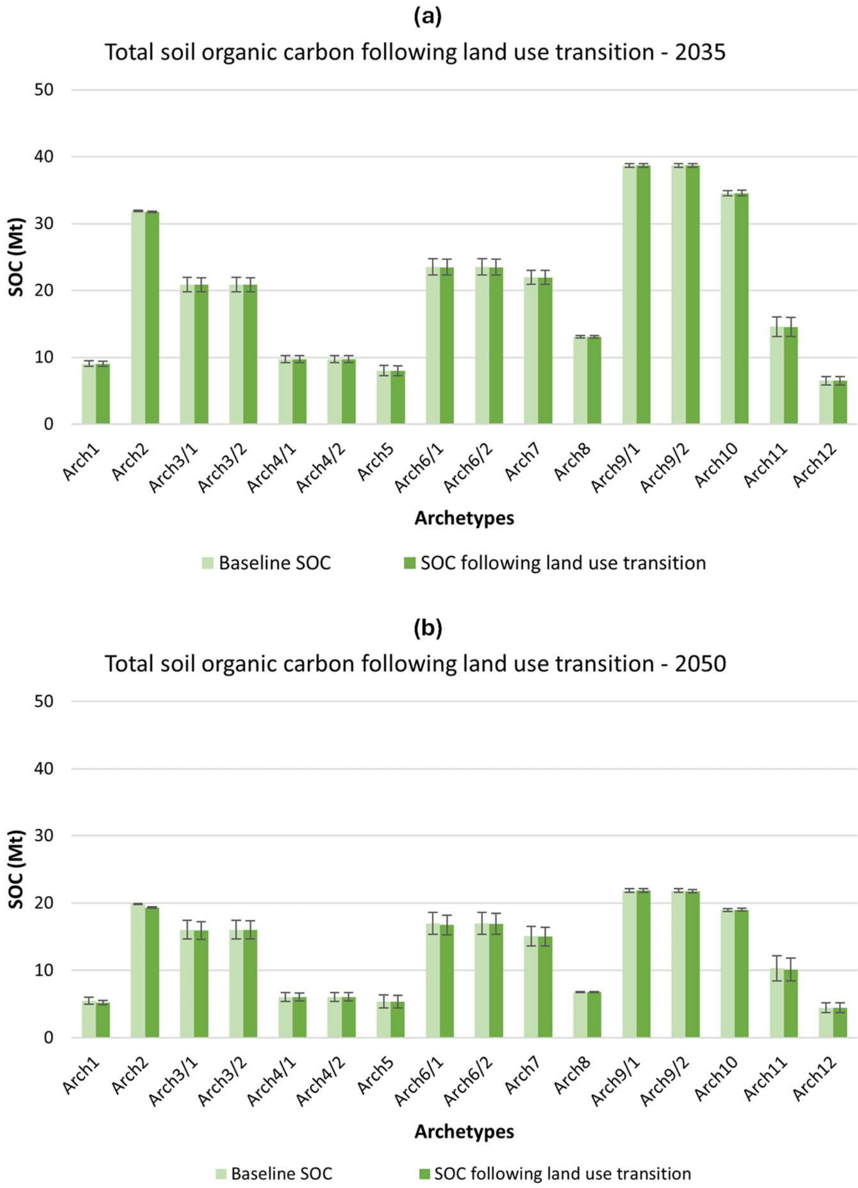


Figure 61 Baseline (*light green*) total soil organic carbon stocks (Mt) compared with the total soil organic carbon stocks (Mt) following land use transition (*dark green*) in 12 archetypes in year 2035 (a) and 2050 (b).

Archetypes: 1-Lowland organic soils; 2- Upland organic soils; 3- Intensive grassland; 4- Suburban fringe; 5- Hilly farmland; 6- Open pasture; 7- Enclosed pasture; 8- Acid upland grassland; 9- Arable on chalk/clay; 10- Arable on sandy soils; 11- Lowland agriculture in Northern Ireland; 12- Uplands in Northern Ireland.

6.8 Costs and benefits

Methodology

To examine the impact on costs and benefits of the archetype transitions, the same method was followed as for baseline land changes in 2035 and 2050 (Section 4.8):

- The six impact categories have been used throughout analysis to ease interpretation of the results.
- All values are in 2023 prices to allow comparison and strip out the impact of inflation.
- Baseline and transition pathways land cover, agricultural projections and emissions data are used to profile impacts to 2050.
- Two transition pathways were modelled for each archetype- where only a single pathway was described in Section 5 this has been replicated (applicable to Archetypes 1, 2, 5, 7, 8, 10, 11, 12).

Note that the results in the following section relate to the 2050 scenario. The same conclusions are reached when looking at 2035 (following the same rate of change described in Sections 5 and 6) and can be explored through the Valuation model.

Results

Figure 62 shows the change in costs and benefits for all 12 archetypes in 2050 for Transition 1 and 2 relative to the 2050 baseline for the six impact categories described in Section 4.8 . As can be seen, there is a substantial increase in net benefits for both Transition pathways compared to the baseline (94% for Pathway 1 and 81% for Pathway 2).

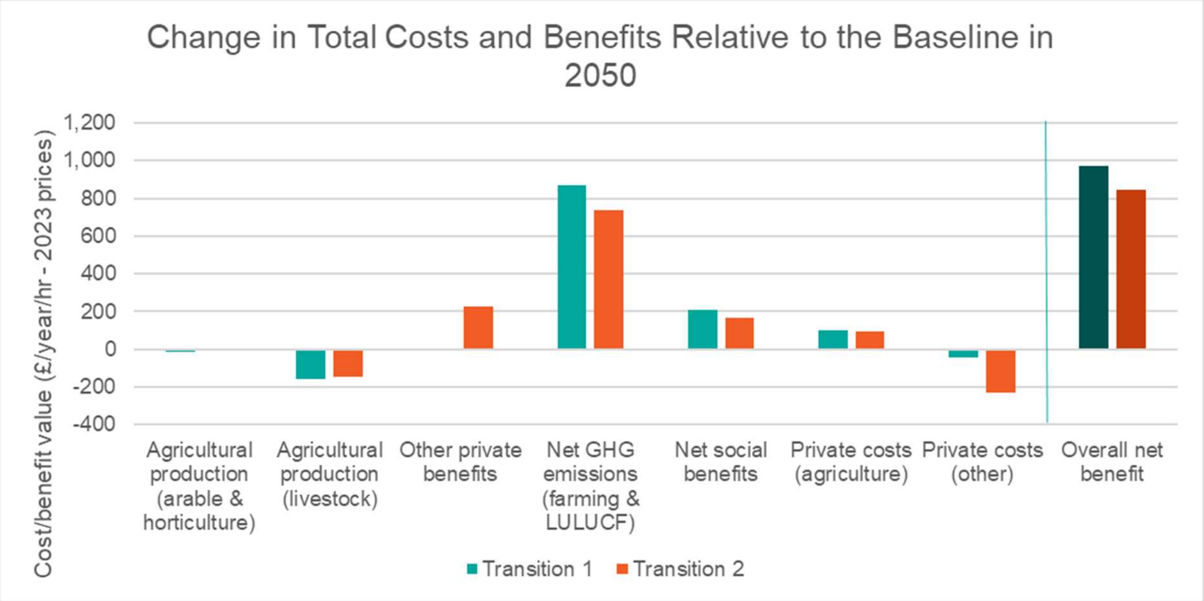


Figure 62 Change in Total Costs and Benefits Relative to the Baseline in 2050.

This increase is largely driven by net GHG sequestration. Net GHG emissions increase under the Baseline pathway between 2021 and 2050 due to higher farming emissions and the higher price of carbon in 2050 relative to 2021. For the transition pathways however, as set out in Sections 6.3 and 6.4, emissions in farming fall and shift to net sequestration in the LULUCF sector across the archetypes. Similarly, there is an increase in social benefits for the two transition pathways relative to the baseline, driven by the increased rates of woodland creation, agroforestry and restoration of semi-natural habitats.

Private benefits (other than agricultural production) increase marginally under Transition 1 and to a greater extent in Transition 2. This reflects the ambitious increase in solar PV electricity generation and extra income that can be earned by land managers. It should be noted however that there is a reduction in agricultural production across the two pathways driven by the modelled reduction in both arable land and livestock numbers. This is matched by a reduction in private agriculture costs, though the net effect is negative for farmers. Finally, private costs excluding agriculture in Transition 1 are only marginally larger than under the baseline, for Transition 2 however, private costs increase, again due to the upfront and maintenance costs involved in the additional solar generation (though less than the additional income received).

Overall, this shows that both transition pathways deliver a significant net gain to society. An important reflection worth stating however is that while the losses to agricultural revenue are outweighed by increases to social benefits, these are not adequately compensated by private benefits (excluding solar) and so those expected to make the land use and land management changes underpinning the pathways, will not always benefit financially. This highlights both the potential importance of solar as a revenue stream and the need for sufficient financial incentives available to land managers to maintain and enhance nature and the wider environment.

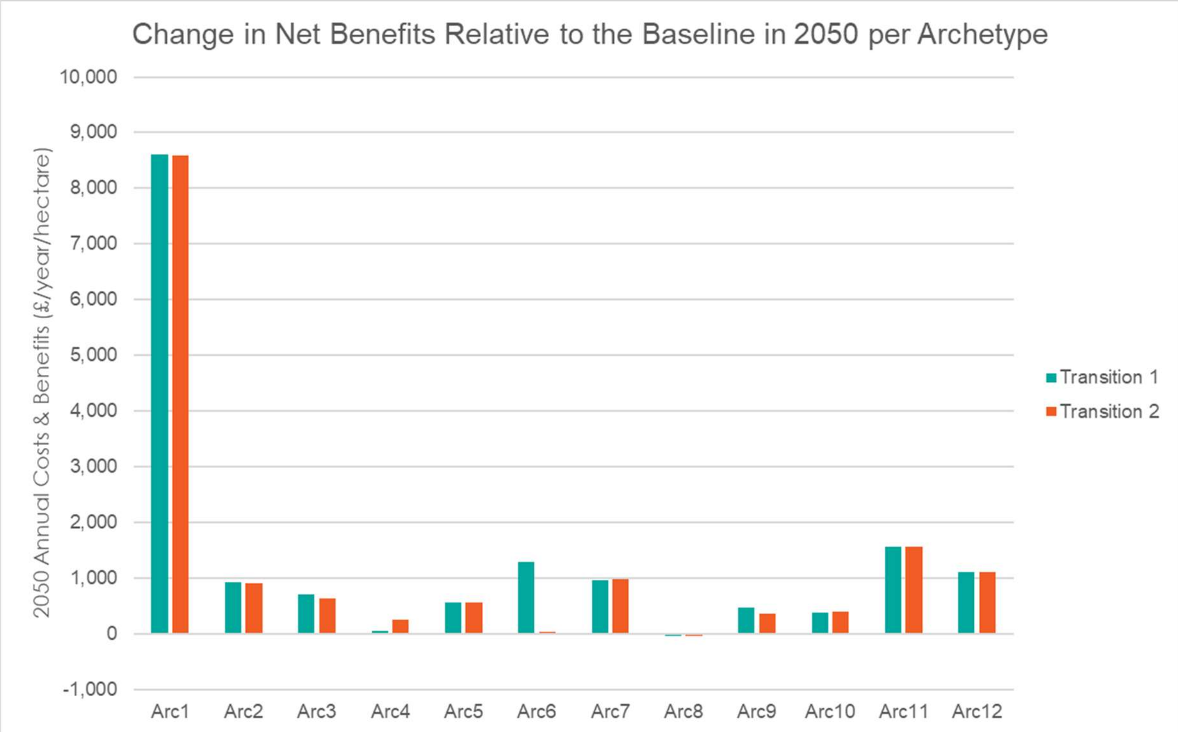


Figure 63 Change in Net Benefits Relative to the Baseline in 2050 per Archetype. *Archetypes: 1-Lowland organic soils; 2- Upland organic soils; 3- Intensive grassland; 4- Suburban fringe; 5- Hilly farmland; 6- Open pasture; 7- Enclosed pasture; 8- Acid upland grassland; 9- Arable on chalk/clay; 10- Arable on sandy soils; 11- Lowland agriculture in Northern Ireland; 12- Uplands in Northern Ireland.*

Looking individually at the 12 archetypes, as shown in Figure 63, net private and social benefits relative to the Baseline in 2050 are positive for each, with the exception of Archetype 8, which has a minor reduction for both transition pathways primarily due to a high relative reduction in livestock production. For the remaining archetypes, the uplift in net benefits for both transition pathways typically ranges from £500 to £1,500 per hectare, with the clear exception being Archetype 1. As shown in Figure 64 and Figure 65 below which split net benefits into the 7 impact categories[17], this is driven primarily by net GHG emissions, with the archetype transitioning from a net source to a net sink of emissions. It is interesting to note that there are only marginal differences between the two transition pathways for each archetype except for in Archetype 6 which, as shown in Figure 64 and Figure 65 below, again is explained primarily by changes to net GHG emissions - in particular, the higher rates of woodland creation, agroforestry and bioenergy crop planting sequestration occurring in transition 1.

[17] Private costs have been separated into "Private costs (agriculture)" which includes costs related solely to agricultural production and "Private costs (other)" which includes the other private costs including nature restoration and management as well as solar PV installation and maintenance.

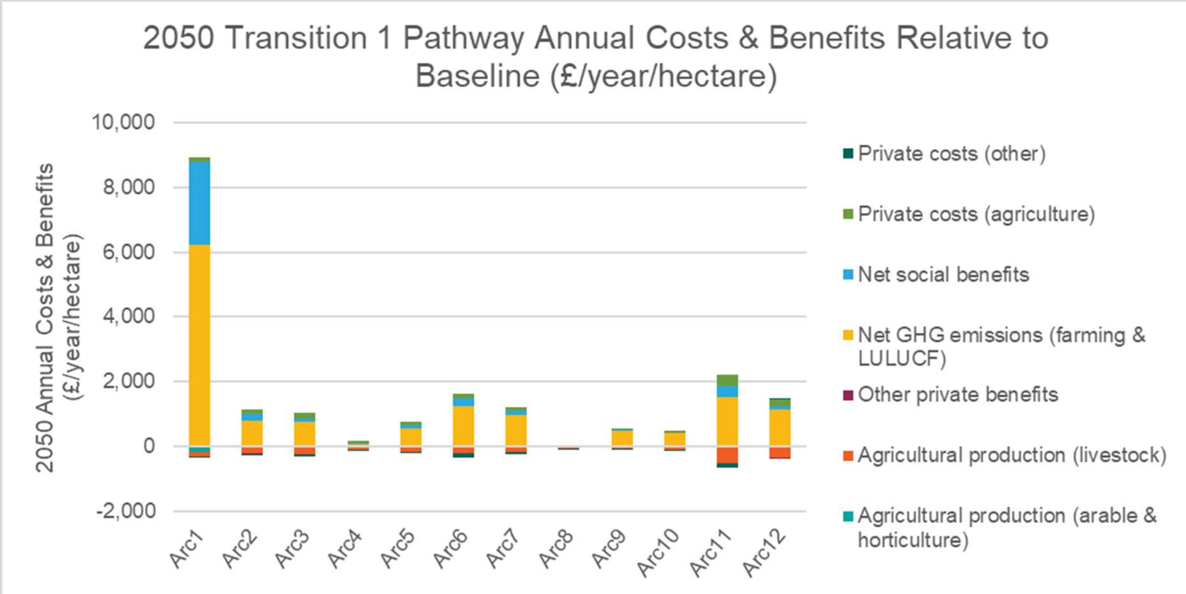


Figure 64 Transition 1 Pathway Annual Costs & Benefits Relative to Baseline.

Looking at just the transition 1 pathway, net GHG emissions make up the majority of the uplift in net benefits for all archetypes, in a relatively proportional manner, making up about 85% of the total uplift. This isn't surprising given the high carbon price in 2050 in DESNZ's carbon price series[18]. The other impact categories also show a consistent pattern across archetypes, with the largest variation occurring for net social benefits (all positive) and livestock production (all negative).

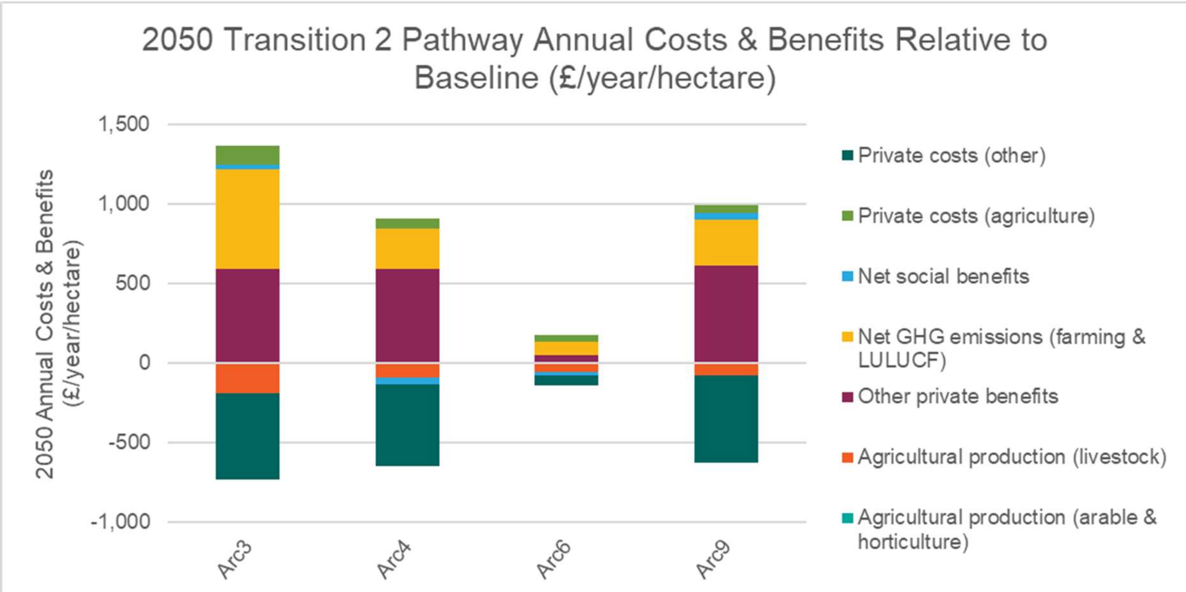


Figure 65 Transition 2 Pathway Annual Costs & Benefits Relative to Baseline.

[18] https://www.gov.uk/government/publications/valuing-greenhouse-gas-emissions-in-policy-appraisal/valuation-of-greenhouse-gas-emissions-for-policy-appraisal-and-evaluation

A very similar pattern across archetypes is found for the transition 2 pathway. A notable exception is the additional private benefits in Archetypes 3, 4 and 9 due to the modelled increase in solar PV electricity generation. Correspondingly, the private costs relating to solar installation and maintenance are greater for these archetypes but these are more than offset by the benefits of solar PV.

7. Climate change risks

The results for the Baseline and Transition metrics assumed no projected climate change. However, the CCC wished to know how future climate risks could affect carbon budget pathways and environmental goals for the land use and agriculture sectors, and these risks are explored in this section.

The teams at UEA and UKCEH mined existing databases, where available, to quantify climate change risks to the Baseline and Transition metrics in the various archetypes. Expert judgement was used to quantify the interaction between these climate change risks and the proposed land use transitions. A full quantitative analysis of this requires a spatially explicit treatment of the transitions, which was beyond the scope of the project. However, where possible, the archetypes likely to be most affected by specific climate risks have been identified, including Archetype 100 (all other rural land) where information is available.

Climate scenarios with levels of warming before 2100 of 1.5°C, 2°C and 3°C above pre-industrial were used. For some sectors additional information is provided at 2.5°C and 4°C warming as the mined data permits. The risks are generally independent of a timeline. Climate data sources vary depending on that used in the mined databases, but all are harmonised in terms of the preindustrial reference point for global warming levels.

Warming scenarios give global trends but cannot project the occurrence of short-term extreme climate events, only that the likelihood of such events will increase. Short-term extreme events will have adverse impacts on many of the mitigation activities and metrics considered in this project, for example woodland creation and agricultural production. These impacts are qualitatively discussed where possible.

7.1 Implications of Heat Stress on Livestock

Livestock, such as dairy cows, goats and sheep can all be affected by heat stress during extreme temperature events and heatwaves. As with humans, livestock also have ideal ambient temperature zones, above which heat stress can occur where livestock are not physiologically adapted or acclimatised to temperature conditions, particularly when combined with humidity. However, there is no universal threshold as this will also depend on the geographic location, animal size, physiological stage, breed, acclimatisation capacity and other factors such as the duration of heat events and whether nighttime cooling occurs (Asseng *et al.,* 2021; Cooke & Rivero, 2023; North *et al.,* 2023). For example, in cattle the ideal ambient temperature is reported as 5°C and 25°C for the UK, with cows starting to suffer when temperature is about 19-20°C, and for shorn sheep the upper critical level is reported as 29°C (For Farmers, 2023; Farmers Guide, 2023).

Whilst increasingly warm temperatures may present some opportunities such as livestock being able to be outdoors for longer periods (CCC, 2021) it is also likely that at higher global warming levels the number of days with extreme temperature and heatwave events, that can have detrimental impacts on livestock, will increase. In south-east England temperatures above 35°C become increasingly common with climate change (CCC, 2021). Kennedy-Asser *et al.,* (2022) estimated that under 3°C global mean warming the extreme mean (days exceeding the 95th percentile) of summer maximum temperature in Greater London, the South East, East and West Midlands regularly approaches 33°C, exceeding the general comfort zones highlighted for livestock (Asseng *et al.,* 2021).

Key impacts of higher temperatures and heat stress in livestock include reduced welfare (i.e., discomfort, though potentially with no long-term repercussions). Outside of their thermal comfort zone it has been reported that livestock eat 3-5% less per additional degree of temperature (Bezner *et al.,* 2022), leading to reduced productivity (milk yields) and decreased fertility (Polsky *et al.,* 2017). Other health risks can also increase such as mastitis, increased susceptibility to disease, heat stress, heat stroke and mortality (CCC, 2021).

Whilst global studies highlight risks are far higher in countries with climates with higher temperature and humidity (Bezner *et al.,* 2021; North *et al.,* 2023) evidence of impacts on livestock in the UK is already available. For example, in the 2023 heatwave in the UK, where unprecedented and record-breaking temperatures were seen in July, Cooke & Rivero (2023) estimated that over 25% of weather stations indicated thresholds were exceeded for severe heat stress risk to livestock and over 5% of weather stations indicated thresholds were exceeded for extreme heat stress risk to livestock. Studies across nine dairy farms in England showed that cows experienced heat stress for 99 days during 2022, and grazing cows heat stress for 37 days. Predicted average milk yield losses of 138 litres and 129 litres were reported for housed and grazing cattle respectively, with economic losses of £24,000 to £90,000 (Farmers Guide, 2023). The summer 2022 heatwave in July resulted in a decline in production of chicken meat by volume of 9.2% from the previous year, particularly in Eastern England, with heat stress leading to significant increases in mortality rates in transported chickens (Davie *et al.,* 2023).

Methods

The majority of studies focused on modelling heat stress in livestock use indicators of temperature and relative humidity, as data is usually readily available, compared to other indicators of thermal radiation, wind speed. The most used metric is the Temperature Humidity Index (THI) with various thresholds defined for levels of stress to support management and precautionary adaptations during high temperatures. THI values of 70 or less (with 70 equivalent to an average temperature of around 21°C with a relative humidity of 75%) are considered comfortable for most livestock, with increasingly high exceedance of this threshold causing moderate, high or extreme stress (Habeeb *et al.,* 2018; Asseng *et al.,* 2021; Thornton *et al.,* 2021)) and related impacts such as reduced productivity.

Following similar modelling approaches (e.g., Dunn *et al.,* 2014; Arnell *et al.,* 2021) the Heat Extreme Analysis Toolbox (HEAT) model is used to estimate the THI and frequency of days that exceed user-defined thresholds. Daily maximum temperature was taken from the UK Met Office's UKCP18 twelve-member regional climate model (RCM) ensemble at 12 km resolution (Murphy *et al.,* 2019). This data has been bias-corrected using ERA5 reanalysis (Hersbach *et al.,* 2020) following the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP) 2b bias correction method (Frieler *et al.,* 2017; Hempel *et al.,* 2013; Lange, 2018), as applied in Kennedy-Asser *et al.*, (2022). For each global warming level, daily maximum temperature data for each 30-year period, representative of the different levels of global warming above pre-industrial temperatures, were extracted. The 30-year time periods for each global warming level were based on start and end years published in Arnell *et al.,* (2021), with the exact years for each global warming level varying slightly between UKCP18 RCM simulations.

Results

Figure 66 shows the number of days where livestock would be at risk of the onset of moderate or worse heat stress levels, using the threshold of THI >70 and at risk of onset of high to extreme heat stress levels, where THI > 80. Based on Thornton *et al.,* (2021) these thresholds would be applicable to dairy and beef cattle, goats, sheep and poultry.

The maps in Figure 66 indicate that at 1.5°C livestock in majority of England and Wales, large areas of Northern Ireland and Southern Scotland could face moderate or worse levels of heat stress on 1-10 days per year, and in South East England up to 20 days per year. The average number of days at the national level are shown in

Table 10.

Limiting global warming to 2°C limits the expansion of days exceeding the moderate threshold, particularly in Scotland and Northern Ireland. At 3 and 4°C, however, the number of days per year exceeding this threshold expands even to Northern Scotland. The exceedance of the THI threshold remains highest in Southeast England, with the potential to put livestock at risk of heat stress up to 60 days per year. The severity and consequences of heat stress on livestock will accrue with higher THI levels. At 1.5 and 2°C the exceedance of days with THI >80 is very limited (less than one day per year in Southeast and parts of Central England only). However, the potential for more extreme thresholds being surpassed are higher at 3 and 4°C. With 4°C global warming there could be up to 4 days per year where livestock are exposed to temperatures and humidity that would cause extreme levels of heat stress in Southeast England.

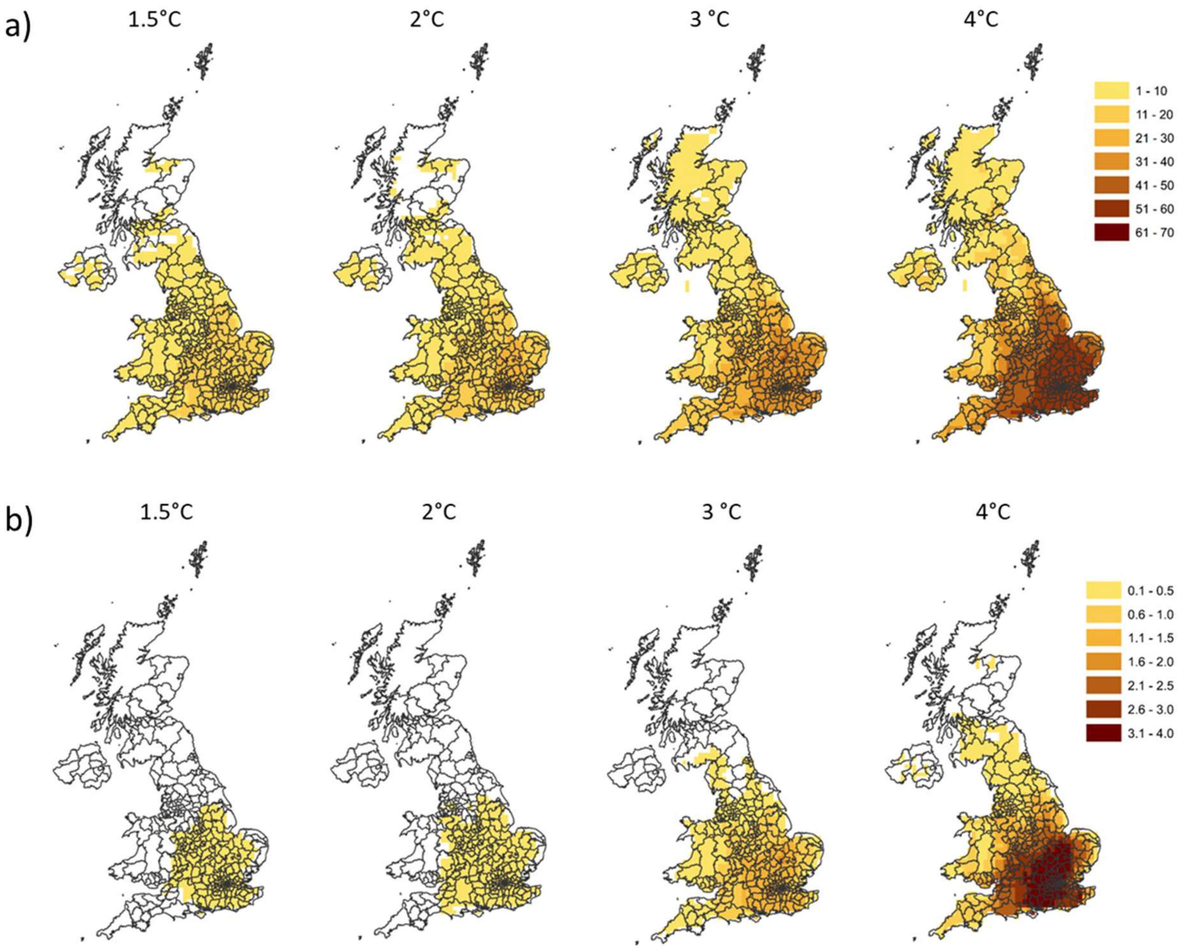


Figure 66 Annual number of days per year when livestock is at risk of onset of moderate or worse heat stress based on a) THI > 70 and b) annual number of days per year when livestock is at risk of onset of high to extreme heat stress based on a THI > 80.

Results show the 12-RCM ensemble average from UKCP18 regional climate projections at 12km for each global warming level above the pre-industrial period. Boundaries for Local Authority Districts are shown for reference. Source: HEAT model. See Kennedy-Asser *et al.,* (2022).

Table 10: The number of days per year when livestock is at risk of onset of moderate or worse heat stress based on a THI > 70, averaged across each nation (10th and 90th percentile range).

Warming Level	England	Wales	Scotland	Northern Ireland
1.5°C	8.9 (1.8, 15.6)	3.7 (2.0, 6.1)	0.6 (0.1, 1.2)	0.8 (0.1, 1.3)
2°C	12.0 (2.6, 20.7)	5.1 (2.8, 8.4)	0.8 (0.1, 1.8)	1.2 (0.2, 1.9)
3°C	23.2 (6.6, 37.0)	11.0 (6.7, 16.6)	2.5 (0.6, 4.9)	3.8 (1.6, 6.0)
4°C	37.6 (13.5, 55.5)	20.8 (13.7, 29.2)	5.5 (1.3, 10.2)	8.7 (4.9, 13.7)

Discussion and implications for the archetypes

The spatial patterns of risk are reflective of similar studies (e.g. Arnell *et al.,* 2021; Garry *et al.,* (2021)) showing heat stress risk for livestock is highest in South-East England (coinciding with areas of Archetypes 4 and 9). However, if livestock numbers and density are also considered then the South-West has been shown to be particularly vulnerable to the consequences of heat stress in cattle (Garry *et al.,* 2021). This correlates to regions dominated by Archetype 3 (intensive grassland) and high cattle and sheep numbers. Spatially, eastern and central areas of England where the exceedance of the THI thresholds are higher also correspond to large areas of Archetype 9 (Arable on chalk/clay), suggesting higher risks given the magnitude of heat stress days projected and the numbers of cattle, sheep, pigs and poultry. Conversely, the consequences of livestock heat stress would be more limited for regions dominated by Archetype 6 (open pasture) despite the livestock density in some regions, given the lower THI values and frequency of heat stress days projected for North-West England and Western Scotland, for example. However, at higher levels of 3°C and 4°C warming the potential for moderate heat stress in these regions increases, with Archetype 6 being particularly vulnerable because of its large grazing livestock herds.

Whilst the THI does not account for livestock numbers, it would be expected that through the transition pathways declines in livestock numbers across most archetypes would reduce the populations exposed and consequently the size of the population at risk of heat stress, heat stroke and mortality.

The above results may also be underestimated given the indicator employed, which excludes wind speed and solar radiation, and may underestimate risks posed to livestock on a given day. For example, Yan *et al.,* (2021) found that the alternative Comprehensive Climate Index (CCI), which includes wind and radiation, showed a better relationship with animal-based indicators of heat stress such as rectal temperature, skin temperature, and eye temperature. Other factors, such as duration of exposure to heat events and whether night-time cooling occurs will also be paramount in linking heat stress to reduced productivity and mortality (Cooke & Rivero, 2023). In the future if livestock are exposed to longer duration heat events, then cattle may also begin to acclimatise (Galán *et al.,* 2018), although little work has examined how heat stress affects an animal's natural coping behaviours or evolutionary adaptations for thermoregulation in breeding (Polsky *et al.,* 2017).

Furthermore, risks will not only be direct but can also be indirect such as the subsequent economic losses of changes in productivity to farmers. Thornton *et al.,* (2022) estimate a decline in the annual value of meat production from 2005 of 0.6 and 2.1% under warming scenarios of ~2 and 4 degree by the end of the century for the UK. Other risk factors not modelled here include that high temperatures and heatwaves can affect water supply. Availability of clean and plentiful water during heat events will be essential, with livestock requirements ranging from 6-52 litres a day depending on the type of livestock (For Farmers, 2023).

Heat can also affect the suitability of pasture and forage. An increased in dry matter could be beneficial for improving forage and livestock production but conversely weeds may also become more prominent and plants in hedgerows, such as nightshades, may be eaten as animals seek shade by hedges (CCC, 2021). Pests may also increase with warmer temperatures, for example bluetongue virus which affects cattle/sheep and is spread by the bites of midges, or blowfly. Hot weather can increase the range, mobility and survival of vector-borne diseases. In August 2022, the risk of airborne introduction of bluetongue virus to the UK through midges from the near-Continent has recently been increased to medium risk (APHA, 2022). Modelling studies also highlight how the risk of bluetongue virus will spread spatially with increased warming, with suitable regions expanding to most of the UK (except for the Scottish Highlands) during July to August with warming of 3.4°C by 2100 (Jones *et al.,* 2019).

7.2 Agricultural models for climate change impacts

Introduction

Climate change can affect agricultural production in variety of ways. These include direct effects on the ability of crops plants to grow and produce harvestable products, as well as indirect effects on the ability of farmers to manage crops in the optimal way (e.g. sowing and harvest) and the flow of ecosystem services and disservices from the wider environment (e.g. pollination and pest damage respectively). All of these interact to determine the yield of a crop (i.e. the quantity of harvestable biomass per unit area), which in turn affects socioeconomic endpoints such as economic viability of the crop for the individual farmer and the UK food supply chain and, ultimately, national food security. There are a wide variety of modelling approaches to project climate impacts on crops. However, many approaches require detailed parameterisation with known agricultural practices and are thus unsuitable for projecting into the future across large extents of gridded data where equivalent spatial data on such practices are unavailable. It is also important to select not only models that can quantify risk to current systems but those that can provide information on the viability of adaptation approaches such as switching to alternative crops that are better suited to changing local climates. We explored results from two models predicting potential crop yield of current crops and an index of crop suitability for both current and future crops.

Methods

Two models were used to assess climate risks to agriculture per archetype. These were the same pair of models used for assessing agricultural services under the baseline, namely CropNet (Hayman et al. 2024) and EcoCrop (Redhead et al. 2025).

The first of these, CropNet, assesses potential yield (outputs in tonnes per hectare) for the UK's three dominant crops (by area): winter wheat, oilseed rape and perennial ryegrass. The CropNet model is a process-based model that simulates crop growth, light interception, biomass accumulation and apportionment to harvestable yield on daily timesteps, using gridded climate and soil parameters (Hayman *et al.,* 2024). The model produces 'potential' yields, representing the maximum achievable yield under climatic constraints, and does not account for the inevitable reductions imposed by imperfect management, pests and diseases and crop nutrient requirements. However, potential yields are broadly indicative of the envelope within which farmers can feasibly work, and reductions in potential yields under climate change are strongly likely to result in reduced actual yields on the ground (Hayman *et al.,* 2024).

For assessing potential future crops, especially those not currently grown in the UK, parameterising process-based models like CropNet is challenging. Running such models over a large number of potential crops is also computationally expensive in terms of processing time and power. The EcoCrop model therefore uses a simpler approach to produce indices of relative suitability for over 160 current and potential future food crops. The model is based on an FAO database of crop climatic requirements (FAO 2022), and models built on these data which have been widely used for assessing suitability under climate change (e.g. Ramirez-Villegas *et al.,* 2013, Manners *et al.,* 2020, Taba-Morales *et al.,* 2020). The model does not attempt to predict yield, but instead quantifies the relative proximity of the climate to the crops optimal range, for both temperature and precipitation. A score of 100 indicates that the crop could be planted on any day of the year, and temperature and precipitation would stay central to the crops optimum range for the minimum duration that the crop requires to produce a harvestable product (i.e. ripe seeds, fruit, roots etc). A score of zero indicates that even for maximum length of time required to produce crop, conditions are not within the optimal range. The score can also drop to zero if temperature falls outside the minimum and maximum endurable by the crop for short periods, even if conditions are otherwise optimal. The model assumes that crops are grown under open, rainfed conditions and managed optimally.

Both models produce gridded outputs, and were run under the OpenClim project using CHESS-SCAPE UKCP18 downscaled climate inputs at 1km resolution (Robinson *et al.,* 2023). We overlaid the archetype data and extracted mean model outputs per archetype, at each of 5 levels of warming (baseline, +1.5°C, +2°C, +3°C, +4°C).

Results

CropNet

Figure 67 shows that winter wheat yields generally increase under climate change up to the +3°C warming scenario. However, by +4°C, many archetypes show a plateau in yield, or even a marked downturn. This is especially notable for those archetypes with a high proportion of arable land, where wheat is currently widely grown (Archetypes 1, 4, 9 and 10). The exception would be the Northern Ireland arable Archetype 11, where impacts on wheat yield appear uniformly positive.

Oilseed rape and grass show generally positive effects on yield under all warming scenarios, across all archetypes. The grass model in particular shows very large increases at +4°C, but it is worth bearing in mind that the grass model assumes that the crop continues to grow until senescence and cannot model the impact of grazing or repeated cutting, and the need for the grass to regrow. At high levels of warming, this may mean that the realism of the model is highly constrained.

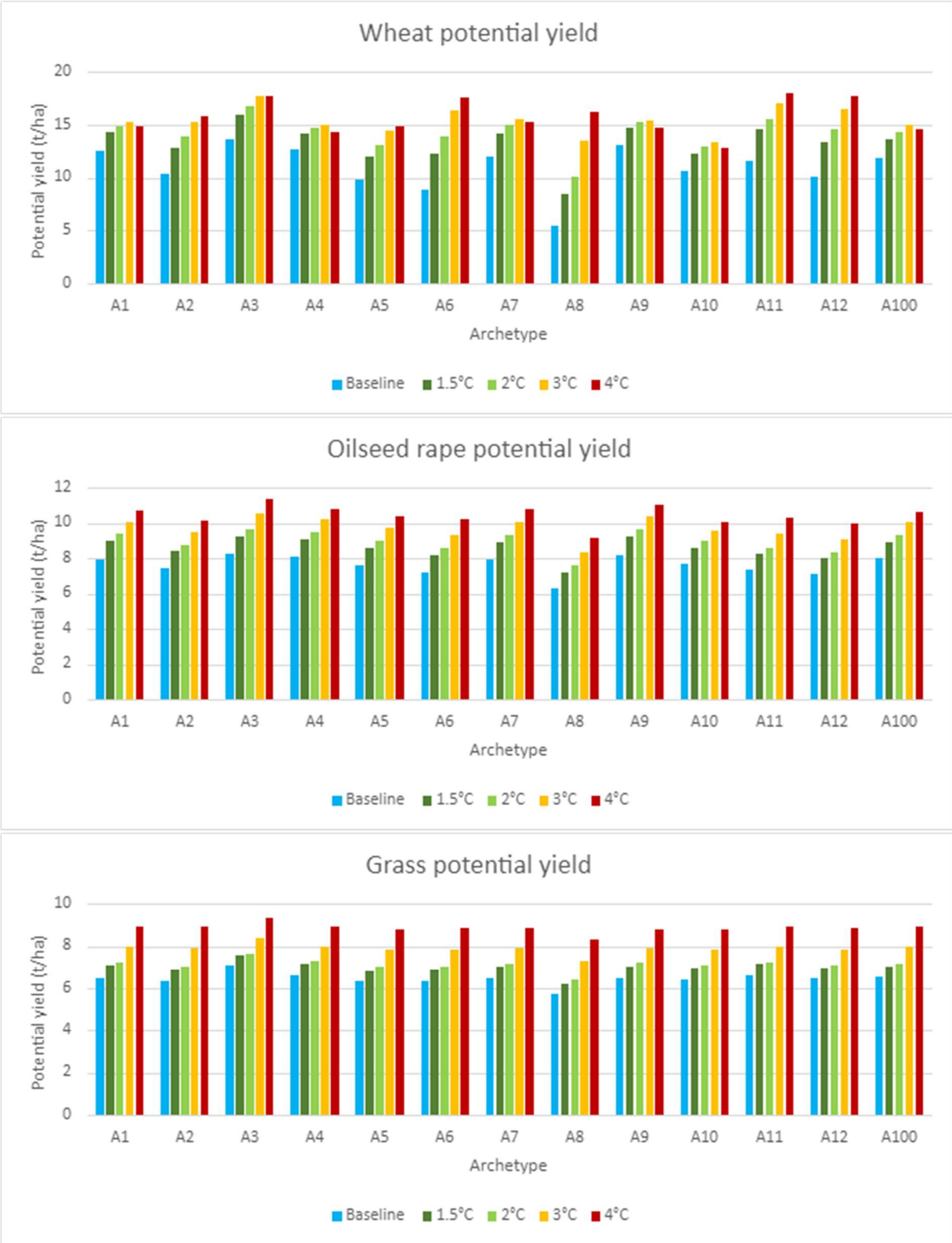


Figure 67 Mean yield in tonnes per hectare, per archetype under each warming level, for each of winter wheat, oilseed rape and perennial ryegrass.

<u>EcoCrop</u>

Because the EcoCrop model produces sperate indices of suitability for over 160 crops, we took the median value of suitability across crops within different groupings. These groupings were: current UK major crops (the crops comprising a cumulative 90% of UK arable land, according to Defra and devolved administration agricultural survey statistics); all current UK crops (as previous, but with the addition of any additional crops currently grown in the UK); and non-UK crops which are not currently commercially grown in the UK.

Figure 68 shows that current UK crops show a similar pattern as Figure 67 did for winter wheat (as might be expected). Suitability rises under climate change up to +3°C, and then begins to plateau or decline (depending on the archetype). The results for all UK crops are different, showing a steady increase across all archetypes, likely reflecting rising suitability for crops which are currently have restricted distributions in the UK due to climatic constraints (e.g. wine grapes, maize, sunflowers). Increases are even more marked for potential future crops. Again, this is unsurprising, as there are many crops grown in continental Europe which are not currently viable commercially in the UK, but which can be grown in gardens or under protected conditions (e.g. okra, citrus fruits, figs), and for which a warming climate is likely to increase suitability.

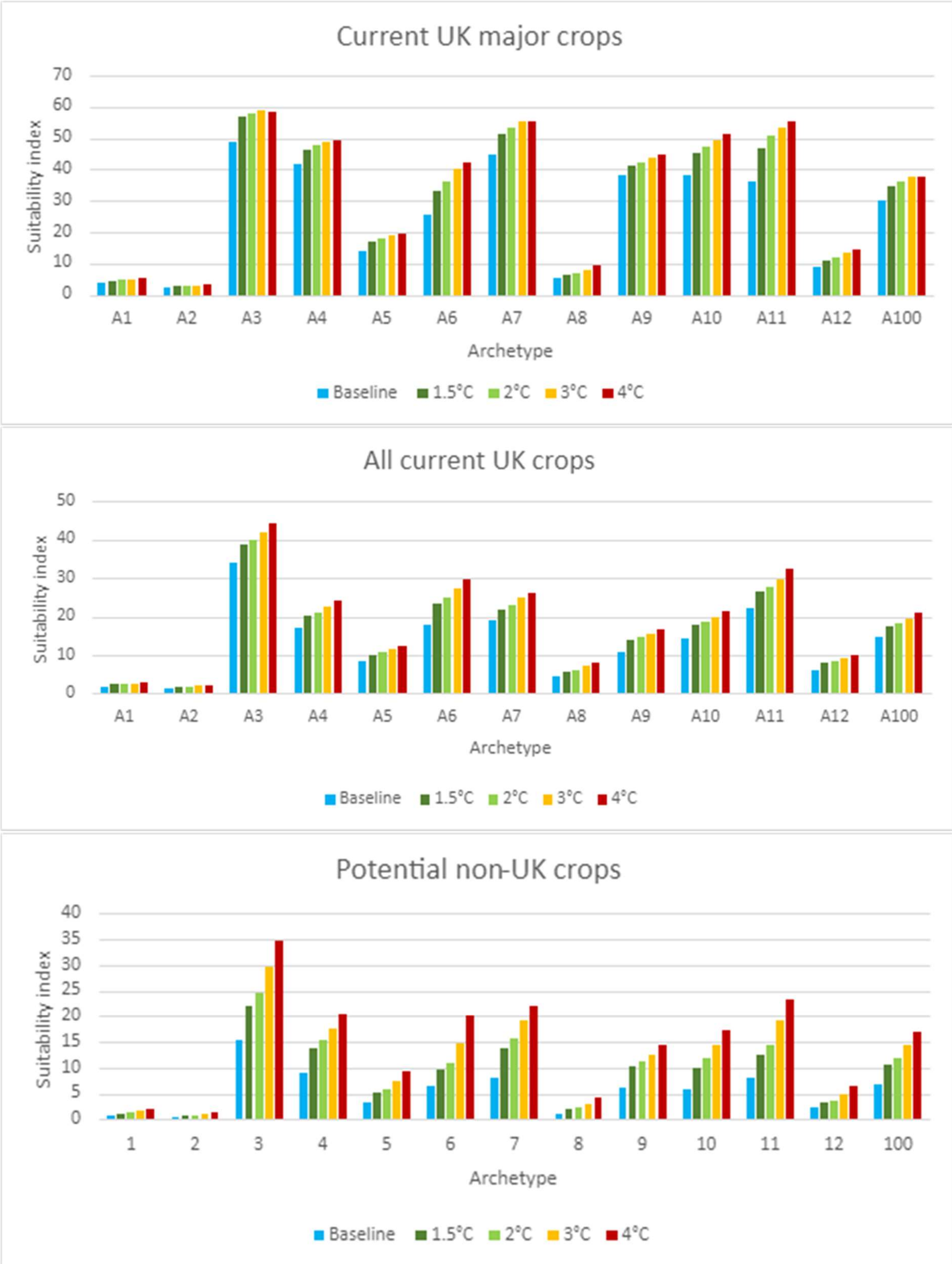


Figure 68 Mean EcoCrop suitability indices per archetype for different crop groupings under climate warming scenarios

Discussion

At first glance, a warming climate appears generally positive for UK agriculture, in terms of both rising yields and increased suitability for a wide range of crops. However, there are several caveats that suggest that, although climate change brings opportunities for UK agriculture, there are also significant risks and barriers to realising the opportunities.

Our current agricultural system is heavily reliant on a narrow range of crops, especially winter wheat (Knight *et al.,* 2022). The fact that potential yields for winter wheat begins to decline under higher levels of warming suggests that actual yields (i.e. those actually achievable in the field) may begin to decline at lower warming levels. For example, our model does not account well for short-lived climatic extremes (e.g. floods and droughts), where these can pose a real threat to yields (Slater *et al.,* 2022). We also do not account for compound or indirect effects on the crop – for example a wet and cloudy spring will directly reduce modelled yield, as it affects available solar radiation and increases the risk of waterlogging. But it also indirectly affects yield by increasing the incidence of fungal disease, which our model cannot capture. Our model also assumes optimal timing and type of management. In reality, climate change can affect both – recent poor years for wheat in the UK (2020 and 2024) arose at least partly because the ground was too wet in autumn for crops to be sown at the optimal time.

The EcoCrop data suggest that there are many new crops which may be viable candidates for adoption under climate change, especially if suitability can be further enhanced by crop breeding. Such opportunities are already being exploited - the UK has seen recent growth in its wine industry (Gannon *et al.,* 2023), with new grape varieties being viable under a warming climate. The UK's first commercial crops of chickpeas, soy and haricot beans have all been grown within the last five years, due to a combination of a warming climate and plant breeding programmes. However, as for potential yield, our models cannot account for many potential barriers, including short-lived climatic extremes and climatic impacts on management and harvest.

The spatial distribution of these opportunities also matters. Although arable archetypes show some increase in projected yields, these are often lower than for other non-arable archetypes (e.g. compare Archetypes 3 and 4 in Figure 67 and Figure 68). Many of the UK's agricultural systems rely strongly on the co-location of farmers with agronomic knowledge, the infrastructure required for crop processing, and the transport infrastructure to enable the product to enter the supply chain. This can be a significant barrier to adaptation by shifting crops to keep pace with the areas of increasing climatic suitability, and to the adoption of new crops (since knowledge and infrastructure must be created or repurposed). Ultimately, there will also be areas where arable farming is non-viable, however climatically suited they are. This is already seen in the South West of England, where potential yields of current crops are generally high, but topography, geographic isolation and land use history means that comparatively little arable land is used for crops (Millward and Robinson 1971). So although there are many opportunities presented to UK agriculture by climate change, realising these opportunities is likely to require overcoming significant challenges.

7.3 Fire Weather

Introduction

Wildfires in the UK are sporadic, with the most severe incidents occurring during particularly dry periods. Spring is the peak season for wildfires due to the abundance of non-forest vegetation that can dry during hot-dry spells, however prolonged hot-dry summers can also lead to more significant outbreaks affecting land covers that respond to the cumulative effects of heat and drought longer time periods, such as in forests, shrublands and moorlands (Perry *et al.,* 2022).
The UK Fire and Rescue Services respond to around 32,000 wildfire incidents annually, though the vast majority are small, affecting less than a hectare (Gazzard *et al.,* 2016). Wildfires typically ignite in areas where human activity is prevalent, near to rural, urban or agricultural land. However, the largest fires tend to occur in more remote landscapes, including moorlands, forests, and peatlands, where suppression efforts are more challenging due to continuous fuel sources. Although woodland fires constitute a smaller proportion of wildfire incidents, their economic and ecological consequences can be significant. Notable examples include the Swinley Forest fire in 2011 and the Wareham Forest fire in 2020, both of which caused extensive damage (Gazzard *et al.,* 2016; Belcher *et al.,* 2021).

Recognising the increasing threat, the UK government added severe wildfire to the National Risk Register in 2013. Wildfires are also considered a threat to human health through their effects on the air quality and were evaluated in the UK Health Security Agency's latest Health Effects of Climate Change (HECC) report (UKHSA, 2023).

The likelihood and severity of wildfires are influenced by both environmental and human factors. Weather conditions such as temperature, humidity, rainfall, and wind speed play a crucial role in determining fuel moisture levels and fire behaviour (Jolly *et al.,* 2015; Abatzoglou *et al.,* 2019; Jones *et al.,* 2022). Spring fires typically spread through dead grasses and surface vegetation accumulated during the prior growing season, whereas summer fires are fuelled by prolonged heat and drought (Abatzoglou *et al.,* 2018; Perry *et al.,* 2022; Jones *et al.,* 2024). While lightning is a major cause of wildfires in some countries, most UK wildfires originate from human activity, either accidentally or deliberately (Janssen *et al.,* 2023; Perry *et al*., 2022). Fire risk is also shaped by land management, including vegetation clearance and prescribed burns, which can reduce fuel availability. The Canadian Fire Weather Index (FWI) is widely used to assess fire danger by incorporating weather data to predict fire spread and intensity (van Wagner, 1987; Jolly *et al.,* 2015). Climate change is projected to heighten fire risk globally, and in the UK, with hotter, drier summers expected to increase wildfire frequency and severity, particularly under high-emission scenarios (Perry *et al.,* 2022; Abatzoglou *et al.,* 2019). However, uncertainties remain regarding the future trajectory of factors such as lightning activity, vegetation responses, management, suppression and policy factors, underscoring that fire weather is an indicator of fire *potential* (or hazard) and does not share a 1-to-1 relationship with fire activity or area.

Methods

The Canadian Fire Weather Index (FWI) is specifically designed for use in forests and other woody environments, optimising for particular fuel types in these settings (van Wagner, 1987; Jones *et al.,* 2022; Abatzoglou *et al.,* 2018). It provides an overall rating of the potential for fires to ignite, spread, and become challenging to control in forests (van Wagner, 1987; Jolly *et al.,* 2015). The FWI combines two sub-indices: the Initial Spread Index, which accounts for fine fuel moisture conditions and potential for wind-driven spread based on meteorological conditions, and the Build-up Index, which accounts for the longer-term accumulation of fuel loads and coarse fuel moisture content. However, the FWI does not make any assumptions about the probability of ignition or suppression. Its use outside of forest environments must be interpreted as indicative only, with increased fire weather broadly corresponding to increased risk in the presence of sufficient fuel stocks and ignition sources, though not on the scale that the index was originally trained to represent. The FWI has been regularly used to make global projections of changing fire risk in past and future periods at a global scale (Jolly *et al.,* 2015; Abatzoglou *et al.,* 2019; Jones *et al.,* 2022).

The input dataset for the Fire Weather Index (FWI) is based on ten CMIP6 models, updating the CMIP5 data from Abatzoglou *et al.,* (2019). It has a spatial resolution of 1 degree and a temporal resolution of daily data. The following scenarios used: SSP245 and SSP370.

Regarding the input parameters, UK-relevant fire danger thresholds have been defined by Kitchen (2006), de Jong *et al.,* (2016), and Perry *et al.,* (2022). Very high fire danger days are based on an FWI greater than 17.35, which is approximately the 90th percentile in the UK. About 61% of UK wildfires occur within this range. Multi-day fires or days with high synchronous fire activity, which are metrics indicative of fires that are challenging to suppress, are most common on very high fire danger days (de Jong *et al.,* 2016). High fire danger days are based on an FWI greater than 9.38, roughly the 75th percentile in the UK, with 85% of UK wildfires occurring within this range.

The processing involves several steps. Firstly, downscaling, which outputs 0.1 degree daily data from the 10 models, is achieved through bi-linear interpolation of daily FWI data to a 0.1 degree (~10 km) resolution. Secondly, calculating high/very high fire danger days results in 0.1 degree annual data from the 10 models by counting annual days exceeding UK-relevant fire danger thresholds at the 0.1 cell level for each model. Thirdly, multi-model averaging produces 0.1 degree annual data, representing the multi-model mean of fire danger days from the previous step. Fourthly, period averaging for Global Warming Levels (GWLs) involves averaging data across years for periods consistent with four GWLs. Values for the 1.5°C and 2°C GWLs are taken from SSP245. Values for the 2.5°C and 3°C GWLs are taken from SSP370. Finally, archetype-level averaging outputs tabular data for the four

GWLs, representing the multi-model mean by averaging gridded data within each archetype. Archetype spatial masks are constructed by mapping archetypes to a 0.1 degree grid and then used to extract the archetype-wide mean of the cell-level counts.

Results

At a warming of 3.0 degrees, very high fire danger days increase by approximately two days or more per year in Archetypes 2 (Upland organic soils), 3 (Intensive grassland), 4 (Suburban fringe), 8 (Acid upland grassland), and 12 (Uplands in Northern Ireland). Other archetypes do not experience a significant increase in very high fire danger (Figure 69), as discussed below.

High fire danger days at 3.0 degrees warming increase by around 30 days per year in Archetypes 2 and 4, by about 20 days per year in Archetype 6 (Open pasture), and approximately 10 days per year in Archetypes 3, 9 (Arable on chalk/clay), and 12.

Archetype 4 shows the most pronounced changes in days with high/very high fire danger. It is projected to experience the greatest rate of increase in very high fire danger days, with a rate roughly 1.5 to 2 times that of Archetypes 2, 3, 8, and 12. While Archetypes 2 and 4 show similar increases in high fire danger days, Archetype 4 starts from a higher baseline.

In these archetypes, each added half-degree of warming results in an incremental increase in high and very high fire danger days. Other archetypes do not see a substantial increase in days with high or very high fire danger compared to the modern baseline. Given the formulation of the fire weather index (described above), this indicates inconsequential change in temperatures or increased heatwave frequency of intensity; inconsequential change in rainfall, relative humidity, drought frequency or intensity, or inconsequential change in wind speeds. Inconsequential change in fire weather can also result from offsetting of the multiple climatic factors that influence the FWI: for example, the impact of increased temperatures on fire danger can be offset by increased rainfall.

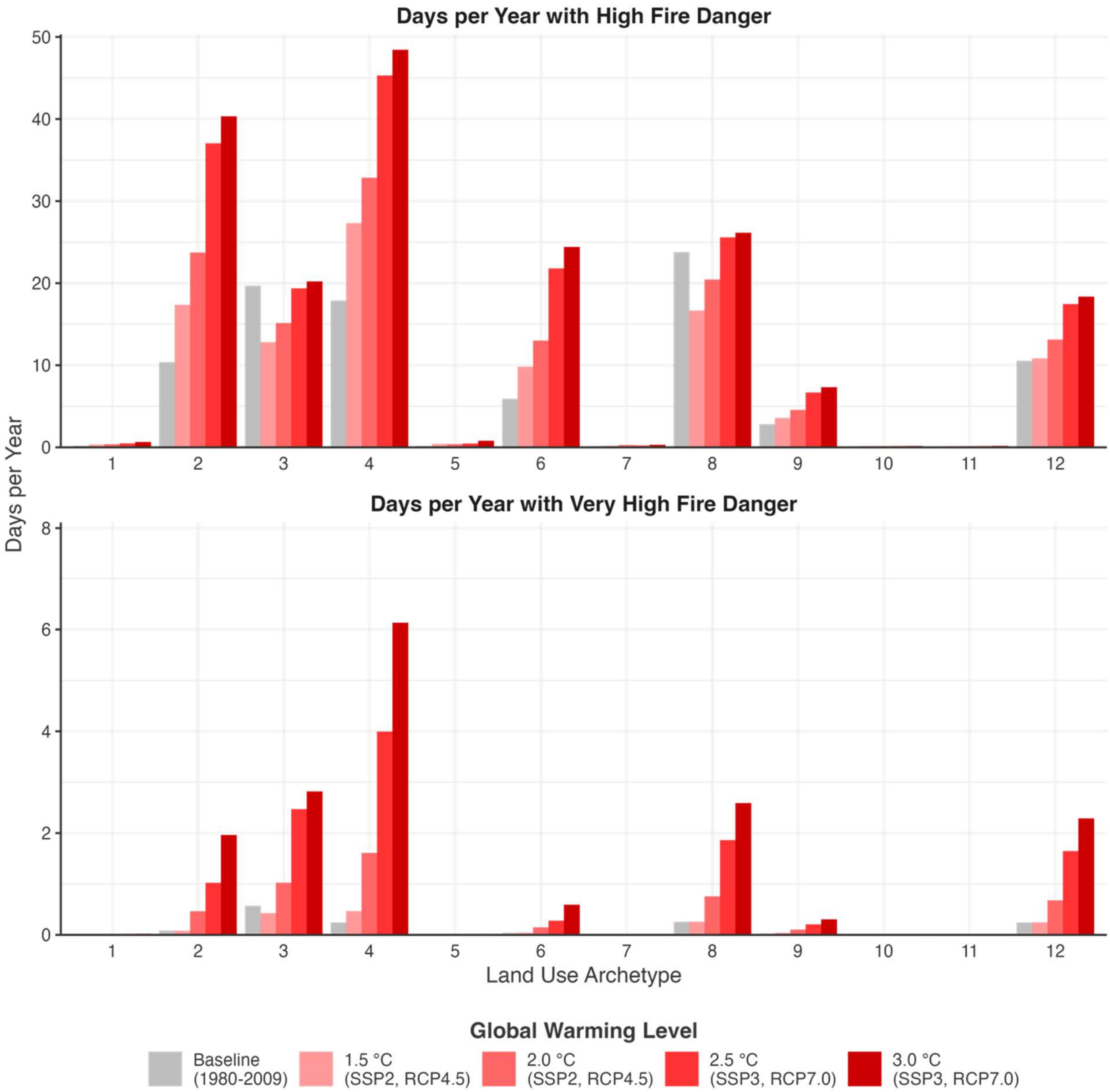


Figure 69 Mean annual number of days with 'high' or 'very high' fire weather index values according to the Met Office system. A 'high' fire weather index exceeds 9.38; 85% of UK fires occur in these conditions. A 'very high' fire weather index value exceeds 17.35; 61% of UK fires occur in these conditions.

Archetypes: 1-Lowland organic soils; 2- Upland organic soils; 3- Intensive grassland; 4- Suburban fringe; 5- Hilly farmland; 6- Open pasture; 7- Enclosed pasture; 8- Acid upland grassland; 9- Arable on chalk/clay; 10- Arable on sandy soils; 11- Lowland agriculture in Northern Ireland; 12- Uplands in Northern Ireland.

Discussion

The implications for archetypes that see an increase in fire danger above the current baseline are discussed here.

Archetype 4 (Suburban fringe) is characterised by predominant land use such as arable/horticulture and livestock grazing on improved grassland and is spatially distributed all over the country at the suburban fringe. The fuel dynamics between arable/horticultural land and grazing land differ greatly. In spring and summer, when the fire weather index typically peaks, arable and horticultural land feature dense fine fuel stocks that are responsive to meteorological drought and other short-term weather conditions. Grazing land may become densely stocked with fuels such as grasses and other herbaceous plants during periods when livestock are kept in winter housing. However, common grazing practices typically remove these fuels once livestock are released. Fire weather peaks in summer when fuel loads are typically far higher on arable and horticultural land than on grazing land. Increased fire weather index is a factor that landowners in this archetype might consider when planning how they distribute land between grazing and arable land.

The Wennington fire during the UK's 2022 heatwave highlights the dangers related to wildfire in the suburban fringe in the UK. The fire ignited from a garden compost heap that spontaneously combusted on the hottest day on record in the UK and quickly spread to neighbouring ungrazed grassland and arable land, destroying a dozen houses and several crops, though thankfully without fatalities[19] . Parallels have been drawn between this event and fires that are more typical of a Mediterranean fire regime, and alarm was expressed about poor preparedness for such an event in the UK[20]. This point is underscored by the fact that the fire encroached on land surrounding a fire station of the London Fire Brigade. Areas currently occupied by Archetype 4 are expected to see increased settlement and reduced agricultural land, suggesting a shift in location as urban areas expand. The assessment applies equally to the 2021 and future coverage of Archetype 4.

Archetype 2 (Upland organic soils) includes conifer plantations and livestock rough grazing and is spatially concentrated in uplands such as the Pennine chain, southwest Scotland, the Highlands, and the Isles. The fire weather index is expected to perform well as a predictor of burned area in conifer plantations, as it was originally defined for forest ecosystems and woody fuel types, though this is not the case for livestock rough grazing. Coniferous forests are often associated with more severe fire behaviour in UK forests (Scottish Government FRS Operational Guidance, 2013; Belcher *et al.,* 2021), a pattern observed globally (e.g., Hély *et al.,* 2000). The fuel loads in forests and grazing lands differ dramatically, challenging the interpretation of fire weather trends for an archetype containing both types of land cover. Increased fire weather might dissuade some landowners or managers from expanding conifer plantations (coniferous woodland currently accounts for around 21% of Archetype 2 land cover). Allowing livestock to graze on forest land is one method to reduce fine fuel loads and mitigate the risk of surface fires, a traditional practice in parts of southern Europe known to reduce fuel loads in deciduous or mixed woodlands and moderate fire risk. However, this is currently a less widespread practice in the UK (e.g., Forestry Scotland, 2024).

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[19] https://en.wikipedia.org/wiki/Wennington_wildfire

[20] https://www.standard.co.uk/news/london/climate-change-impact-uk-heatwaves-floods-extreme-weather-b1132789.html

Forest fuel reduction via grazing or prescribed burning is generally not considered effective against the spread of fires that develop more extreme behaviour, such as crowning fires reaching the canopy (e.g., Fernandes, 2015). Coniferous forest extent is expected to decrease in Archetype 2, which would likely have positive outcomes for potential fire risk in this archetype.

Three of the archetypes, Archetype 3 (Intensive grassland), Archetype 8 (Acid upland grassland) and Archetype 12 (Uplands in Northern Ireland) are notably associated with livestock grazing. Due to the relatively low fuel stocks through grazing during the summer peak of fire weather, projected increases in fire weather in these archetypes are not likely to translate into increased summer fire activity or burned area (except in coniferous forests of Archetype 12). Increased fire weather during spring could translate into increased fire activity on grasslands if the spells of fire weather precede the grazing season. The most dangerous scenario in these archetypes would be a warm and wet spring, which drives high fuel production and extends the period of livestock winter housing, followed by abrupt flash drought or heatwave conditions in spring or early summer.

Archetype 12 features some coniferous forest as a minor component of total land cover, though the extent of coniferous forests is expected to decline in future. Meanwhile, no substantial changes in land cover distribution are expected in Archetypes 3 or 8. Changes in land cover distribution would be expected to interact with future change in fire weather, and in particular a reduction in coniferous forest extent would be expected to moderate the increased risk that comes with increased future fire weather (see discussion of the particular dangers related to high fire weather in coniferous forests in respect of Archetype 2).

Relevance of Archetype-level Changes in Fire Weather to National woodland creation Strategy

Consideration should be given to what archetypes may be most suitable for woodland creation schemes in line with the government's commitment to expand forest area in the UK to 16.5% by 2050 (Environment Act, 2021). Woodland creation efforts aimed at sequestering carbon are likely to face a lesser threat from wildfire on Archetypes 1, 5, 6, 7, 9, 10, and 11. According to the land cover trajectories in the archetypes with fastest rate of increase in high fire weather days (see summary above), is that coniferous forest extent will fall in the Archetypes where it is currently a significant feature (Archetypes 2 and 12). Deciduous forest is expected to remain a small component of land cover in Archetypes 2, 3, 4, 8, and 12.

This is positive because forests are expected to respond particularly sensitively to change in fire weather. The expansion of forest and woodland in Archetypes 1, 5, 6, 7, 9, 10, and 11 would likely be more appropriate from a fire risk perspective (though note that the suitability of these archetypes for forest planting may vary for other reasons).

7.4 Soil carbon

Introduction

Soils can act as a source or sink of atmospheric CO_2 and the soil carbon pool is the largest carbon pool in the terrestrial ecosystem (Smith *et al.,* 2008; Lal, 2013). Land-based mitigation measures that help to sequester carbon in soil have the potential to contribute significantly to the mitigation goals, however, climate change may impact this potential (Thomson *et al.,* 2006). Climate change affects soil carbon dynamics in various ways. The SOC pool may increase due to the CO_2 fertilisation effect resulting in the increase in biomass production (which then increases the C inputs to soil), or the SOC pool may decrease due to the rise in global temperature (Lal, 2008). Therefore, it is important to predict the impacts of climate change on soil carbon especially SOC in the archetypes and the use of SOC modelling is key to achieving this. The Roth-C model is a process-based model which requires relatively simple input data and has been widely used and tested globally and regionally (Coleman and Jenkinson, 1996; Falloon and Smith, 2002; Gottschalk *et al.,* 2021). Given the simplicity of data input requirement and the functions of the model, the Roth-C model was selected in this project to simulate the impacts of climate change (i.e. temperature, precipitation and evapotranspiration) on SOC stocks following land use transition and under baseline conditions.

Methodology

To assess the climate change risks on SOC, climate data from the period of January 2021 to November 2080 was used instead of the historical climate data. The SOC results were generated for when the temperature reached 1.5°C, 2°C and 3°C by simulating SOC for the 1.5°C, 2°C and 3°C threshold years particular to each of the utilised GCMs. These warming threshold years were sourced from Arnell *et al*. (2021) for the six UKCP18 models used in this part of the project. The soil inputs were the same as Section 4.7 (Baseline) and Section 6.7 (following land use transition).

Results

Following climate change at 1.5°C, 2°C and 3°C of warming, SOC in eight of the 12 archetypes was predicted to decrease compared with the baseline SOC (Figure 70 and Figure 71). SOC in Archetypes 3 (Intensive grassland), 5 (Hilly grassland), 6 (Open pasture) and 12 (Uplands in Northern Ireland) was predicted to increase following climate change. At 1.5°C of global warming, the greatest increase and decrease in SOC density were predicted to be in Archetype 3 (1.3 t ha^{-1}) and Archetype 8 (Acid upland grassland) (1.3 t ha^{-1}), respectively (Figure 70). The greatest increase and decrease in SOC stocks were predicted to be in Archetype 3 (1.7 Mt) and Archetype 9 (Arable on chalk/clay) (2.6 Mt), respectively (Figure 71). At 2.0°C and 3.0°C of global warming, the greatest increase and decrease in SOC (both density and stocks) were predicted to be in Archetype and Archetype 9, respectively (Figure 70 and Figure 71).

In this project, it was not possible to compare the impacts between the different warming levels as the temperature reached these warming levels at different years. However, it was noticed that in Archetype 100 (All other rural land) the SOC was predicted to increase at 1.5°C of global warming but decrease at 2.0°C and 3.0°C of global warming.

The joint impacts of land use transition and climate change were also modelled. At 1.5°C of global warming, the greatest increase and decrease in SOC density were predicted to be in Archetype 3/pathway 2 (1.3 t ha^{-1}) and Archetype 11 (Lowland agriculture in Northern Ireland) (1.3 t ha^{-1}), respectively (Figure 72). The greatest increase and decrease in SOC stocks were predicted to be in Archetype 3/pathway 2 (1.7 Mt) and Archetype 9/pathway 2 (2.6 Mt), respectively (Figure 73). At 2.0°C and 3.0°C of global warming, the greatest increase and decrease in SOC density were predicted to be in Archetype 3/pathway 2 and Archetype 1 (Lowland organic soils), respectively (Figure 72). At 2.0°C of global warming, the greatest increase and decrease in SOC stocks were predicted to be in Archetype 3/pathway 2 (0.7 Mt) and Archetype 9/pathway 2 (2.1 Mt), respectively (Figure 73). At 3.0°C of global warming, the greatest increase and decrease in SOC stocks were predicted to be in Archetype 3/pathway 2 (0.6 Mt) and Archetype 2 (1.2 Mt), respectively (Figure 73). The impacts of land use transition were very small compared to the impacts of climate change, when both factors were considered the contribution of land use transition to the changes in SOC was not very noticeable.

Discussion

Climate change is expected to have significant impacts on SOC in the archetypes due to the raising temperature, increased evaporation rates and altered precipitation patterns. As temperature rises, microbial activity and soil organic matter decomposition are expected to increase which can lead to a faster turnover of SOC, potentially resulting in a decline in SOC stocks (Trumbore, 1997). With global warming the temperature increases and causes SOC stocks to decrease, thus in most archetypes a decrease in SOC stocks was predicted.

In some regions, increased precipitation could enhance soil moisture, supporting plant growth and microbial activity. However, excessive rainfall can lead to waterlogged conditions, reducing oxygen availability and slowing decomposition. If decomposition rates are significantly reduced, SOC stocks might increase, but if plant growth and residue inputs are also reduced, SOC stocks could decline (Trumbore, 1997). In regions where evaporation exceeds precipitation, leading to a soil moisture deficit, the balance between organic matter inputs (e.g. from plant residues) and outputs (e.g. through decomposition) becomes crucial. Some regions might face SOC losses due to reduced moisture while others might experience SOC gains due to increased plant growth and organic inputs. This explains why an increase in SOC stocks were predicted in some archetypes.

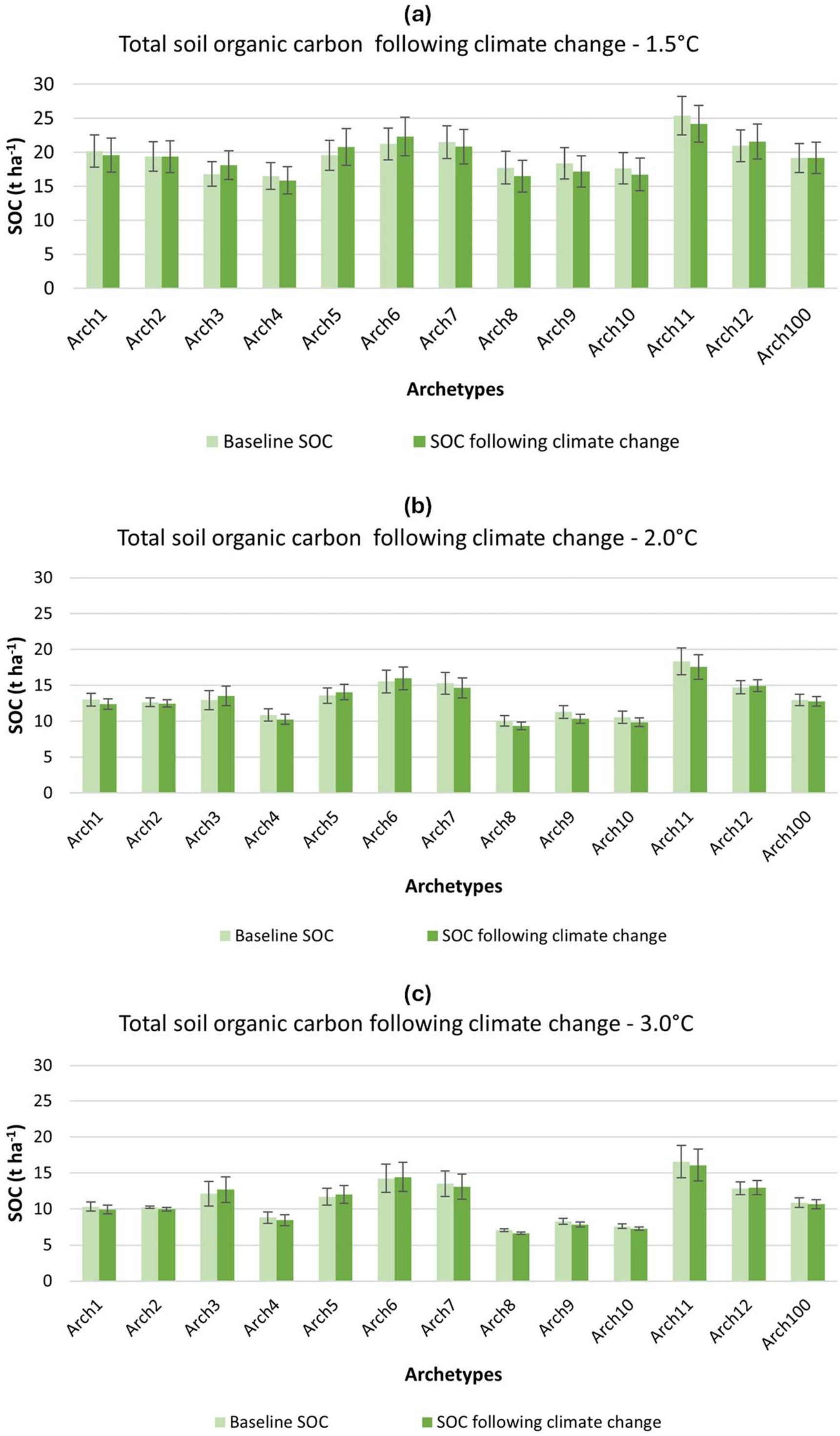


Figure 70 Baseline (*light green*) soil organic carbon stocks per unit area (t ha^{-1}) compared with the soil organic carbon stocks (t ha^{-1}) following climate change only (*dark green*) at warming levels 1.5°C (a), 2.0°C (b) and 3.0°C (c) in all archetypes.

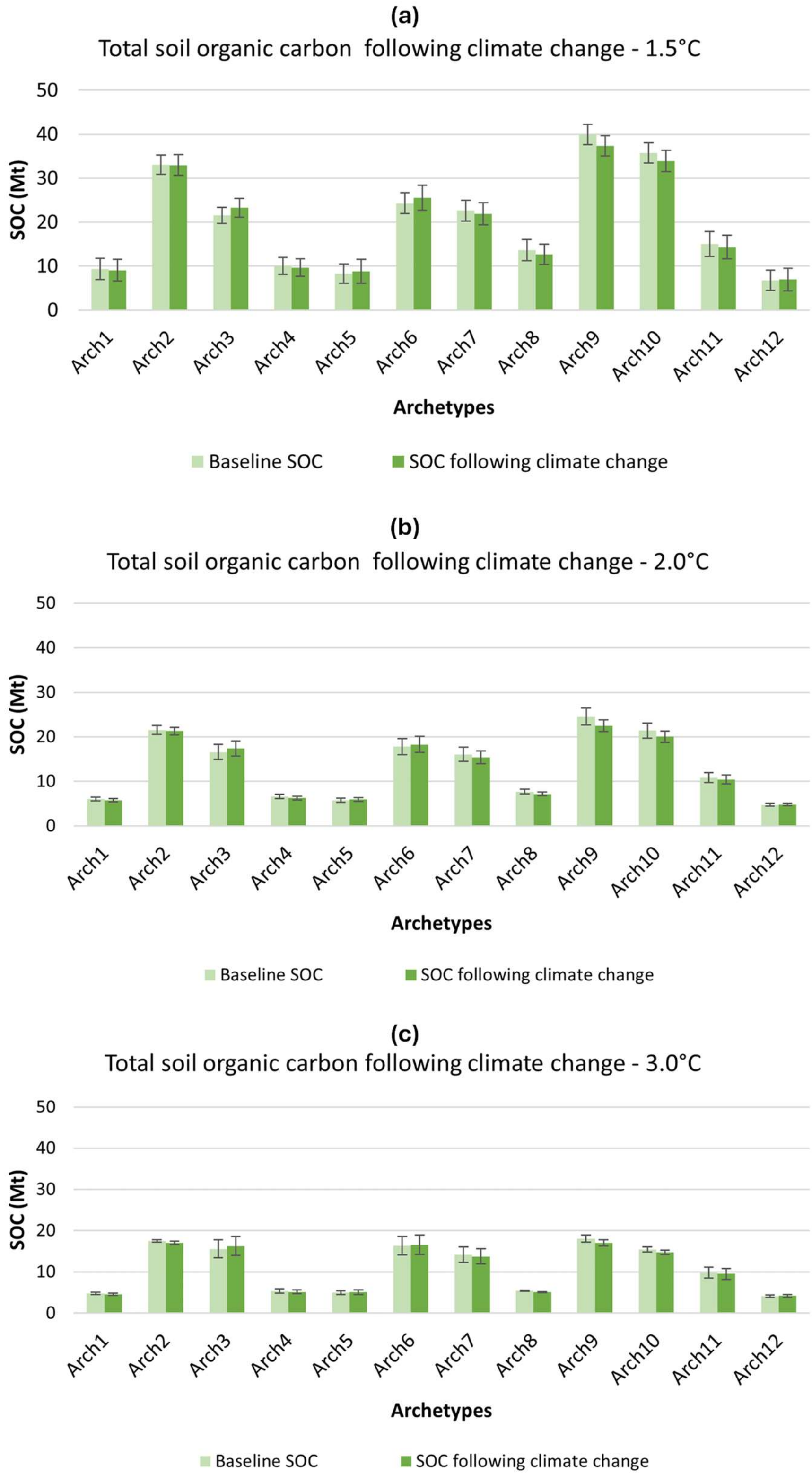


Figure 71 Baseline (*light green*) total soil organic carbon stocks (Mt) compared with the total soil organic carbon stocks (Mt) following climate change (*dark green*) at warming levels 1.5°C (a), 2.0°C (b) and 3.0°C (c) in all archetypes.

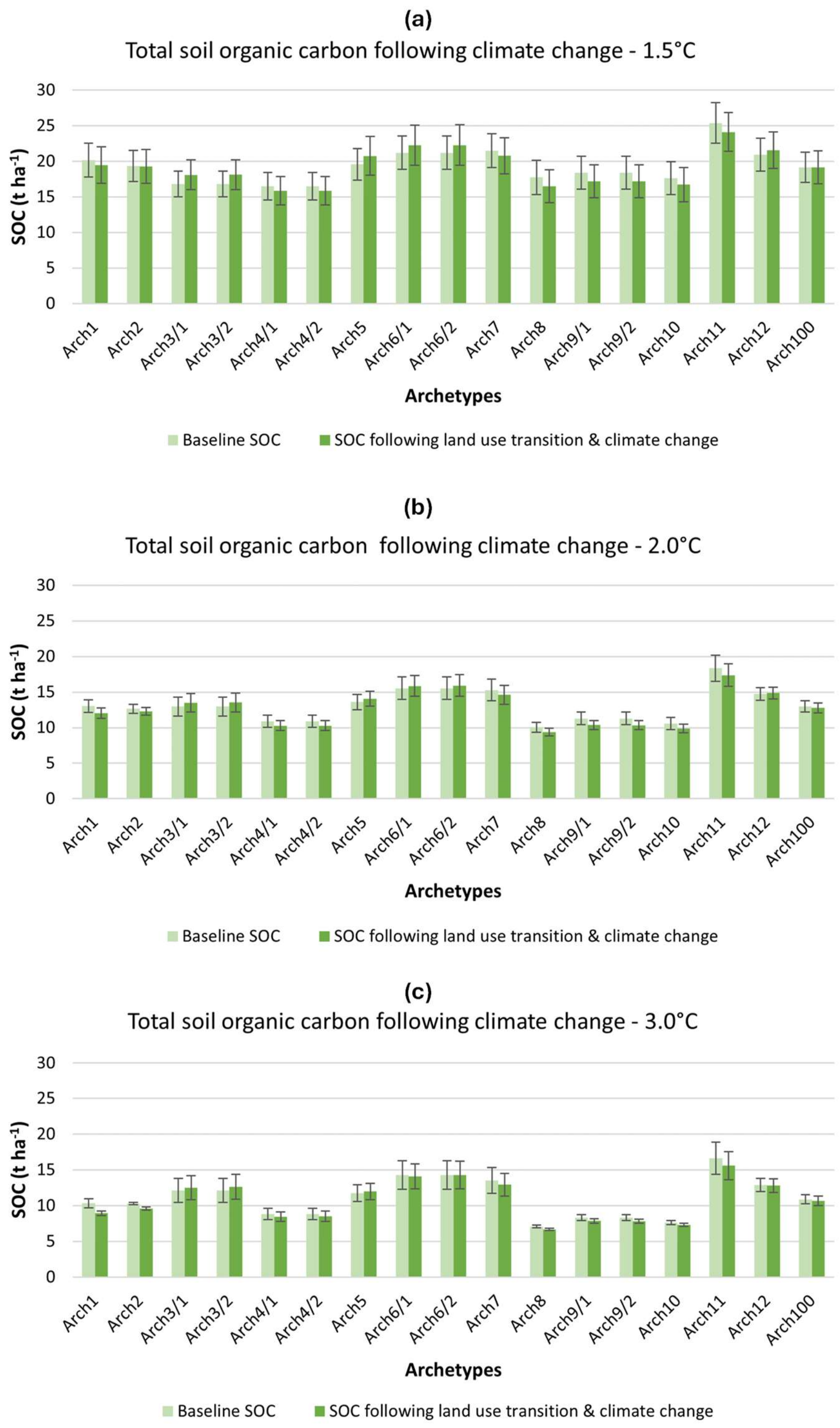


Figure 72 Baseline (*light green*) soil organic carbon stocks per unit area (t ha^{-1}) compared with the total soil organic carbon stocks (t ha^{-1}) following land use transition and climate change (*dark green*) at warming levels 1.5°C (a), 2.0°C (b) and 3.0°C (c) in all archetypes.

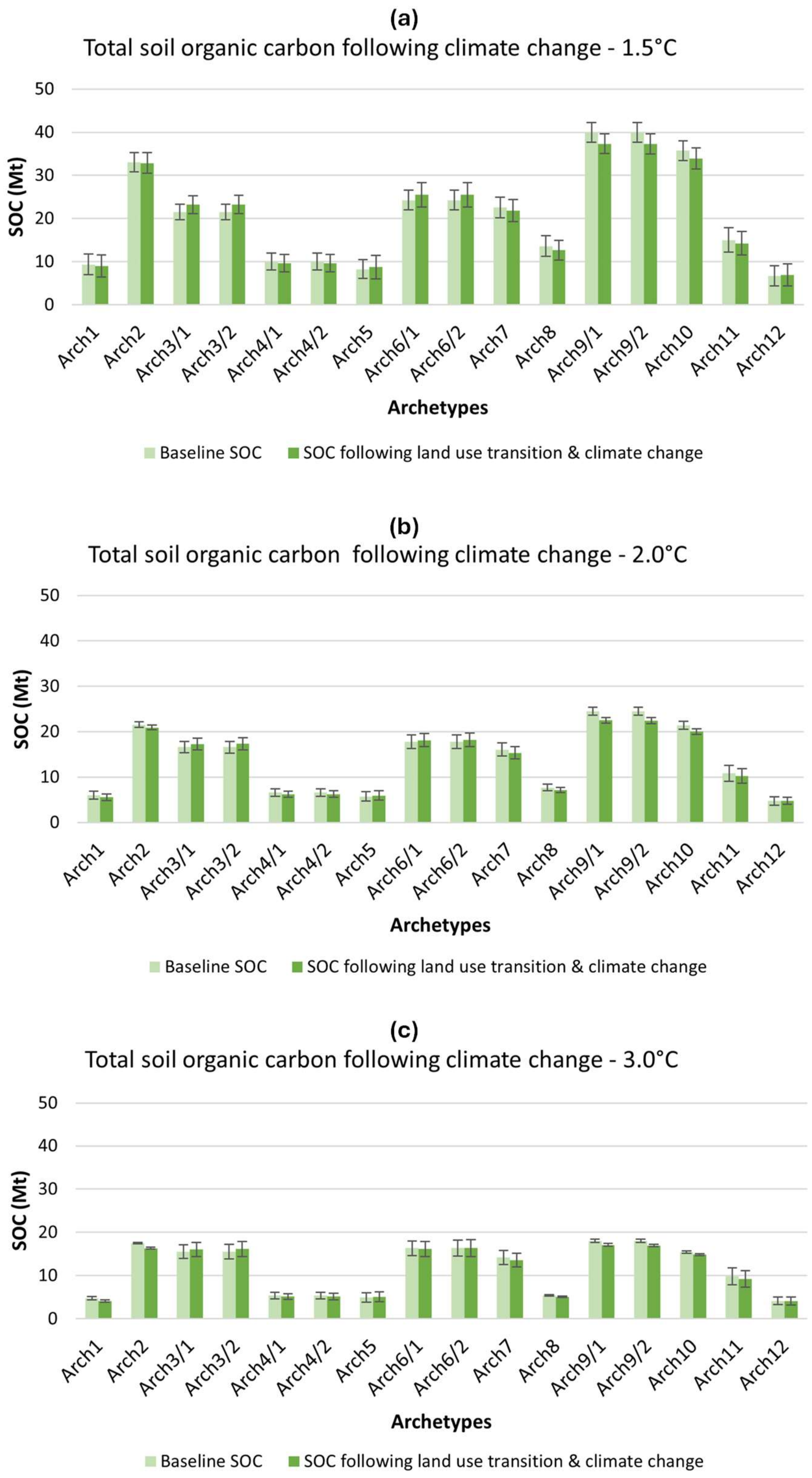


Figure 73 Baseline (*light green*) total soil organic carbon stocks (Mt) compared with the total soil organic carbon stocks (Mt) following land use transition and climate change (*dark green*) at warming levels 1.5°C (a), 2.0°C (b) and 3.0°C (c) in all archetypes.

7.5 Biodiversity

Introduction

Biodiversity is a broad term here covering different groups of species. The potential impacts of climate change upon one group of species is not necessarily that of a different group. Similarly, not considering all components of biodiversity when looking at the potential costs and benefits of transitions in land use can be problematic. For example, natural grasslands (including rough and acid) have high biodiversity benefits to some species, especially rare plants, insects, and some declining iconic bird species, even though the overall species diversity is low. Thus, taking a narrow view of the benefits of a transition to one group, while ignoring others, of over-reliance on the number of species present as a metric to aid decision making, can lead to negative consequences and maladaptation.

The terms reforestation and afforestation are often used interchangeably in the literature when they should not be. The confusion obscures an important difference: reforestation refers to restoration of an ecosystem to a state potentially similar to that which had occurred at an earlier period of time. Afforestation, in contrast, refers to planting trees where they were not known to have occurred in the past (or at least the recent past), converting one ecosystem type into an entirely new ecosystem type. Best practices (Parmesan et al. 2022) argue that afforestation be limited in scope, if used at all for carbon dioxide removal (CDR), especially from a biodiversity point of view.

Papers showing that afforestation (woodland creation) of areas in the UK can have a positive biodiversity benefit have focussed principally on one group of species (e.g., the number of bird species present) and have not also considered the potential impacts of climate change. Climate change will lead to some rearrangements of bird communities as they disperse to track their suitable climates, and woodland creation would be expected to have a positive impact as there are more bird species found in woodland habitats than grassland habitats. However, this takes a very narrow view of biodiversity as it considers only one group and a biased metric (species richness – the number of species) that tends to skew results away from areas that have low species richness but high species uniqueness and often these are species of conservation concern. Without carefully considering a broad suite of species' groups, and at least considering that some areas with low richness may be very important owing to uniqueness then transitions that may appear to be beneficial to biodiversity may very well be detrimental. The greatest benefit to biodiversity comes with restoration (be it woodland or natural grassland). So, areas defined as degraded grasslands, if they have historically been grasslands, would better be restored than forested. Grasslands can also take up sizeable stocks of carbon but it is perhaps more easily released (fire and other disturbance).

In this report we consider both species richness (either as percent remaining or as percent lost) and refugia (areas remaining climatically suitable for more than 75% of the species present). The biodiversity results presented here includes terrestrial fungi, plants, invertebrates, and vertebrates. As there are more plants and invertebrates in the UK then the overall metric is weighted towards those species in terms of projected changes. This is important, as invertebrates, as a group, show the greatest exposure to climate change with projected impacts rapidly increasing even with 1.5°C. In other words, they would show the greatest changes in potential climate suitability (climatic range declines) followed by plants, then vertebrates. Note that we use *change* in species richness as a metric, and not absolute species richness, to quantify risk.

We also present results for insect pollinators, owing to their importance to the ability to grow many crops and wild plant species as well as typical timber species (as defined by the FAO, which could be native or plantation species) as they are the ones most likely to be planted in any restoration effort. As a general point, describing the potential benefits/dis-benefits to biodiversity of transitions on archetypes as a whole is inherently problematic, since transitions might be positive or negative for biodiversity in different parts of the archetype, depending on the location within the UK or the native species presently or historically found there. Therefore, decisions should not be taken until a spatial analysis has been conducted to properly assess the implications of changes in land use.

Methods

The global analysis reported in Warren et al (2013, 2018a) is based on the Wallace Initiative database and contains projections of potential climate change impacts, based on the climatically determined geographic ranges, of more than 135,000 individual terrestrial species. This study uses the most up to date version of this database to extract projections of the impacts of climate change upon plants and vertebrates in the UK, at alternative levels of global warming (specific warming levels, SWLs) of 1.5, 2, 2.7, 3.2, and 4.5°C (as well as 6°). The individual species data were then aggregated into metrics including species richness remaining (the % of species whose climatic ranges remain suitable at that warming level compared to the model baseline), local species extinction (the inverse of species richness remaining), and refugia (defined as an area (cell) containing a minimum of 75% of the species remaining). For consistency with other projects, we have subsequently interpolated linearly between these aggregations to extract projections matching SWLs of 0.5°C to 4.5°C of warming in 0.5°C increments. These aggregated data were then extracted and summarized for each archetype.

The data found in the Wallace Initiative database has been widely used in the studies published in peer-reviewed journals (e.g., Jenkins et al., 2021; Manes et al., 2022; Price, et al., 2024a,b; Saunders, et al., 2023; Smith, et al., 2018; and Warren et al. 2013, 2018a, 2018b) and in multiple chapters of the IPCC AR6. The results from the Wallace Initiative database should be viewed as a statistical sample to attempt to discover the underlying relationships, trends and patterns for broader populations. To that end, extensive resampling and testing have been done to assess how well it performs in terms of general trends and patterns. Results have been found to be generally robust to choice of climate model - CMIP3 vs CMIP5 (current) vs. high resolution RCM models (EU project Helix).

The methodology follows that used in Warren *et al*. 2018 (a,b) and Warren *et al*. 2013. The global scale Wallace Initiative (WI) database was created using an established species distribution model, MaxENT, to estimate potential changes to the ranges of more than 135,000 terrestrial fungi, plants, invertebrate and vertebrate species associated with levels of global warming between 1.5 and 6°C (relative to pre-industrial levels), using 21 alternative regional climate change projections for each level of warming to incorporate uncertainty in regional climate projection, derived from the CMIP5 model inter-comparison project. As in Warren et al (2018a,b), calculations were carried out at an ~20km x20km scale. The MaxENT analyses relies on developing statistical relationships between current species distributions and current climate, and assumes this relationship holds into the future. To develop these models, species distribution data was sourced via the Global Biodiversity Information Facility. A complete consideration of the caveats of the modelling process can be found in Price, et al. (2024a) and Warren, et al. (2013, 2018a, 2018b).

While the original Wallace Initiative database was modelled at a spatial resolution of approximately 20km x 20km, the aggregated data were subsequently 'elevationally' downscaled to ~1km x 1km following the methodology outlined in Price et al., 2024a and Saunders et al., 2023. To match land cover maps these data were then resampled (ArcGIS Pro, RESAMPLE, nearest neighbour) to match the subsequently used land cover data - either 300mx300m (ESA-CCI, global, used in the natural capital climate risk register), or 20mx20m (CEH, used in OpenCLIM and here). ArcGIS Pro (PROC Zonal Statistics) was then used to analyse the data per archetype.

Results

Climate change is projected to have a major impact on the amount of land in most archetypes available to be a refugia (areas remaining climatically suitable for 75% or more species currently present there) with increasing warming (Figure 74). The refugia are climatic refugia based on the climatic suitability for the species but is unable to account directly for current landcover (which, if converted from natural landcover, may mean biodiversity was previously impacted by the landcover change) For climate change alone, only Archetypes 2 (Upland organic soils), 8 (Acid upland grassland), 11 (Lowland agriculture in Northern Ireland) and 12 (Uplands in Northern Ireland) show resilience to 3°C.

Changes in biodiversity, insect pollination and timber species richness in agricultural and semi-natural land cover by archetype are shown in Figures 75-80.

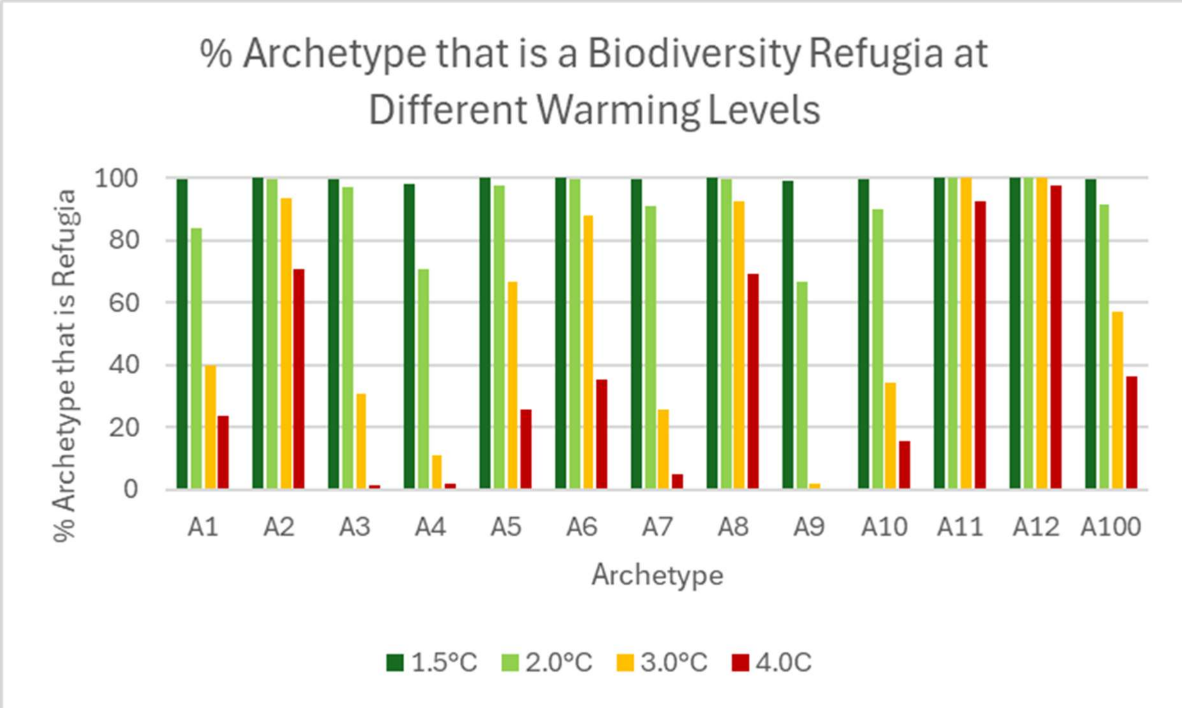


Figure 74 Percentage of archetype that is a biodiversity refugia at different warming levels.

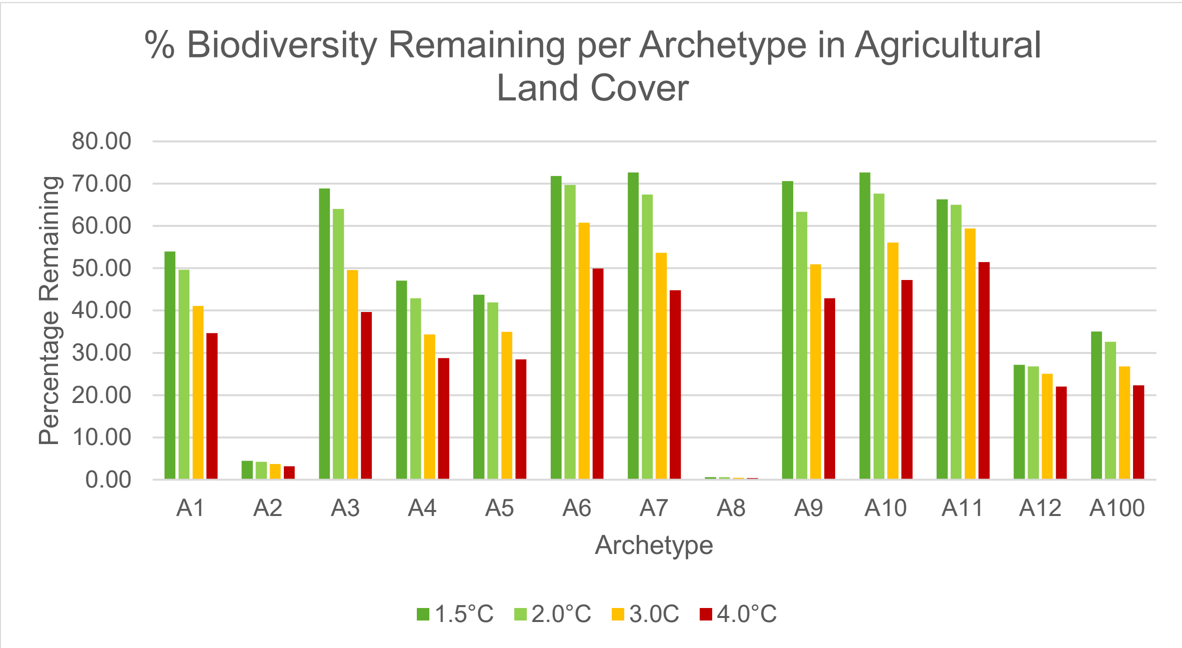


Figure 75 Percentage biodiversity remaining per archetype in agriculture land cover

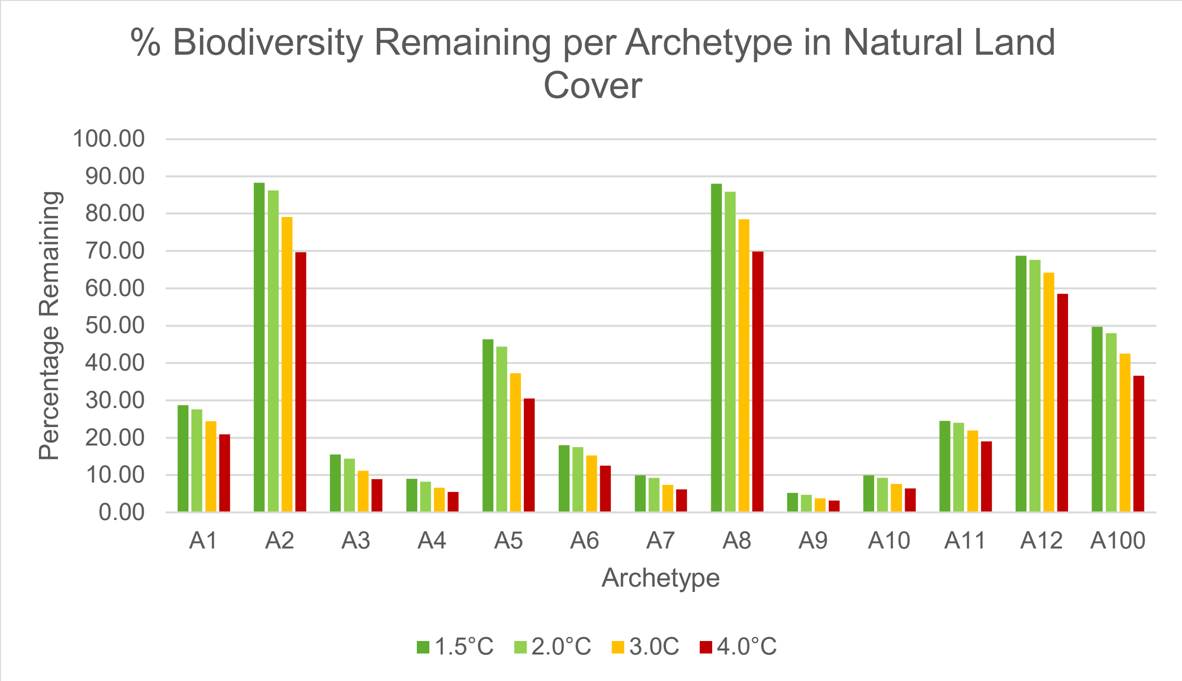


Figure 76 Percentage biodiversity remaining per archetype in natural land cover

Archetypes: 1-Lowland organic soils; 2- Upland organic soils; 3- Intensive grassland; 4- Suburban fringe; 5- Hilly farmland; 6- Open pasture; 7- Enclosed pasture; 8- Acid upland grassland; 9- Arable on chalk/clay; 10- Arable on sandy soils; 11- Lowland agriculture in Northern Ireland; 12- Uplands in Northern Ireland.

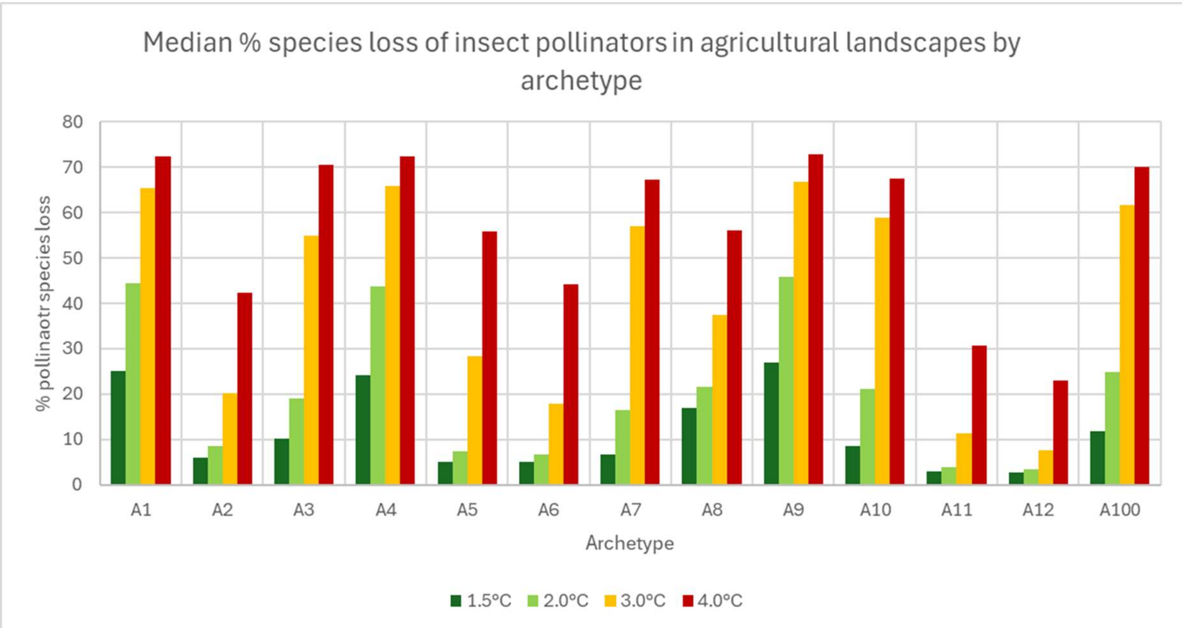


Figure 77 Median % species loss of insect pollinators in agricultural landscapes by archetype.

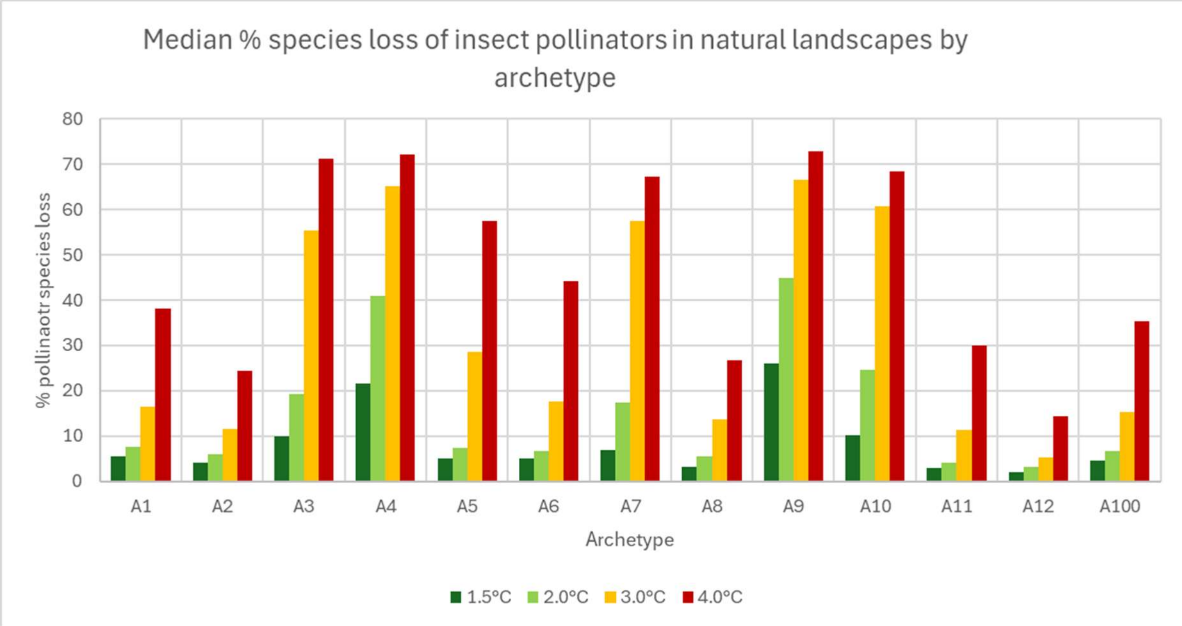


Figure 78 Median % species loss of insect pollinators in natural landscapes by archetype

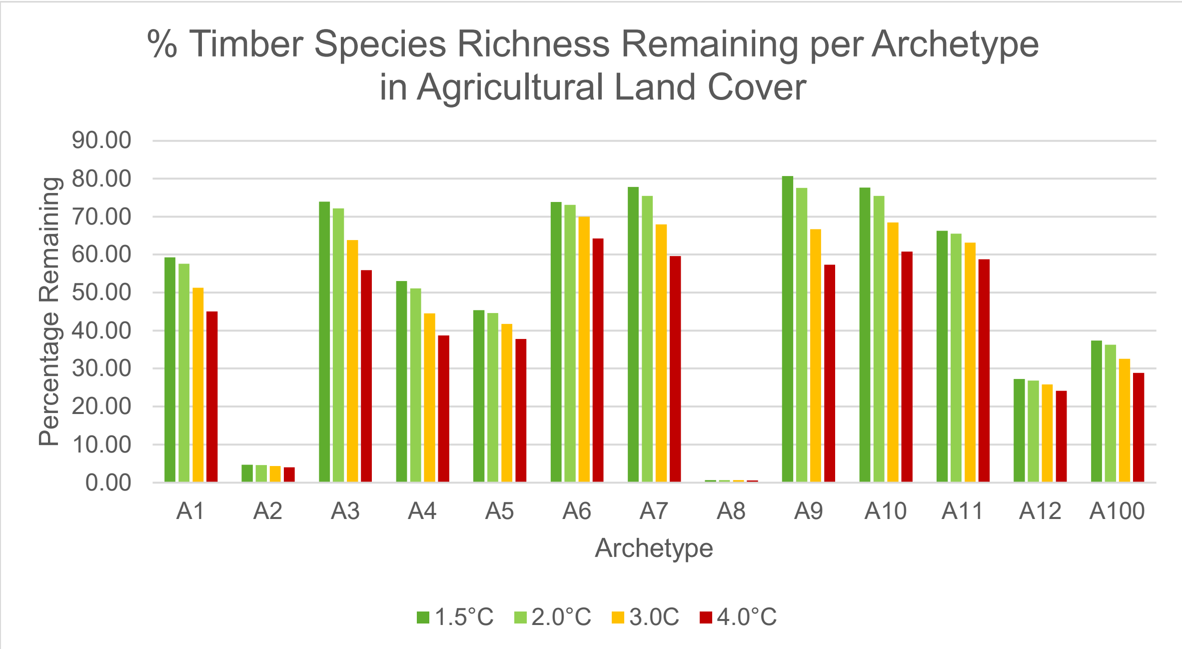


Figure 79 Percentage timber species richness remaining per archetype in agricultural land cover

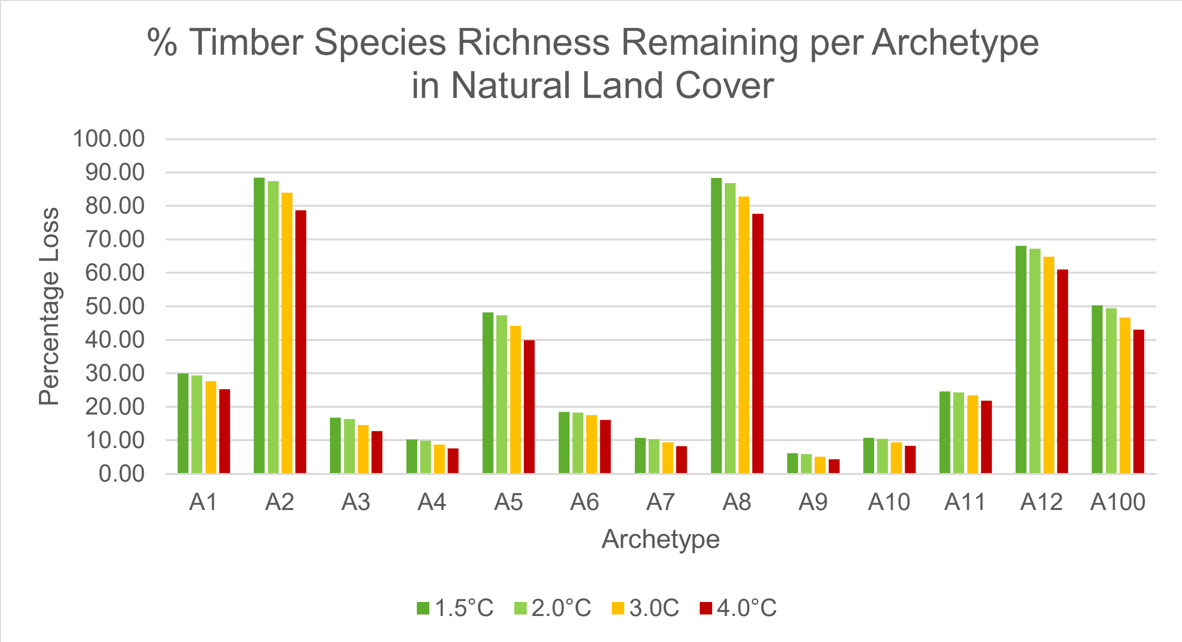


Figure 80 Percentage timber richness remaining per archetype in natural land cover

Discussion

Archetype 1 (lowland organic soils). Land use change is mostly a change from agriculture to rough grassland and wetland, which will benefit grassland and wetland biodiversity with warming of 2°C and below, at higher warming levels focus should be on more northerly areas. The amount of area lost as climate refugia ranges from ~20% at 2°C to ~80% at 4°C. Overall species richness remaining in agricultural land drops from 53% at 1.5°C to 35% at 4°C. In areas classified as natural landcover the drop is from 30% to 20%. The large difference between the projected impacts in agricultural versus natural landscapes suggests that, climatically, agriculture occupies the 'better' climatic space. Restoration of agricultural land (included lands degraded by grazing) would potentially show some benefits to biodiversity, but this rapidly falls off with increasing warming. An examination of a subset of biodiversity, insect pollinators, shows a projected loss of suitable climate space in agricultural landcover areas of 25% of the species with 1.5°C warming rising to ~70% with 4°C warming. This indicates that the ability to grow insect pollinated crops could potentially become seriously constrained. In areas classified as natural landcover, the loss of climatic space for insect pollinators is less severe and ranges from 5% at 1.5°C to >35% at 4°C. Proper siting of a matrix of natural and agricultural land could help provide a pollinator 'bank' for insect pollinated crops. Across the total number of commercial timber species (derived from FAO list of timber species, this could be natural or introduced species often used in plantations) that could potentially be used for restoration, the percentage of species to choose from drops to 58% of the potential at 1.5°C to 45% of the potential at 4°C. In areas classified as natural landcover, the species richness remaining is low, with only 30% of the species with 1.5°C warming falling to 25% at 4°C. This indicates that in wooded natural landscapes the species may be increasingly stressed with increasing warming.

Archetype 2 (Upland organic soils). Land use change is mostly a change from coniferous forest to rough grassland (due to peatland restoration), which will benefit grassland biodiversity with some negative impacts on coniferous forest biodiversity at warming levels of 3°C and below, at higher warming levels conservation focus should be on more northerly areas. The amount of area lost as climate refugia ranges from ~0% at 2°C to ~30% at 4°C. Overall species richness remaining in agricultural land is generally low (<10% owing to the large-scale spatial averaging). In areas classified as natural landcover the drop is from 85% to 70%. An examination of a subset of biodiversity, insect pollinators, shows a projected loss of suitable climate space in agricultural landcover areas of 5% of the species with 1.5°C warming rising to ~40% with 4°C warming. This indicates that the ability to grow insect pollinated crops could potentially become constrained. In areas classified as natural landcover, the loss of climatic space for insect pollinators is less severe and ranges from <5% at 1.5°C to 25% at 4°C. Proper siting of a matrix of natural and agricultural land could help provide a pollinator 'bank' for insect pollinated crops. In areas classified as natural landcover, the species richness remaining is ~88% of the species with 1.5°C warming falling to 78% at 4°C. The proposed transition in this Archetype would lead to a reduction in biodiversity by the metric of species richness, but a potential increase by the metric of unique species.

Archetype 3 (Intensive grassland) The amount of area lost as climate refugia ranges from ~5% at 2°C to 100% at 4°C. Overall species richness remaining in landcover identified as agriculture drops from 69% at 1.5°C to 40% at 4°C. In areas classified as natural landcover the drop is from 16% to 9%. Restoration of agricultural land (included lands degraded by grazing) would potentially show some benefits to biodiversity, but this rapidly falls off with increasing warming. An examination of a subset of biodiversity, insect pollinators, shows a projected loss of suitable climate space in agricultural landcover areas of 12% of the species with 1.5°C warming rising to 68% with 4°C warming. This indicates that the ability to grow insect pollinated crops could potentially become seriously constrained. In areas classified as natural landcover, the loss of climatic space for insect pollinators is equally severe and ranges from 13% at 1.5°C to 69% at 4°C. In areas classified as natural landcover, the species richness remaining is low, with only 17% of the species with 1.5°C warming falling to 13% at 4°C. This indicates that in treed natural landscapes the species may be increasingly stressed with increasing warming.

Archetype 3/pathway 1. For reforestation of grassland to woodland there are positive benefits to biodiversity for improved grasslands but negative impacts for rough grasslands (where focus should be on restoration) at warming levels of 2°C and below, at higher warming levels focus should be on more northerly areas. Across the total number of commercial timber species that could potentially be used for restoration, the percentage of species to choose from drops to 74% of the potential at 1.5°C to 56% of the potential at 4°C.

Archetype 3/pathway 2. For reforestation of agriculture to woodland there are positive benefits to biodiversity at 2°C and below, at higher warming levels focus should be on more northerly areas. Across the total number of commercial timber species that could potentially be used for restoration, the percentage of species to choose from drops to 74% of the potential at 1.5°C to 56% of the potential at 4°C. This indicates that there needs to be careful selection of tree species to plant.

Archetype 4 (Suburban fringe). The amount of area lost as climate refugia ranges from 70% at 2°C to 0% at 4°C indicating this Archetype is highly exposed to higher levels of warming. Overall species richness remaining in landcover identified as agriculture drops from 47% at 1.5°C to 29% at 4°C. In areas classified as natural landcover the drop is from 9% to 6%. The large difference between the projected impacts in agricultural versus natural landscapes suggests that, climatically, agriculture occupies the 'better' climatic space. Restoration of agricultural land (included lands degraded by grazing) would potentially show some benefits to biodiversity, but this rapidly falls off with increasing warming. An examination of a subset of biodiversity, insect pollinators, shows a projected loss of suitable climate space in agricultural landcover areas of 26% of the species with 1.5°C warming rising to 70% with 4°C warming. This indicates that the ability to grow insect pollinated crops could potentially become seriously constrained. In areas classified as natural landcover, the loss of climatic space for insect pollinators is less severe and ranges from 25% at 1.5°C to 69% at 4°C.

Archetype 4/pathway 1. For reforestation of agriculture to woodland there are positive benefits to biodiversity at <2°C, at higher warming levels focus should be on more northerly areas. Transitions occur at higher temperatures reducing benefits. Across the total number of commercial timber species that could potentially be used for restoration, the percentage of species to choose from drops to 53% of the potential at 1.5°C to 39% of the potential at 4°C.

Archetype 4/pathway 2. For reforestation of grassland to woodland there are positive benefits to biodiversity for improved grasslands but negative for rough grasslands at <2°C. Priority should be more on broadleaved than coniferous and increases in settlement could offset other biodiversity benefits. In areas classified as natural landcover, the timber species richness remaining is low, with only 10% of the species with 1.5°C warming falling to 8% at 4°C. This indicates that this transition would be very difficult, and that emphasis might best be placed on restoration of natural grasslands.

Archetype 5 (Hilly farmland). Afforestation of grassland to broad-leaved woodland is beneficial in areas with improved grassland but detrimental in areas with rough grassland (afforestation should be avoided here). Overall biodiversity benefits lower than in other archetypes and steadily decrease over time. The amount of area lost as climate refugia ranges from 10% at 2°C to 75% at 4°C. Overall species richness remaining in landcover identified as agriculture drops from 44% at 1.5°C to 28% at 4°C. In areas classified as natural landcover the drop is from 46% to 31%. Afforestation would further impact on biodiversity. An examination of a subset of biodiversity, insect pollinators, shows a projected loss of suitable climate space in agricultural landcover areas of 7% of the species with 1.5°C warming rising to 54% with 4°C warming. This indicates that the ability to grow insect pollinated crops could potentially become seriously constrained. In areas classified as natural landcover, the loss of climatic space for insect pollinators ranges from 8% at 1.5°C to 53% at 4°C. Across the total number of commercial timber species that could potentially be used for restoration, the percentage of species to choose from drops to 45% of the potential at 1.5°C to 38% of the potential at 4°C. In areas classified as natural landcover, the species richness remaining is 48% of the species at 1.5°C warming falling to 40% at 4°C. Tree-planting in this Archetype would need to carefully consider species choice.

Archetype 6 (pen pasture). The amount of area lost as climate refugia ranges from 0% at 2°C to 65% at 4°C. Overall species richness remaining in landcover identified as agriculture drops from 72% at 1.5°C to 50% at 4°C. In areas classified as natural landcover the drop is from 18% to 13%. Restoration of agricultural land (included lands degraded by grazing) would potentially show some benefits to biodiversity, but this rapidly falls off with increasing warming. An examination of a subset of biodiversity, insect pollinators, shows a projected loss of suitable climate space in agricultural landcover areas of 5% of the species with 1.5°C warming rising to 44% with 4°C warming. This indicates that the ability to grow insect pollinated crops could potentially become seriously constrained. In areas classified as natural landcover, the loss of climatic space for insect pollinators is less severe and ranges from 5% at 1.5°C to 44% at 4°C. Across the total number of commercial timber species that could potentially be used for restoration, the percentage of species to choose from drops to 74% of the potential at 1.5°C to 64% of the potential at 4°C. In areas classified as natural landcover, the species richness remaining is low, with only 19% of the species with 1.5°C warming falling to 16% at 4°C. This indicates that in treed natural landscapes the species may be increasingly stressed with increasing warming.

Archetype 6/pathway 1. Afforestation of grassland to broad-leaved woodland is beneficial in areas with improved grassland but detrimental in areas with rough grassland (afforestation should be avoided here). This archetype could achieve some of the greatest biodiversity gains, at least up to 2°C.

Archetype 6/ pathway 2. This transition has even greater biodiversity benefits than pathway 1 as rough grasslands also increase.

Archetype 7 (Enclosed pasture). This archetype and transition can see large biodiversity benefits, with caveats. The large increase in coniferous woodland is only beneficial if a) native species; b) areas that naturally had coniferous woodlands and c) diverse species planted. As above, rough grassland conversion should be avoided. Benefits decline steadily with increased warming but are still higher than many other archetypes. The amount of area lost as climate refugia ranges from 10% at 2°C to 95% at 4°C. Overall species richness remaining in landcover identified as agriculture drops from 73% at 1.5°C to 45% at 4°C. In areas classified as natural landcover the drop is from 10% to 6%. Restoration of agricultural land (included lands degraded by grazing) would potentially show some benefits to biodiversity, but this rapidly falls off with increasing warming. An examination of a subset of biodiversity, insect pollinators, shows a projected loss of suitable climate space in agricultural landcover areas of 13% of the species with 1.5°C warming rising to ~65% with 4°C warming. This indicates that the ability to grow insect pollinated crops could potentially become seriously constrained. In areas classified as natural landcover, the loss of climatic space for insect pollinators is less severe and ranges from 14% at 1.5°C to 64% at 4°C. Across the total number of commercial timber species that could potentially be used for restoration, the percentage of species to choose from drops to 78% of the potential at 1.5°C to 60% of the potential at 4°C. In areas classified as natural landcover, the species richness remaining is low, with only 11% of the species with 1.5°C warming falling to 8% at 4°C.

Archetype 8 (Acid upland grassland) is mostly natural land although much has potentially been degraded by overgrazing. It currently holds few species, but these are rare species and if restored to heathland, the habitat could once again support breeding waders and rare plants, especially in the wetter areas which still support declining numbers of curlew and lapwing. This habitat would be resilient to climate changes to at least 3°C. However, baseline projections of afforestation with pines severely threaten this resilience and would lead to overall loss of biodiversity as opposed to restoration to heathland. The transition would be beneficial as it reduces slightly the amount of afforestation and reduces stocking density. The amount of area lost as climate refugia ranges from 0% at 2°C to 30% at 4°C. Overall species richness remaining in landcover identified as natural drops from 88% to 70%. Thus, this is an archetype best considered as being prime for land sparing opportunities. An examination of a subset of biodiversity, insect pollinators, shows a projected loss of suitable climate space in agricultural landcover areas of 16% of the species with 1.5°C warming rising to 53% with 4°C warming. This indicates that the ability to grow insect pollinated crops could potentially become seriously constrained. In areas classified as natural landcover, the loss of climatic space for insect pollinators is less severe and ranges from 5% at 1.5°C to 29% at 4°C. Proper siting of a matrix of natural and agricultural land could help provide a pollinator 'bank' for insect pollinated crops. In areas classified as natural landcover, the species richness remaining is 88% of the species with 1.5°C warming falling to 78% at 4°C.

Archetype 9 (Arable on chalk/clay) The amount of area lost as climate refugia ranges from 35% at 2°C to 100% at 4°C. Overall species richness remaining in landcover identified as agriculture drops from 71% at 1.5°C to 43% at 4°C. In areas classified as natural landcover the drop is from 5% to 3%. The large difference between the projected impacts in agricultural versus natural landscapes suggests that, climatically, agriculture occupies the 'better' climatic space. Restoration of agricultural land (included lands degraded by grazing) would potentially show some benefits to biodiversity, but this rapidly falls off with increasing warming. An examination of a subset of biodiversity, insect pollinators, shows a projected loss of suitable climate space in agricultural landcover areas of 28% of the species with 1.5°C warming rising to ~72% with 4°C warming. This indicates that the ability to grow insect pollinated crops could potentially become seriously constrained. In areas classified as natural landcover, the loss of climatic space for insect pollinators is less severe and ranges from 28% at 1.5°C to 72% at 4°C. Proper siting of a matrix of natural and agricultural land could help provide a pollinator 'bank' for insect pollinated crops. Across the total number of commercial timber species that could potentially be used for restoration, the percentage of species to choose from drops to 81% of the potential at 1.5°C to 57% of the potential at 4°C. In areas classified as natural landcover, the species richness remaining is low, with only 6% of the species with 1.5°C warming falling to 4% at 4°C. This indicates that in treed natural landscapes the species may be increasingly stressed with increasing warming.

Archetype 9/pathways 1 and 2 mostly benefit biodiversity (except for loss of rough grassland) but overall benefits rapidly decline with increasing warming and with increasing settlement size.

Archetype 10 (Arable on sandy soils). The amount of area lost as climate refugia ranges from 10% at 2°C to 85% at 4°C. Overall species richness remaining in landcover identified as agriculture drops from 73% at 1.5°C to 47% at 4°C. In areas classified as natural landcover the drop is from 10% to 6%. Restoration of agricultural land (included lands degraded by grazing) would potentially show some benefits to biodiversity, but this rapidly falls off with increasing warming. An examination of a subset of biodiversity, insect pollinators, shows a projected loss of suitable climate space in agricultural landcover areas of 15% of the species with 1.5°C warming rising to 61% with 4°C warming. This indicates that the ability to grow insect pollinated crops could potentially become seriously constrained. In areas classified as natural landcover, the loss of climatic space for insect pollinators is less severe and ranges from 16% at 1.5°C to 62% at 4°C. Proper siting of a matrix of natural and agricultural land could help provide a pollinator 'bank' for insect pollinated crops. Across the total number of commercial timber species that could potentially be used for restoration, the percentage of species to choose from drops to 78% of the potential at 1.5°C to 61% of the potential at 4°C. In areas classified as natural landcover, the species richness remaining is low, with only 11% of the species with 1.5°C warming falling to 8% at 4°C. This indicates that in treed natural landscapes the species may be increasingly stressed with increasing warming. The Archetype 10 transition mostly benefits biodiversity (except for loss of rough grassland) but overall benefits rapidly decline with increasing warming and with increasing settlement size.

Archetype 11 (Lowland agriculture in Northern Ireland). The land use transition is very beneficial for biodiversity overall, benefits decline slightly with increasing warming. The amount of area lost as climate refugia ranges from 0% at 2°C to ~10% at 4°C. Overall species richness remaining in landcover identified as agriculture drops from 66% at 1.5°C to 51% at 4°C. In areas classified as natural landcover the drop is from 25% to 19%. Restoration of agricultural land (included lands degraded by grazing) would potentially show benefits to biodiversity. An examination of a subset of biodiversity, insect pollinators, shows a projected loss of suitable climate space in agricultural landcover areas of 3% of the species with

1.5°C warming rising to ~31% with 4°C warming. This indicates that the ability to grow insect pollinated crops could potentially become seriously constrained. In areas classified as natural landcover, the loss of climatic space for insect pollinators is similar, ranging from 3% at 1.5°C to 31% at 4°C. Across the total number of commercial timber species that could potentially be used for restoration, the percentage of species to choose from drops to 37% of the potential at 1.5°C to 29% of the potential at 4°C. In areas classified as natural landcover, the species richness remaining is low, with only 25% of the species with 1.5°C warming falling to 22% at 4°C. This indicates that in treed natural landscapes the species may be increasingly stressed with increasing warming.

Archetype 12 (Uplands in Northern Ireland). The land use transition is beneficial for biodiversity. The amount of area lost as climate refugia ranges from 0% at 2°C to 5% at 4°C. Overall species richness remaining in landcover identified as agriculture drops from 27% at 1.5°C to 22% at 4°C. In areas classified as natural landcover the drop is from 69% to 59%. An examination of a subset of biodiversity, insect pollinators, shows a projected loss of suitable climate space in agricultural landcover areas of 3% of the species with 1.5°C warming rising to ~24% with 4°C warming. This indicates that the ability to grow insect pollinated crops could potentially become constrained. In areas classified as natural landcover, the loss of climatic space for insect pollinators is less severe and ranges from 2% at 1.5°C to 16% at 4°C. Across the total number of commercial timber species that could potentially be used for restoration, the percentage of species to choose from drops to 27% of the potential at 1.5°C to 24% of the potential at 4°C. In areas classified as natural landcover, the species richness remaining is higher, with 68% of the species with 1.5°C warming falling to 61% at 4°C.

Archetype 100 (all other rural land). The amount of area lost as climate refugia ranges from 10% at 2°C to ~65% at 4°C. Overall species richness remaining in landcover identified as agriculture drops from 35% at 1.5°C to 22% at 4°C. In areas classified as natural landcover the drop is from 50% to 37%. An examination of a subset of biodiversity, insect pollinators, shows a projected loss of suitable climate space in agricultural landcover areas of 18% of the species with 1.5°C warming rising to 62% with 4°C warming. This indicates that the ability to grow insect pollinated crops could potentially become seriously constrained. In areas classified as natural landcover, the loss of climatic space for insect pollinators is less severe and ranges from 8% at 1.5°C to 40% at 4°C. Proper siting of a matrix of natural and agricultural land could help provide a pollinator ‘bank’ for insect pollinated crops. Across the total number of commercial timber species that could potentially be used for restoration, the percentage of species to choose from drops to 37% of the potential at 1.5°C to 29% of the potential at 4°C. In areas classified as natural landcover, the species richness remaining is low, with only 30% of the species with 1.5°C warming falling to 43% at 4°C. This indicates that in treed natural landscapes the species may be increasingly stressed with increasing warming

8. Discussion and conclusions

This project has brought together a range of metrics to characterise 12 rural land use archetypes, covering 55% of the UK's rural area, and how these metrics will change under future land transition pathways with and without changes in climate. There are common themes across all archetypes and within groups of archetypes. These common themes and notable outliers are described and there is a discussion of the overall conclusions that can be drawn from this work and the advantages and limitations of the archetype approach.

8.1 Changes common to all archetype pathways

Baseline pathways

Rural land cover in the UK in 2021 is dominated by grassland habitats (62%) and arable land (26%), with smaller areas of woodland and other semi-natural habitats. In the baseline pathway for all archetypes there is limited land use change, and a small decline in arable and improved pasture grassland as areas of woodland, urban/suburban land and bog habitats increase in line with current policies and trends (Section 4). The area of semi-natural habitats only increases by 1.6% by 2050. Combined Agriculture and LULUCF sector GHG emissions fall by only 2.2% by 2050 under the Baseline pathway. Agriculture emissions increase by 10%. Ecosystem service metrics do not change substantially from 2021 in the baseline pathway as land use change is limited. All archetypes, except Archetype 1 (Lowland organic soils), provide a net economic benefit in the baseline pathway, delivering around £1000 of net benefits per hectare per year in 2021. These remain stable to 2050, with increases in net GHG emission costs balanced by increase in livestock production and reductions in private costs. Soil carbon modelling predicted losses of soil organic carbon across all archetypes, but limitations in the scope of modelling indicates that these predictions should be treated with caution.

Transition pathways

In the transition pathways (with no climate change assumed) the land use change trends seen in the Baseline pathway are amplified, with intensive agricultural land changing to woodland and semi-natural habitats. A fall in livestock numbers across most archetypes drives a reduction in agricultural emissions, with more than half the archetypes seeing >20% reductions by 2050. LULUCF GHG emissions from archetypes with organic soils also decline markedly, and there are large increases in carbon sequestration for Archetypes dominated by livestock grazing (3-7) and in 9 (Arable on chalk/clay). Different mitigation measures can have similar impacts on GHG emissions, for example pathways 1 and 2 for Archetype 3 (Intensive grassland) have similar levels of reduction, but this comes from increased afforestation in pathway 1 and bioenergy crop production in pathway 2. The combined reduction in Agriculture and LULUCF sector GHG emissions is 1-7 Mt CO_2e per archetype, with five pathways becoming a net GHG sink in 2050, compared to a net source in the baseline pathway. Overall, there was a 23.8-28.1 Mt CO_2e reduction in combined net emissions. This is 45-53% of the net emissions reduction estimated under the Balanced Pathway in the 7th Carbon Budget.

There is a larger percentage change in ecosystem service provision by 2035 and 2050 compared to the baseline pathway, with some change evident across most archetypes. In all archetypes, the transitions increase carbon storage and soil ecosystem services over and above baseline changes, with the significant proportion of this change occurring between 2035 and 2050. Land cover diversity and recreation metrics increase as there is a shift from agriculturally productive land-uses to more multifunctional landscapes. However, the direction of change for individual transitions is quite variable and relative change in biodiversity species richness tends to be very small. The modelled impact of land use change on soil organic carbon density were very small but may be conservative as increased carbon inputs from growing trees (after the initial soil disturbance from planting) were not considered.

The cost/benefit modelling showed a substantial increase in net benefits compared to the baseline, due to reduced net GHG emissions and increased net social benefits. These typically range from £500 to £1,500 per hectare per year (archetype 1 (Lowland organic soils) excepted). Reductions in agricultural revenue are not adequately compensated for by increases in other private benefits (except in archetypes with increased solar PV generation). However, any loss of net private benefits is outweighed by increases in social benefits. This highlights both the potential importance of solar as a revenue stream and the need for sufficient financial incentives to deliver the land use and management changes to maintain and enhance nature and the wider environment.

Climate change risks

Future climate change is likely to affect the modelled metrics under the baseline and transition pathways (Section 7). The risks assessed by this project are those that can be derived from long-term climate modelling; it was not possible to quantify the impact of extreme events within the scope of this project. Adaptation can also mitigate the impacts of climate change, for example by changes in agricultural management, and choice of crops and tree species that are better able to cope with predicted climate conditions and fire weather.

Heat stress is modelled as mostly affecting archetypes in the south and east of England (1, 4, 9, 10) under 1.5°C and 2°C climate scenarios, but has much wider impacts across most GB archetypes under 3°C and 4°C scenarios. This not only affects livestock but also has implications for existing woodland, new woodland and agroforestry and bioenergy crops. Yields of existing UK crops are modelled to increase up to the 3°C scenario, but then to plateau or even decline under the 4°C scenario, with particular implications for the arable dominated archetypes (1, 4, 9, 10). However, the suitability of existing marginal or potential future crops is modelled as increasing under the different climate scenarios, although increasing suitability does not necessarily translate into increasing viability.

The increase in fire weather risk across archetypes depends both upon their geographic location and the mixture of land cover and management at higher risk times of year.

The impact of climate change on soil organic carbon stocks showed a mixed picture, with predicted declines in many archetypes under 1.5°C, 2°C and 3°C climate scenarios but increases in others. Decrease in SOC was predicted in the archetypes where the decomposition of SOC (enhanced by increasing temperature) exceeded the organic matter inputs (enhanced by increasing precipitation – but not waterlogged). An increase in SOC was predicted in the archetypes where the organic matter inputs were likely enhanced by increasing precipitation (especially the areas near the coast) that exceeded the impacts of increasing temperature. The impact of climate change on soil carbon was more marked than the impact of land use change across the archetypes between 2021 and 2050.

Climate change is projected to have a major negative impact on the amount of land available as biodiversity refugia, with archetypes with large areas of intensive agriculture in GB most affected. Biodiversity, insect pollination and timber species richness is projected to decline with increasing warming across all archetypes, but these metrics show steeper declines on agricultural land than natural land cover. This indicates that the ability to grow insect pollinated crops could potentially become seriously constrained but proper siting of a matrix of natural and agricultural land could help provide a pollinator 'bank' for insect pollinated crops. 'natural' woodland cover may become increasingly stressed with increased warming, reducing its resilience to extreme climate events.

8.2 Summaries of archetype groups

Archetypes have been aggregated into predominantly arable, improved lowland grassland, upland grassland, organic soil-dominated and suburban fringe. Tables summarising the principal metrics for each archetype enable comparison between and within these groups. Graphical elements are intended to indicate the relative proportions of components within land cover and costs/benefits, so quantified scales have been omitted for simplicity. Detailed quantitative information is included in the Appendix workbook. Information has been categorised for ease of interpretation as follows:

- Area: Small <6,000 km^2 (<600,000 ha); Medium 6,000-12,000 km^2 (600,000-1,200,000 ha); Large >12000 km^2 (>1,200,000 ha);
- Land in 2021
  - Percentage that is ALC Grade 1-3 in Great Britain (high quality agricultural land);
  - Land composition Bw (Broadleaved woodland), Cw (Coniferous woodland), Cr (Arable and horticulture), Pg (Improved grassland), Rg (Semi-natural grassland), W (Near-natural bog/fen and peat extraction), S (Urban and suburban land);

- GHG emissions (net balance of agricultural and LULUCF emissions): Small source/sink <2 Mt CO_2e; Large source/sink >2 Mt CO_2e; dominant source/sink noted in brackets;
- Ecosystem Services, expressed in comparison to total national average: ◆ above average, ◆ below average, ◆ mixed response, ◇ no data.
  - Cseq (GHG sequestration and carbon storage metrics); Water (Water quantity and quality metrics); Crops (Crop production metrics); Rec (Recreation metrics); Bio(b) (Bird biodiversity metrics); Bio(v) (Other vertebrate biodiversity metrics); Poll (Pollination and pest control metrics).
- Costs and benefits: Overall net benefit value (excluding biodiversity);
  - **Private.** AgC: Agricultural production (arable and horticulture); AgL: Agricultural production (livestock); Pb: Other private benefits; Pc: Private costs.
  - **Social.** GHG: Net GHG emissions (agriculture and LULUCF); Sb: Net social benefits;

Predominantly arable archetypes

Archetypes 9 (Arable on chalk/clay) and 10 (Arable on sandy soils) (Table 11) are very similar in their baseline metrics: both are large and dominated by high-grade arable land and improved grassland. They have large livestock herds and both have much higher numbers of pigs and poultry than other archetypes: 40% of UK pigs and 33% of UK poultry are farmed in these archetypes. They are a net source of GHG emissions, predominantly from the Agriculture sector, although Archetype 10 also has substantial LULUCF emissions from cropland. They have the largest agricultural ammonia emissions, with a larger proportional contribution from pigs, poultry and fertilizer than other archetypes.

As intensively farmed landscapes, both score below average for carbon sequestration, water quality and quantity and recreation metrics, but above average for crop production metrics. Ecosystem service metrics do not change substantially by 2050 in the baseline pathway. For biodiversity they score well above average for farm bird species richness, other vertebrate metrics and bee/natural enemy occurrence but below average pollinator visits. Both have high private costs/benefits and low social costs/benefits with high overall net benefits compared to other archetypes (less marked when compared on a per hectare basis). There is a small decline in overall net benefit by 2050 in the baseline pathway.

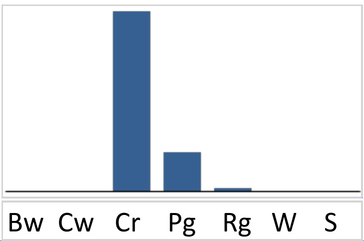
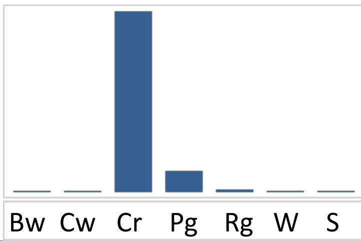
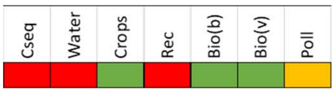
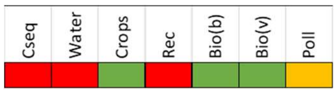
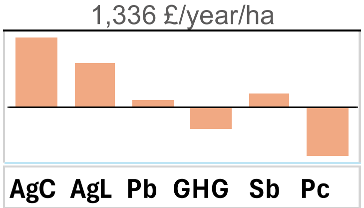
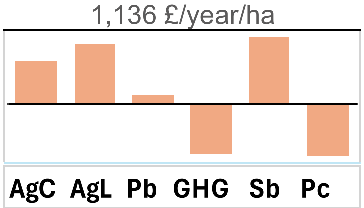
In the transition pathways 9/1 and 10/1 both focus on agroforestry, hedgerows and energy crop production. Pathway 9/2 is an alternative with woodland creation for habitat creation and solar PV, but no energy crop production. All three transitions have net conversion from cropland and intensive grassland to woodland, with a smaller amount from semi-natural grassland, although the relative contributions vary between the transition pathways. GHG emissions reduce compared to the baseline, with LULUCF becoming a net sink in 2050 in both Archetype 9 transitions and a smaller net source in Archetype 10. There was very little change in agricultural ammonia emissions.

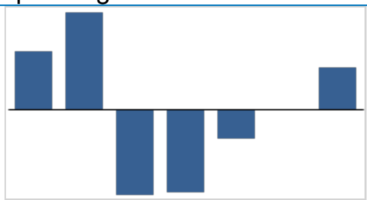
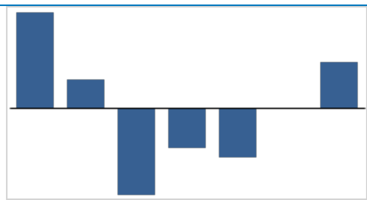
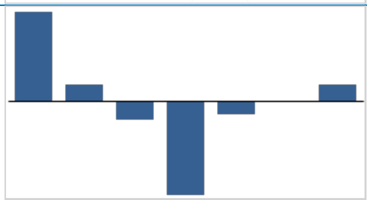
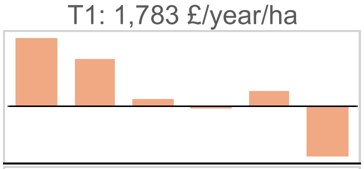
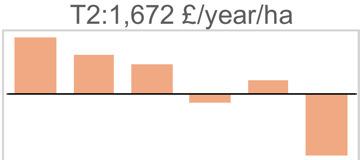
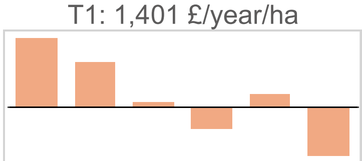
Changes in ecosystem service metrics were small: with reductions in the grassland potential production metric and a more noticeable increase in the land cover biodiversity index under all transitions.

In contrast to the baseline pathway, both archetypes show an increase in net overall benefit in the transition pathways. Other private benefits show a substantial increase under Archetype 9 pathway 2, compared to the Baseline and pathway 1. The net cost of GHG emissions reduces due to increased carbon sequestration from tree cover in both archetypes.

These archetypes are modelled as being particularly vulnerable to increasing heat stress under all climate scenarios, which will impact on their large livestock herds and flocks. This may be mitigated by the increased agroforestry in the transition pathways with tree canopies providing additional shade and shelter to both livestock and crops. They are also predicted to experience noticeable impacts on crop yields which will require shifts in crop choice and agricultural management. Compared with the baseline pathway for these archetypes, transitions will mostly benefit biodiversity but this rapidly declines under increased warming and with expanding urban areas.

Table 11: Summary of predominantly arable archetypes

	Archetype 9	Archetype 10
Name	Intensive and valley/floodplain arable on chalk/clay soils in England	Arable on sandy soils in England and Scotland
Area	Large	Large
Land in 2021	91% ALC 1-3 	92% ALC 1-3 
2021 GHG emissions	Large net source (Agriculture)	Large net source (Agriculture)
2021 Ecosystem services		
2021 Costs and benefits	1,336 £/year/ha 	1,136 £/year/ha 

	Archetype 9	Archetype 10
2050 baseline net benefits	1,312 £/year/ha	1,020 £/year/ha
Transition description	1- Expansion of on-farm tree cover and bioenergy crops 2-Tree planting for habitat creation, expansion of on-farm tree cover and solar power generation	1- Expansion of on-farm tree cover and bioenergy crops
Change in Land in Transition 1 by 2050		
Change in Land in Transition 2 by 2050		N/A
2050 GHG emissions	Trans. 1: Small source (Agriculture) Trans. 2: Large source (Agriculture)	Trans. 1: Large source (Agriculture)
Change in Ecosystem Services by 2050 (Trans. 1 And 2)		
2050 Costs and benefits	T1: 1,783 £/year/ha  T2:1,672 £/year/ha 	T1: 1,401 £/year/ha 

Improved grassland lowland archetypes

Archetypes 3 (Intensive grassland), 7 (Enclosed pasture) and 11 (Lowland agriculture in Northern Ireland) (Table 12) are all dominated by pasture grassland of high agricultural quality. They have large herds of cattle and sheep and have the highest milk production of all the archetypes. Archetype 11 has particularly high livestock-based agricultural production, considering its small size. They are all net sources of GHG emissions in the Baseline pathway, with Agriculture emissions dominant. These archetypes have comparatively large agricultural ammonia emissions, predominantly from dairy and beef cattle.

As intensively farmed pasture landscapes, all score below average for carbon sequestration, water quality and quantity and recreation metrics and cropland metrics except grass potential production. There is a mixed picture for biodiversity metrics, with different bird species richness above average in different archetypes. Other vertebrate species richness/diversity metrics are above average in Archetypes 3 and 7, but not in Arcehtype 11. Ecosystem service metrics do not change substantially by 2050 in the baseline pathway, apart from a decline in cropland metrics in Archetype 11. Archetypes 3 and 7 have similar balances of private and social costs and benefits, and overall net cost/benefit value. Archetype 11 has much higher agricultural benefit value, but this is balanced by higher GHG emissions and private costs, producing a much lower net cost/benefit value.

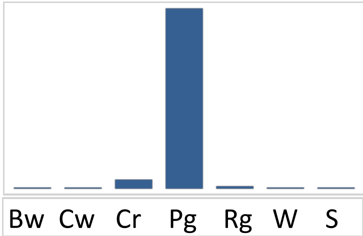
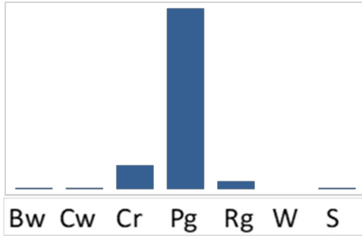
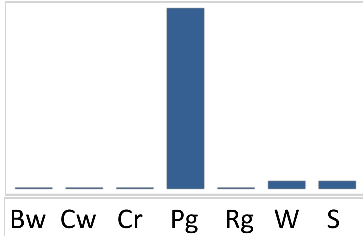
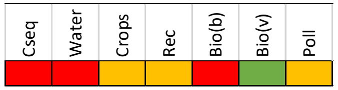
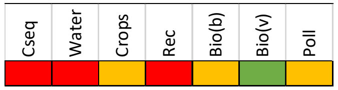
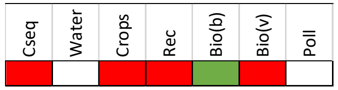
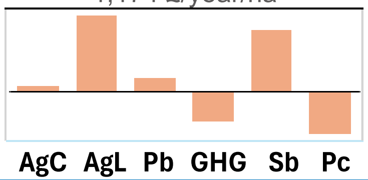
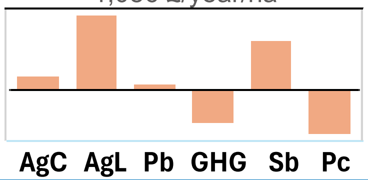
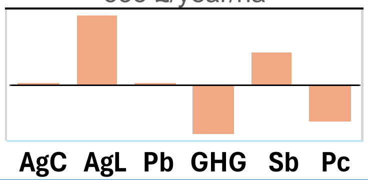
In the transition pathways 3/1, 7/1 and 11/1 a mixture of measures are applied including the planting of productive timber plantations, agroforestry and hedgerows. Pathway 3/2 is an alternative with energy crop production, solar PV (also in 7/1) and restoration of intensive agricultural land to semi-natural habitats. In the two Archetype 3 pathways livestock densities on pasture are also increased to offset falls in agricultural production with reduced pasture area. The transition for Archetype 11 in Northern Ireland includes woodland habitat creation, restoration of lowland and upland peat and sustainable management of lowland peat where possible. GHG emissions reduce compared to the baseline, although only 7/1 shifts to a net sink.

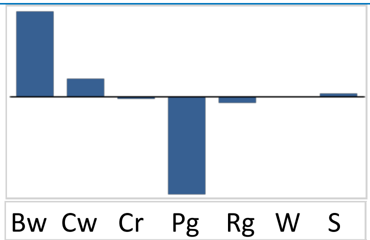
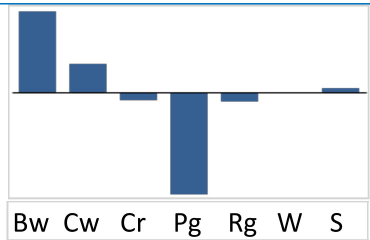
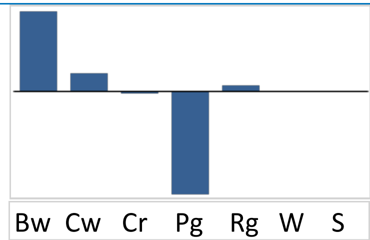
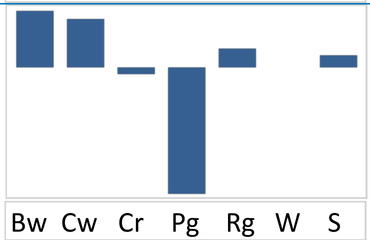
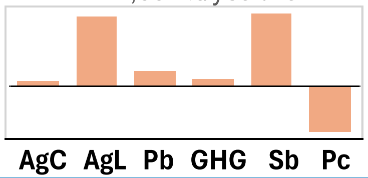
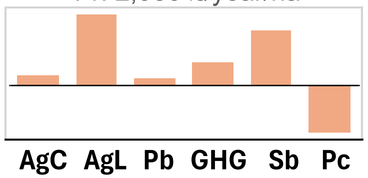
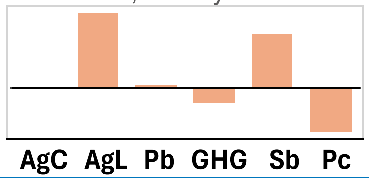
Changes in ecosystem services under the transition pathways were generally small. Pathways 3/1, 3/2 and 7/1 all showed increases in carbon sequestration and water metrics and declines in cropland metrics. The decline in cropland production metrics was substantial in 11/1, and all transitions showed an increase in landscape diversity.

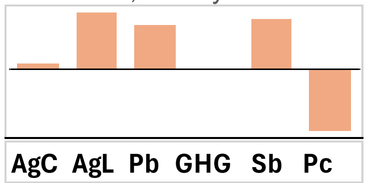
All transitions see a considerable increase in net benefits, particularly in 7/1 and 11/1, due to reduction in net GHG emissions and an increase in net social benefits and other private benefits (3/2).

These archetypes are increasingly affected by heat stress, with Archetype 3 being particularly vulnerable because of its large grazing livestock herds. Although these archetypes become climatically suitable for a wider range of crops under climate change, they may not be geographically suitable and would require a large-scale shift in agricultural systems. Archetype 3 is also predicted to have increasing fire danger under climate change, which may threaten carbon sequestration under the transition pathways. In contrast to 3/1 and 3/2, transitions 7/1 and 11/1 are projected to have large biodiversity benefits (with caveats). Although these benefits decline with increased warming they are still higher than many other archetypes, and Archetype 11 remains a biodiversity refugia even under the highest levels of warming.

Table 12: Summary of improved grassland lowland archetypes

	Archetype 3	**Archetype 7**	**Archetype 11**
Name	Intensive grassland in Wales and south-west England	Enclosed pasture in England and Wales	Lowland agriculture in Northern Ireland
Area	Large	Medium	Small
Land in 2021	67% ALC 1-3 	84% ALC 1-3 	N/A 
2021 GHG emissions	Large net source (Agriculture)	Small net source (Agriculture)	Large net source (Agriculture)
2021 Ecosystem services			
2021 Costs and benefits	1,174 £/year/ha 	1,086 £/year/ha 	535 £/year/ha 
2050 baseline net benefits	994 £/year/ha	1,084 £/year/ha	265 £/year/ha
Transition description	1- Plantation woodland creation and expansion of on-farm tree cover, increased stocking	1- Plantation woodland creation, expansion of on-farm tree cover and bioenergy crops	1- Tree planting for production and habitat creation, expansion of on-farm tree cover,

	Archetype 3	Archetype 7	Archetype 11
	2- Expansion of on-farm tree cover, bioenergy crops and solar power generation, increased stocking		restoration of degraded organic soils.
Change in Land in Transition 1 by 2050			
Change in Land in Transition 2 by 2050		N/A	N/A
2050 GHG emissions	Trans. 1: Small source (Agriculture) Trans. 2: Small source (Agriculture)	Trans. 1: Small sink (LULUCF)	Trans. 1: Small source (Agriculture)
Change in Ecosystem Services by 2050 (Trans. 1 And 2)			
2050 Costs and benefits	T1: 1,694 £/year/ha 	T1: 2,050 £/year/ha 	T1: 1,818 £/year/ha 

	Archetype 3	Archetype 7	Archetype 11
	T2: 1,616 £/year/ha 		

Upland grassland archetypes

Archetypes 5 (Hilly farmland), 6 (Open pasture) and 8 (Acid upland grassland) (Table 13) are grassland-dominated regions located in GB uplands or on the upland fringe. They are on a continuum from improved pasture-dominated (Archetype 6) to rough grazing-dominated (Archetype 8) with a corresponding reduction in high quality agricultural land and agricultural production. Sheep and beef cattle are the characteristic livestock. Archetype 8 has the lowest agricultural production, agricultural GHG emissions and ammonia emissions of all the archetypes. Archetypes 5 and 6 are small net GHG sources in 2021 while Arcehtype 8 is a small net sink.

Archetypes 5 and 6 are close to, or slightly below the national average for ecosystem service metrics. Archetype 8 is more distinctive, with above average carbon sequestration and water quality and quantity and recreation metrics but below average biodiversity metrics apart from pollinator visits. Ecosystem service metrics do not change substantially by 2050 in the baseline pathway, apart from a substantial reduction in grass potential production in Archetype 8. Archetype 8 also has one of the lowest overall net cost/benefit values reflecting its low agricultural income with other costs and benefits balancing each other. Archetype 6 has higher net social impacts and agricultural production than Archetype 5 but both are similar in terms of overall net cost/benefit per hectare. Net overall benefit increases by 2050 for all three archetypes in the baseline pathway.

The transition pathways include changes to livestock densities (5/1, 6/2), woodland creation to plantations (5/1, 6/1) or woodland habitat (6/2, 8/1), agroforestry and hedgerows (5/1, 6/1, 6/2) and semi-natural habitat restoration (6/2). Archetype 8 has very limited capacity for land use change due to its upland nature and low availability of suitable land for woodland creation, so transition options were limited. All archetypes become net GHG sinks by 2050, with transition 6/1 being larger than 6/2.

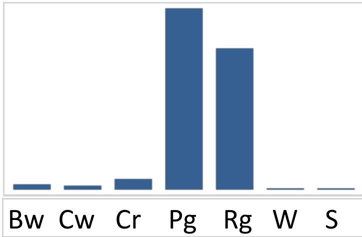
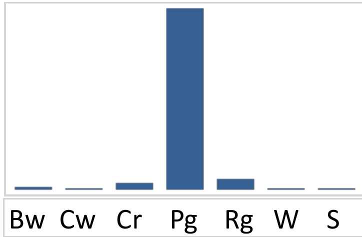
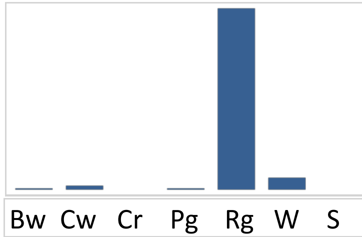
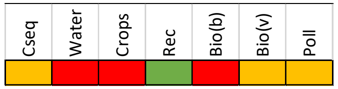
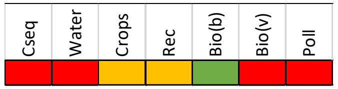
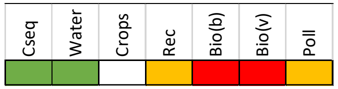
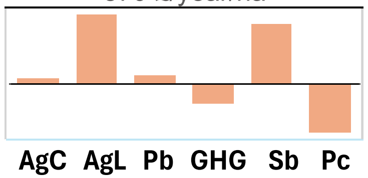
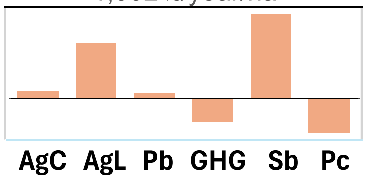
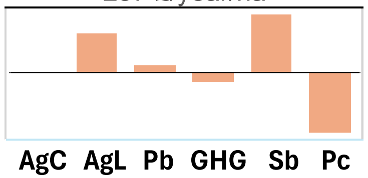
Changes in ecosystem metrics in transition 5/1, 6/2 and 8/1 were small, but more noticeable in transition 6/1 with increases in carbon sequestration and water metrics and landscape diversity.

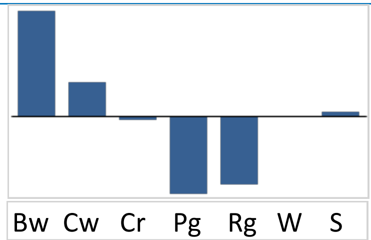
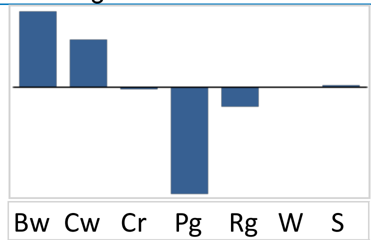
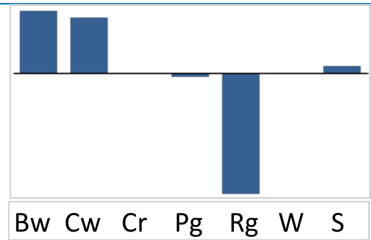
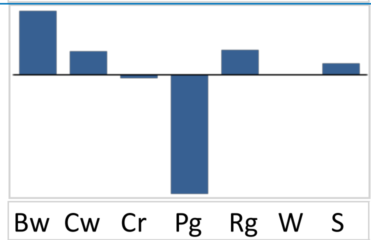
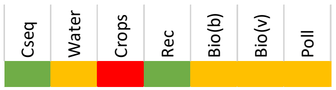
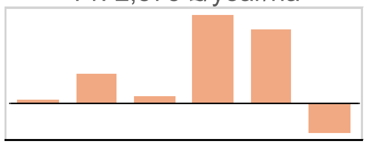
The Archetype 6 transition pathways showed a considerable increase in net benefit for 6/1 (>£1200 £/year/ha), due to the increased carbon sink from woodland creation and net social benefits, but only a small increase for 6/2. Transition 5/1 showed an increase in net benefit but overall net benefit actually declined slightly for 8/1 due to declining livestock production.

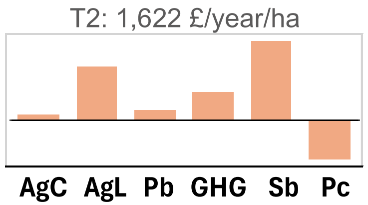
These archetypes are increasingly affected by heat stress under the 3°C and 4°C scenarios, with Archetype 6 being particularly vulnerable because of its large grazing livestock herds. Although these archetypes become climatically suitable for a wider range of crops under climate change, only Archetype 6 has a high percentage of high-grade agricultural land. Archetypes 6 and 8 are also predicted to have increasing fire danger under climate change, which may threaten carbon sequestration under the transition pathways and semi-natural habitats in Archetype 8.

Archetype 5 has lower overall biodiversity benefits than other archetypes, which decline steadily over time. In contrast, transitions 6/1 and 6/2 could achieve large biodiversity gains with conversion of land to broadleaved woodland and rough semi-natural grassland. Archetype 8, with low amounts of agricultural land, is more resilient to climate change, but woodland creation of this archetype (under the baseline pathway) will threaten this resilience and lead to loss of biodiversity.

Table 13: Summary of upland grassland archetypes

	Archetype 5	Archetype 6	Archetype 8
Name	Hilly farmland on improved and semi-natural grassland on nonorganic soils in GB	Open pasture on the upland fringe in England and Scotland	Acid grassland on hilly uplands in GB
Area	Small	Medium	Medium
Land in 2021	18% ALC 1-3 	35% ALC 1-3 	0% ALC 1-3 
2021 GHG emissions	Small net source (Agriculture)	Small net source (Agriculture)	Small net sink (LULUCF)
2021 Ecosystem services			
2021 Costs and benefits	870 £/year/ha 	1,002 £/year/ha 	257 £/year/ha 
2050 baseline net benefits	1,344 £/year/ha	1,591 £/year/ha	581 £/year/ha
Transition description	1-Plantation woodland creation and expansion of on-farm tree cover, reduced stocking	1-Plantation woodland creation and expansion of on-farm tree cover	1-Tree planting for habitat creation, reduced stocking

	Archetype 5	Archetype 6	Archetype 8
		2-Tree planting for habitat creation and on-farm tree cover expansion, increased stocking	
Change in Land in Transition 1 by 2050			
Change in Land in Transition 2 by 2050			
2050 GHG emissions	Trans. 1: Small sink (LULUCF)	Trans. 1: Large sink (LULUCF) Trans. 2: Small sink (LULUCF)	Trans. 1: Small sink (LULUCF)
Change in Ecosystem Services by 2050 (Trans. 1 And 2)			
2050 Costs and benefits	T1: 1,896 £/year/ha 	T1: 2,875 £/year/ha 	T1: 532 £/year/ha 

	Archetype 5	Archetype 6	Archetype 8
	AgC AgL Pb GHG Sb Pc	AgC AgL Pb GHG Sb Pc	AgC AgL Pb GHG Sb Pc
			

Organic soil archetypes

Archetypes 1 (Lowland organic soils), 2 (Upland organic soils) and 12 (Uplands in Northern Ireland) (Table 14) have large areas of organic soils with a range of agricultural land use and habitats. Archetype 1 is lowland with more intensive agriculture on high quality land, whereas Archetypes 2 and 12 are uplands with large proportions of semi-natural grassland and conifer woodland. All three have similar levels of meat production, although the livestock composition is different with more poultry in Archetypes 1 and 12, and more beef cattle and sheep in Archetype 2. All three are net sources of GHG emissions, with Archetypes 1 and 2 dominated by LULUCF emissions from organic soils. Agricultural ammonia emissions are relatively low compared to other archetypes.

Archetype 1 shows a very mixed picture for ecosystem metrics, whereas Archetypes 2 and 12 are above average for carbon sequestration and water quality/quantity but below average for biodiversity. Ecosystem service metrics do not change substantially by 2050 in the baseline pathway. Archetype 1 is the only archetype to have a strongly negative net cost/benefit value due to the large cost of GHG emissions. In contrast Archetype 2 (Upland organic soils) has the highest overall net benefit, due to high net social impacts, which is also the case for Archetype 12 when compared on a per hectare basis. By 2050 in the baseline pathway, net overall benefit has declined in all three archetypes, with a substantial negative value in Archetype 1.

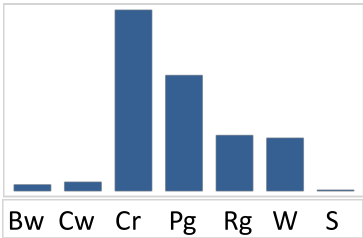
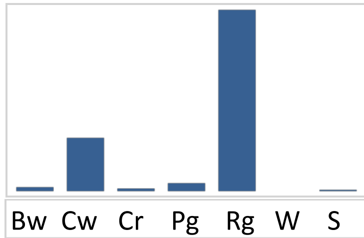
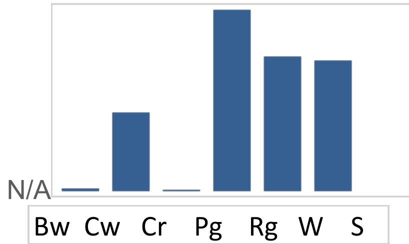
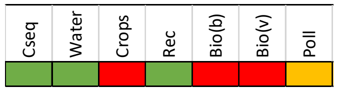
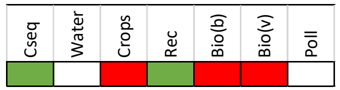
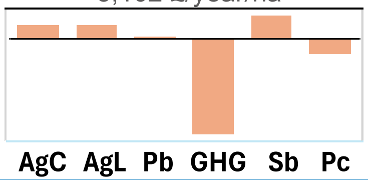
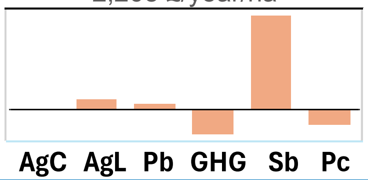
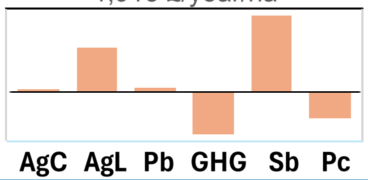
The transition pathways focussed on peatland restoration and sustainable management of peatland in the lowlands. This resulted in substantial change from arable and improved grassland to fen habitats in 1/1 and 12/1, and from conifer woodland to bog habitat in 2/1 and 12/1. Milk production declined markedly in 1/1, compared with other transitions, as the transition away from improved grassland was assumed to lead to a reduction in dairy cattle. The reduction in agricultural and LULUCF GHG emissions was particularly substantial in 1/1 and 2/1, due to peatland restoration and reduction in land used for agricultural production.

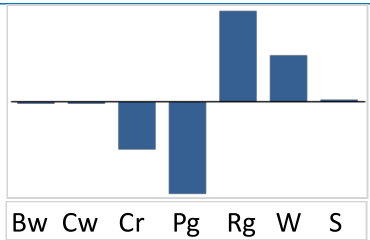
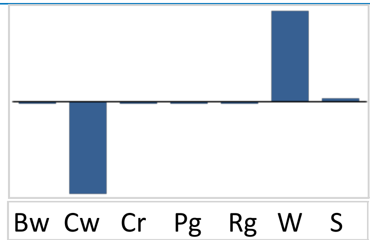
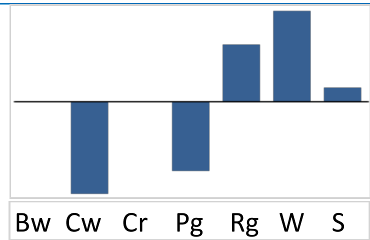
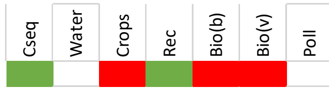
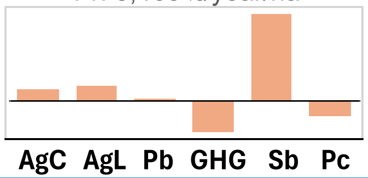
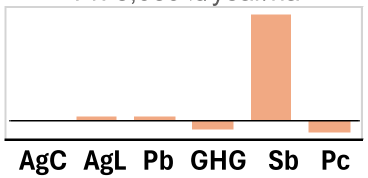
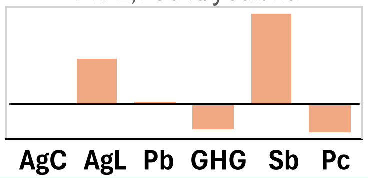
Changes in ecosystem service metrics in pathways 2/1 and 12/1 are very small but substantial in pathway 1/1 with increases in carbon sequestration and water metrics and declines in cropland metrics, reflecting the impacts of peatland restoration. There was a mixed response in the biodiversity and pollinator metrics.

Net overall benefits substantially increased in the transition pathways compared to the baseline pathway, primarily due to the reduction in GHG emissions and increase in net social benefits (particularly in 1/1) outweighing the reduction in agricultural production.

Archetype 1 is projected to be particularly vulnerable to heat stress and declining arable crop yields under future climate change, which will likely exacerbate degradation of its organic soils, but potentially strengthen the case for peatland restoration. The other two archetypes are less impacted by heat stress, except under the highest 4°C scenario, but do have increased fire risk, which threatens their existing stocks of soil carbon. Archetypes 2 and 12 continue to act as biodiversity refugia under increasing warming, whereas archetype 1 undergoes rapid decline. Transition 2/1 leads to a reduction in biodiversity in the species richness metric, but a potential increase in unique species. Transition 12/1 is beneficial for biodiversity, presumably due to the reduction in conifer plantations.

Table 14: Summary of organic soil archetypes

	Archetype 1	Archetype 2	Archetype 12
Name	Highly degraded lowland organic soils in GB	Degraded upland grazing land and forest on organic soils in GB	Uplands with large extent on organic soils in Northern Ireland
Area	Small	Large	Small
Land in 2021	52% ALC 1-3 	1% ALC 1-3 	
2021 GHG emissions	Large net source (LULUCF)	Large net source (LULUCF)	Small net source (Agriculture)
2021 Ecosystem services			
2021 Costs and benefits	-3,102 £/year/ha 	2,268 £/year/ha 	1,913 £/year/ha 
2050 baseline net benefits	-5,133 £/year/ha	2,124 £/year/ha	1,685 £/year/ha
Transition description	1-Restoration and sustainable management of lowland organic soils	1-Restoration of upland organic soils.	1-Restoration of degraded organic soils, reduced stocking and hedgerow expansion

	Archetype 1	Archetype 2	Archetype 12
Change in Land in Transition 1 by 2050			
2050 GHG emissions	Trans. 1: Small source (LULUCF)	Trans. 1: Small source (LULUCF)	Trans. 1: Small source (Agriculture)
Change in Ecosystem Services by 2050 (Trans. 1 And 2)			
2050 Costs and benefits	T1: 3,465 £/year/ha 	T1: 3,039 £/year/ha 	T1: 2,780 £/year/ha 

Suburban fringe

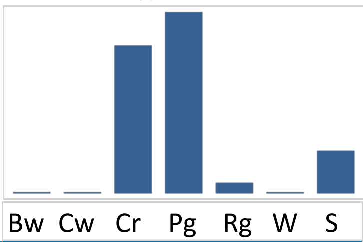
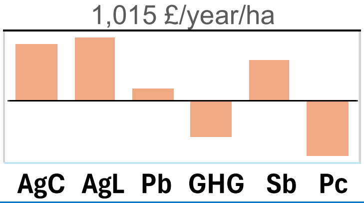
Archetype 4 (Suburban fringe) (Table 15) is a lowland archetype with intensive agriculture on high quality agricultural land and unique pressures due to proximity to urban areas. It falls 'mid-table' for many of the baseline metrics but is above-average for the biodiversity metrics. Ecosystem service metrics do not change substantially by 2050 in the baseline or transition pathways.

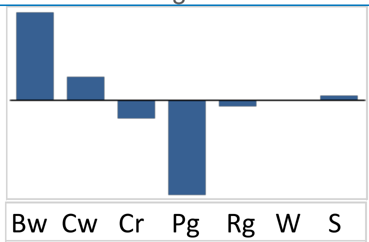
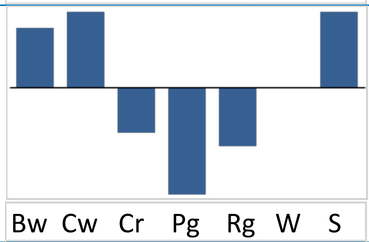
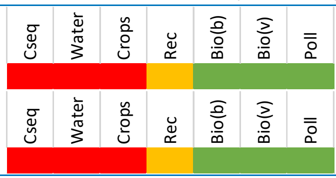
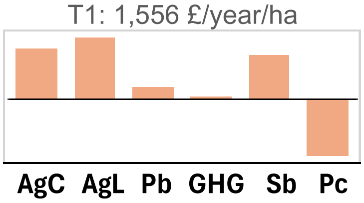
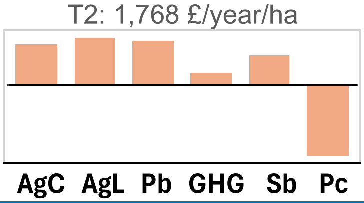
Net overall benefit substantially increases by 2050 in the baseline pathway, due to reduction in GHG emissions.

In the transition pathways 4/1 focussed on woodland habitat and hedgerow creation. Measures applied in the alternative pathway 4/2 were agroforestry on cropland and grassland, hedgerow creation, energy crop production and solar PV. Areas of habitat change were relatively low, primarily from improved grassland to broadleaved woodland under 4/1. Combined agricultural and LULUCF GHG emissions decline to close to zero.

Archetype 4 is projected to be particularly vulnerable to increasing heat stress and fire risk under future climate change, which is likely to have noticeable impacts on human populations and property due to the proximity to urban and suburban areas. The decline in the area of biodiversity refugia under increasing warming indicates that this archetype is highly exposed to increased warming levels. Land use change from agricultural land to woodland is likely to be very difficult and it may be better to focus on restoration to natural grassland in this archetype.

Table 15: Summary of suburban fringe archetype

	Archetype 4
Name	Farming on the suburban fringe in England
Area	Medium
Land in 2021	77% ALC 1-3 
2021 GHG emissions	Small net source (Agriculture)
2021 Ecosystem services	
2021 Costs and benefits	1,015 £/year/ha 

	Archetype 4
2050 baseline net benefits	1,513 £/year/ha
Transition description	1- Tree planting for habitat creation and hedgerow expansion 2- Expansion of on-farm tree cover, bioenergy crops and solar power generation
Change in Land in Transition 1 by 2050	
Change in Land in Transition 2 by 2050	
2050 GHG emissions	Trans. 1: Small source (Agriculture) Trans. 2: Small sink (LULUCF)
Change in Ecosystem Services by 2050 (Trans. 1 And 2)	
2050 Costs and benefits	T1: 1,556 £/year/ha  T2: 1,768 £/year/ha 

8.3 Discussion of the archetype approach

This is the first time a detailed examination of environmental and socio-economic metrics in relation to greenhouse gas mitigation and climate change has been undertaken at the landscape level across the UK. Previous analyses have been at the UK or devolved administration level, and the archetype approach represents a step towards more local spatial analysis. The finer spatial scale allows for a more detailed investigation of the opportunities and limitations of GHG mitigation within an archetype landscape, dependent upon the land cover, climate, soil and land management within that archetype. Because archetypes can span devolved administrations, similar issues and opportunities within a single archetype can be explored without boundary limitations. This makes for transparent land transition 'storylines' for different agricultural landscapes that can be understood by policy makers and land managers in different parts of the UK.

There are limitations to the archetype approach. The archetypes are not contiguous areas and land area changes can only be expressed as "a percentage of the archetype has changed land-use" and not *where* that land use change has occurred. Some archetypes are more regionally concentrated, e.g., Archetype 3 (Intensive grassland) and some are highly fragmented, e.g., Archetype 4 (Suburban fringe). This means that it was not possible to investigate the impact of mitigation measures beyond archetype boundaries, for example, whether tree planting mitigates down-stream flooding, because there is not a spatial link between the location of the new woodland and the river system. It is also difficult to draw detailed conclusions about the impact of climate change on the archetypes except at a high level, because of the fragmentary spatial nature of the archetypes. The Northern Irish archetypes (11 and 12) were more contiguous land areas, as they were derived from different source material (Young and Thomson 2023), but also contained a greater mixture of land uses and agricultural management, making it more difficult to derive coherent transition 'storylines'.

In part one of the archetypes project, archetypes were partly short-listed based on their total land area; for example, coastal landscapes were not considered because of their small land area. Short-listing was also based on the distinctiveness of chosen archetypes from other archetypes on the short-list. Much rural UK land area outside of the 12 archetypes is a blend of short-listed archetypes and the findings of this project are also applicable to those areas.

Many of the limitations of the archetype approach could be resolved by a finer scale spatial analysis (e.g. at the <1 km grid scale). This would enable more focussed location of mitigation measures and assessment of the impact on ecosystem service and socio-economic costs and benefits. For example, habitat-focussed woodland planting on formerly wooded areas will likely have more rapid biodiversity gains, and the consideration of transport infrastructure areas of high energy demand will affect the net economic benefit of locations for bioenergy crop production and solar PV. However, the increase in spatial scale would lead to a huge increase in complexity and resource requirements. Careful consideration would need to be given to the purpose of the analysis, its users and the intended audience for results.

8.4 Gaps and future work

It was not possible to cover all the topics of interest outlined in the initial scope. These include changes to above-ground biomass under future climate change; the impact of farm-level mitigation measures (cover crops, rotational management, methane reducing livestock feed additives); natural flood management; wind farms, paludiculture crop production; and detailed recreation metrics. Some of these are being addressed by current projects, e.g. the DESNZ/Defra Land Climate Programme and the UKRI Land Use for Net Zero programme. Others could be assessed with a finer-scale spatial analysis (see above). Improved modelling of mineral soil carbon changes under the transitions and future climate change would be achieved by coupling the soil modelling with above-ground carbon modelling to improve the soil inputs. This has been considered in the woodland creation modelling, but implementation for non-forest habitats was beyond the resources of the project.

The analysis of climate risks highlighted that the greater risks to agricultural production and carbon sequestration arise from short-lived climatic extremes (floods, droughts, wind storms), or indirect effects such as improved conditions for agricultural pests and diseases, or sub-optimal land management and timing. Quantification of the impacts of these events and effects is outside the scope of this project, particularly as the size of the impact would be greatly increased by the combination and timing of events. This could be a topic for further research as it is also a key aspect of analysing measures and impacts of climate change adaptation. Because of its basis in analysis of archetypes of land use, each of which is found in many different locations in the UK, the study can only give a general indication of the implications of the transitions. Whilst archetypes are a useful way to classify land use, a full spatial analysis is needed to properly guide policy. We also recommend an analysis of the implications of the policies assumed in the baseline, since some of these may have adverse implications.

Climate change risks and land-based mitigation measures are active research areas, and new scientific evidence and high-resolution datasets will continue to appear over the near- to medium-term. These can inform future work on this area. For example, high-resolution (10km) Fire Weather Index projections from the UK Met Office's HadGEM3 may be preferred, which can be made available on request. This approach would have the advantage of avoiding the downscaling used to estimate the impacts of fire weather (Section 7.3) but these projections are only available for one model, the UK Met Office's HadGEM3.

Other socio-economic research and tools are also needed to assess the viability of changes in land use and land management required to achieve the archetype transitions. This is particularly the case where climate change may affect the suitability of different agricultural systems and local agricultural infrastructure and knowledge need to change as a result.

8.5 Conclusions

In this project we have modelled the multiple impacts of a range of land-based mitigation measures applied to UK rural archetypes. Some measures are applicable across a wide range of rural landscapes, e.g. agroforestry and hedgerow creation, and some apply to only certain archetypes, e.g. peatland restoration. The archetype transitions illustrate a range of land-use and land management futures and how they contribute to GHG mitigation, agricultural production, ecosystem services and renewable energy generation. Alternative transitions have been explored for a subset of archetypes, exploring the outcomes of a more production-focussed versus a more mitigation-focussed transition in the same archetype. The analysis has explored the trade-offs between measures, such as potential carbon sequestration versus loss of biodiversity or net farm incomes.

Mitigation measures in the transition pathways can contribute 45-53% of the 7th Carbon Budget Balanced Pathway reduction in combined agriculture and LULUCF GHG emissions, in line with their 55% coverage of all UK land area (excluding landscapes dominated by existing forest). However, the LULUCF sector makes a higher proportional contribution (66-78% of the Balanced pathway projected abatement in 2050) than the agriculture sector (30-34% of the Balanced pathway projected abatement). The archetype transitions do not include non-area based agricultural mitigation measures (e.g., technical innovations to reduce livestock CH_4 emissions) so do not reflect total potential agricultural emissions reductions.

There is potential for expanding mitigation measures on lower-quality agricultural land, thus preserving highly productive farmland for agriculture, but this can have knock-on impacts on farm incomes and rural communities. The economic cost-benefit analysis indicates that net economic benefits and social benefits increase under the transition pathways, but the private cost/benefit balance may not, so additional financial incentives may be required to encourage change. We have also explored and qualitatively assessed a range of climate change risk impacts on carbon sequestration, biodiversity, agricultural production and ecosystem services on the archetypes. Agricultural land is more impacted by climate change and in certain archetypes, climate change limits the mitigation measures that can be implemented although this can be modified by adaptation measures.

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10. Appendices

Inputs and calculated metrics by archetype are provided in an MS Excel workbook accompanying this report.

A.1.0 Archetype summary

Summary of climate, soil and agricultural characteristics of the shortlisted archetypes

Archetype	Description	Main location	Climate	Soil drainage[21]	Soil moisture	Agricultural Land Class[22]	Predominant agricultural use	Area, '000 hectares
1	Highly degraded lowland organic soils	E, S	Cold winters, warm summers, relatively dry	Deep and wasted peats	Medium	ALC 2-3	Arable/horticulture and livestock grazing on improved grassland	**GB 406.4** *E 273* *S 117.3* *W 16.1*
2	Degraded upland grazing land and forest on organic soils in GB	E, S	Mild or cold winters, cool summers, relatively wet	Deep peats	Wet	ALC 5, SALC 4-6	Conifer plantation and livestock rough grazing	**GB 938.6** *E 269.5* *S 619.9* *W 49.2*

[21] Scottish soils https://map.environment.gov.scot/Soil_maps/?layer=5 and NSRI Soilscapes

[22] The Agricultural Land Classification (ALC) system classes land into grades according to the extent to which physical r chemical characteristics impose long-term limitations on agricultural use for food production. This is the general ALC grade for the archetype, but the archetype may contain pockets of other ALC grades. The grades for England, Wales and Northern Ireland are Grade 1: Excellent Quality, Grade 2: Very Good Quality, Grade 3: Good to Moderate Quality, Grade 4: Poor Quality, Grade 5: Very Poor Quality. The Scottish ALC (SALC) classes are Class 1: Land capable of producing a very wide range of crops, Class 2: Land capable of producing a wide range of crops, Class 3: Land capable of producing average to high yields of a narrower range of crops, Class 4: Land capable of producing a narrow range of crops (primarily grassland with short arable breaks), Class 5: Land capable of use as improved grassland, Class 6: Land capable of use as rough grazing, Class 7: Land of very limed agricultural value.

3	Intensive grassland in Wales and south-west England	E, W	Mild winters, warm summers, relatively wet	Mineral, Freely draining	Medium	ALC 3-4	Livestock grazing on improved grassland	**GB 1283.2** *E 640.1* *S 7.2* *W 634.8*
4	Farming on the suburban fringe in England	E	Mild or cold winters, warm summers, relatively dry	Mineral, Wide range	Dry-medium	ALC 1-4	Arable/horticulture and livestock grazing on improved grassland	**GB 608** *E 541.4* *S 33.5* *W 33.1*
5	Hilly farmland on improved and semi-natural grassland on non-organic soils in GB	E, S, W	Mild or cold winters, cool or warm summers, relatively wet	Mineral, slowly permeable	Medium-wet	ALC 4 SALC 4	Livestock rough grazing	**GB 424.5** *E 201* *S 106.4* *W 117.1*
6	Open pasture on the upland fringe in England and Scotland	E, S	Mild or cold winters, cool summers, relatively wet	Mineral, slowly permeable	Medium	ALC 3 SALC 3-4	Livestock grazing on improved and rough grassland	**GB 1148.3** *E 304.9* *S 814.3* *W 29.1*
7	Enclosed pasture in England and Wales	E, W	Mild or cold winters, cool or warm summers, relatively dry	Mineral, slowly permeable or freely draining	Medium	ALC 3	Livestock grazing on improved grassland with some arable	**GB 1051.1** *E 921.8* *S 9.9* *W 113.1*
8	Acid grassland on hilly uplands in GB	S	Mild winters, cool summers, relatively wet	Shallow, acidic soils, sometimes with surface water	Wet	ALC 5 SALC 6-7	Livestock rough grazing	**GB 860.9** *E 65.7* *S 767.4* *W 27.8*
9	Intensive and valley/floodplain arable on chalk/clay soils in England	E	Cold winters, warm summers, relatively dry	Lime-rich soils with variable drainage	Dry	ALC 1-3	Arable with some livestock on improved grassland	**GB 2172.6** *E 214.1* *S 12.9* *W 18.7*

10	Arable on sandy soils in England and Scotland	E, S	Cold winters, warm summers, relatively dry	Mineral, freely draining	Dry-medium	ALC 1-3	Arable with some livestock on improved grassland	**GB 2027.4** *E 1502.4* *S 511.9* *W 13.1*
11	Lowland agriculture around Lough Neagh, Northern Ireland	NI	Mild winters, cool summers, relatively wet	Poorly drained soils with peaty areas	Medium	ALC 3 (4 on peat)	Livestock grazing on improved grassland with some arable	**NI 122.8**
12	Uplands with large extent on organic soils in Northern Ireland	NI	Mild winters, cool summers, relatively wet	Deep organic soils	Wet	ALC 4	Livestock rough grazing	**NI 321.8**

A.2.0 Baseline data

A.2.1 Baseline land cover by archetype in 2021, hectares

Archetype	Broadleaved woodland	Coniferous Woodland	Arable and Horti-culture	Improved Grassland	Neutral Grassland	Calcareous Grassland	Acid grassland	Fen, Marsh and Swamp	Heather	Heather grassland	Bog	Urban and suburban
1	7900	10300	196400	125600	14000	700	23400	5500	8500	29300	35900	1700
2	25100	357900	13800	56300	2900	1000	276200	2800	212600	324200	409900	1700
3	10000	3800	57600	1191300	3800	1400	8500	700	200	700	0	900
4	2900	900	232300	285700	12500	1600	400	700	400	200	0	66300
5	7000	5100	12400	221100	21700	41800	91100	3600	3400	10600	1100	800
6	11900	9200	33900	1023500	1700	5700	24000	200	2300	21800	5300	1200

7	1600	400	120100	886200	39300	500	1200	0	500	600	0	100
8	2400	13400	0	1400	0	800	603200	0	51800	33600	17000	0
9	3100	300	1745900	382600	23900	900	0	3700	400	800	300	3700
10	11100	18800	1756000	207700	13600	1300	900	100	6500	800	0	4000
11	4900	3300	4400	520400	21900	400	2600	200	400	1000	3000	21700
12	1600	47800	100	109300	8100	1800	54000	0	18200	11300	66800	0
100	725400	898200	1715700	3030700	87300	134100	1198600	3300	793800	742000	506700	140700

A.2.2 Baseline peatland condition category by archetype in 2021, ha

Archetype	Cropland	Domestic Extraction	Eroded	Extensive Grassland	Forest	Industrial Extraction	Intensive Grassland	Modified Bog	Modified Bog Drained	Modified Bog Undrained	Near Natural Bog	Near Natural Fen	Rewetted Bog	Saltmarsh	Settlement
1	199,300	49,300	-	47,400	-	7,800	159,700	-	-	-	-	-	-	-	-
2	-	-	330,900	-	413,000	-	-	733,600	72,100	156,100	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	200	300	-	-	-
4	-	-	-	-	-	-	-	-	-	-	100	-	-	-	1,400
5	-	-	-	-	-	-	-	-	-	-	1,500	200	1,000	100	200

6	-	-	-	-	-	-	-	-	-	-	2,200	200	-	-	100
7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	44,500	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	1,100	-	400	-	1,400
10	-	-	-	-	-	-	-	-	-	-	800	-	100	-	1,500
11	1,900	19,200	-	4,200	3,200	500	15,800	-	100	2,200	4,500	-	-	-	400
12	200	53,900	6,500	13,400	24,700	100	5,500	-	10,400	8,900	25,000	-	-	-	500
100	1,300	14,900	200	3,200	2,800	-	8,700	200	1,700	2,600	558,900	1,800	1,700	700	5,900

Mapping peatland condition categories to LULUCF categories

- Forest: Forest
- Cropland: Cropland
- Grassland-pasture: Intensive grassland
- Grassland – rough: Eroded, Extensive grassland, Modified bog (all), 75% Rewetted Bog, Saltmarsh
- Wetland: Domestic extraction, Industrial extraction, Near-natural bog, Near-natural fen, 25% Rewetted bog
- Settlement: Settlement

A.2.3 Baseline projected land cover in 2035, hectares

Archetype	Broadleaved woodland	Coniferous Woodland	Arable and Horti-culture	Improved Grassland	Neutral Grassland	Calcareous Grassland	Acid grassland	Fen, Marsh and Swamp	Heather	Heather grassland	Bog	Urban and suburban
1	7,814	10,039	192,529	122,114	13,941	697	23,301	12,174	8,464	29,176	36,049	2903
2	25,072	346,805	13,327	55,967	2,898	999	276,048	2,865	212,483	324,022	420,596	3317
3	11,106	4,431	56,517	1,188,718	3,594	1,324	8,040	700	189	662	-	3617
4	7,047	6,429	230,216	284,200	11,529	1,476	369	701	369	184	50	61330
5	10,841	7,713	12,060	218,980	21,062	40,572	88,423	3,600	3,300	10,288	1,100	1761
6	19,592	21,936	32,920	1,004,118	1,609	5,396	22,722	200	2,178	20,639	6,129	3261
7	1,932	609	118,253	884,450	38,266	487	1,168	-	487	584	-	4264
8	3,916	15,805	-	1,246	-	795	599,397	-	51,473	33,388	17,228	352
9	4,737	676	1,739,641	380,207	21,765	820	-	3,808	364	729	300	12554
10	15,020	22,916	1,746,132	205,034	12,316	1,177	815	100	5,886	724	-	10680
11	4,801	3,287	3,572	518,859	21,057	385	2,500	362	385	962	3,000	25032
12	3,770	48,572	99	108,891	7,826	1,739	52,174	-	17,584	10,918	66,800	627
100	786,119	966,537	1,701,595	3,008,417	83,572	128,374	1,147,418	3,313	759,903	710,315	511,132	29105

A.2.4 Baseline projected land cover in 2050, hectares

Archetype	Broadleaved woodland	Coniferous Woodland	Arable and Horti-culture	Improved Grassland	Neutral Grassland	Calcareous Grassland	Acid grassland	Fen, Marsh and Swamp	Heather	Heather grassland	Bog	Urban and suburban
1	7,734	9,776	188,564	118,492	13,898	695	23,229	19,325	8,438	29,086	36,209	3754
2	25,044	334,941	12,970	55,707	2,897	999	275,919	2,935	212,383	323,870	432,056	4679
3	12,233	5,074	55,858	1,186,583	3,482	1,283	7,788	700	183	641	-	5075
4	11,211	12,024	228,764	283,102	10,890	1,394	348	702	348	174	104	54837
5	14,593	10,345	11,834	216,934	20,444	39,381	85,828	3,600	3,203	9,987	1,100	2451
6	27,192	34,698	32,027	984,621	1,518	5,091	21,435	200	2,054	19,470	7,017	5378
7	2,377	849	117,128	883,185	37,683	479	1,151	-	479	575	-	6594
8	5,431	18,209	-	1,093	-	790	595,562	-	51,144	33,175	17,472	723
9	6,633	1,085	1,735,002	378,808	20,575	775	-	3,923	344	689	300	17466
10	18,900	27,101	1,737,107	202,866	11,309	1,081	748	100	5,405	665	-	15518
11	4,878	3,409	3,302	518,138	20,821	380	2,472	535	380	951	3,000	25935
12	5,767	49,448	97	108,771	7,577	1,684	50,513	-	17,025	10,570	66,800	749
100	846,443	1,035,828	1,691,608	2,989,189	79,936	122,788	1,097,492	3,327	726,839	679,408	515,881	47061

A.2.5 Baseline livestock numbers in 2021

	Arch1	Arch2	Arch3	Arch4	Arch5	Arch6	Arch7	Arch8	Arch9	Arch10	Arch11	Arch12	Arch100
Cattle and calves	131615	381180	939298	220112	189641	541908	629094	140866	533459	622818	753891	341856	3936431
Sheep and lambs	425726	2005420	3926309	590993	1165882	2021510	1940696	789257	1538938	1934612	866941	506512	14750069
Pigs	1735116	1735116	1735116	1735116	1735116	1735116	1735116	1735116	1735116	1735116	1735116	1735116	1735116
Poultry	4972216	3375323	8435567	6000125	2954186	3942295	14225417	1049972	31945350	30479840	13336653	4994109	63352894

A.2.6 Baseline projected livestock numbers in 2035

	Arch1	Arch2	Arch3	Arch4	Arch5	Arch6	Arch7	Arch8	Arch9	Arch10	Arch11	Arch12	Arch100
Cattle and calves	141,208	411,392	999,450	234,608	202,646	585,622	669,748	152,335	568,023	666,812	807,022	365,948	4,213,482
Sheep and lambs	474,234	2,233,922	4,373,681	658,332	1,298,725	2,251,846	2,161,823	879,187	1,714,288	2,155,046	965,722	564,225	16,430,724
Pigs	172,547	121,851	117,309	177,095	68,209	74,780	248,755	12,890	1,059,966	1,321,248	455,358	133,745	1,932,819
Poultry	5,538,760	3,759,915	9,396,734	6,683,792	3,290,792	4,391,489	15,846,291	1,169,608	35,585,271	33,952,778	14,856,260	5,563,148	70,571,458

A.2.7 Baseline projected livestock numbers in 2050

	Arch1	Arch2	Arch3	Arch4	Arch5	Arch6	Arch7	Arch8	Arch9	Arch10	Arch11	Arch12	Arch100
Cattle and calves	145,829	426,678	1,025,911	241,122	208,662	607,953	687,757	158,222	583,365	687,579	832,063	377,303	4,343,942
Sheep and lambs	502,884	2,368,880	4,637,909	698,104	1,377,185	2,387,887	2,292,425	932,302	1,817,853	2,285,239	1,024,065	598,311	17,423,356
Pigs	182,971	129,213	124,396	187,794	72,329	79,297	263,783	13,668	1,124,002	1,401,069	482,868	141,825	2,049,587
Poultry	5,873,375	3,987,063	9,964,420	7,087,582	3,489,600	4,656,793	16,803,617	1,240,267	37,735,091	36,003,974	15,753,774	5,899,236	74,834,906

A.2.8 Baseline annual agricultural GHG emissions, Mt CO_2e

Archetype	2021	2035	2050
Arch1	0.653	0.692	0.711
Arch2	1.364	1.487	1.547
Arch3	3.477	3.735	3.867
Arch4	0.917	0.979	1.014
Arch5	0.766	0.826	0.857
Arch6	2.006	2.159	2.228
Arch7	2.429	2.600	2.698
Arch8	0.493	0.539	0.561
Arch9	3.454	3.628	3.731
Arch10	3.743	3.951	4.064
Arch11	2.444	2.635	2.706
Arch12	1.065	1.152	1.186
Arch100	15.499	16.639	17.219

A.2.9 Baseline LULUCF GHG emissions, Mt CO_2e

Archetype	2021	2035	2050
1	8.302	8.158	7.954
2	3.330	3.199	3.240
3	-0.803	-0.523	-0.613
4	0.072	0.130	-0.594
5	-0.396	-0.322	-0.705
6	-0.901	-0.702	-2.106
7	-0.521	-0.345	-0.340
8	-0.545	-0.515	-0.793
9	0.145	0.406	0.379
10	1.894	2.314	1.929
11	0.762	0.854	0.865
12	0.767	0.816	0.676
100	-10.182	-6.574	-13.841

A.3.0 Transition data

A.3.1 Transition pathways projected land cover in 2035, hectares

Archetype	Pathway	Broadleaved woodland	Coniferous Woodland	Arable and Horti-culture	Improved Grassland	Neutral Grassland	Calcareous Grassland	Acid grassland	Fen, Marsh and Swamp	Heather	Heather grassland	Bog	Urban and suburban
1	1	7,814	10,188	186,021	105,832	13,941	697	23,301	34,964	8,464	29,176	35,900	2,903
2	1	25,072	324,120	13,381	55,977	2,898	999	276,048	2,800	212,483	324,022	443,281	3,317
3	1	48,970	11,569	55,980	1,147,691	2,694	992	6,026	700	142	496	-	3,640
	2	19,679	12,397	56,165	1,168,680	4,581	1,688	10,247	700	241	844	-	3,679
4	1	12,959	3,642	229,414	274,199	11,473	1,469	367	700	367	184	-	69,126
	2	5,478	4,377	229,892	280,572	10,104	1,293	323	700	323	162	-	70,677
5	1	17,948	8,362	12,030	213,346	20,789	40,046	87,277	3,600	3,257	10,155	1,100	1,789
6	1	63,383	39,827	32,934	952,956	1,285	4,309	18,142	200	1,739	16,479	5,300	4,147
	2	24,088	12,651	33,013	997,941	1,939	6,501	27,371	200	2,623	24,862	5,300	4,212
7	1	32,135	12,856	116,337	847,374	35,038	446	1,070	-	446	535	-	4,264

8	1	4,366	15,138	-	1,240	-	795	599,790	-	51,507	33,410	17,000	352
9	1	11,662	9,397	1,734,396	372,667	19,234	724	-	3,700	322	644	300	12,554
	2	27,469	4,193	1,738,369	358,179	19,153	721	-	3,700	321	641	300	12,554
10	1	23,445	20,826	1,745,819	202,647	9,768	934	646	100	4,669	575	-	11,371
11	1	31,022	8,933	3,305	487,581	20,160	368	2,393	2,224	368	921	3,000	23,926
12	1	1,597	45,725	100	108,271	8,084	1,796	53,891	671	18,163	11,277	68,796	627

A.3.2 Transition pathways projected land cover in 2050

Archetype	Pathway	Broadleaved woodland	Coniferous Woodland	Arable and Horti-culture	Improved Grassland	Neutral Grassland	Calcareous Grassland	Acid grassland	Fen, Marsh and Swamp	Heather	Heather grassland	Bog	Urban and suburban
1	1	7,734	10,084	145,911	27,727	13,898	695	23,229	152,742	8,438	29,086	35,900	3,754
2	1	25,044	274,497	13,084	55,728	2,897	999	275,919	2,800	212,383	323,870	492,500	4,679
3	1	132,912	30,297	54,173	1,049,846	1,539	567	3,442	700	81	283	-	5,061
	2	30,993	21,656	55,073	1,143,745	5,606	2,065	12,540	700	295	1,033	-	5,194

4	1	37,642	10,393	225,388	248,604	10,687	1,368	342	700	342	171	-	68,263
	2	8,599	8,137	228,020	275,480	7,819	1,001	250	700	250	125	-	73,518
5	1	41,163	16,266	11,687	196,391	18,920	36,446	79,431	3,600	2,964	9,242	1,100	2,489
6	1	178,929	113,506	31,613	789,662	442	1,481	6,237	200	598	5,666	5,300	7,066
	2	45,353	21,416	32,178	960,513	2,097	7,031	29,603	200	2,837	26,889	5,300	7,284
7	1	94,463	33,528	111,743	771,363	30,626	390	935	-	390	468	-	6,594
8	1	9,088	19,433	-	1,026	-	785	591,764	-	50,818	32,963	17,000	723
9	1	21,982	31,997	1,718,002	355,702	15,122	569	-	3,700	253	506	300	17,466
	2	75,546	13,625	1,731,787	307,026	14,847	559	-	3,700	248	497	300	17,466
10	1	37,778	27,118	1,732,280	196,777	5,795	554	384	100	2,770	341	-	16,904
11	1	90,077	22,758	2,158	411,053	18,864	345	2,240	10,313	345	861	3,000	22,186
12	1	1,597	42,766	100	105,518	8,081	1,796	53,870	3,355	18,156	11,273	71,740	749

A.3.3 Transition pathways projected livestock numbers in 2035 and 2050

		2035	2035	2050	2050
Archetype	Pathway	Cattle	Sheep	Cattle	Sheep
Arch1	1	131,615	425,726	82,831	320,227
Arch2	1	381,180	2,005,420	82,656	171,854
Arch3	1	939,298	3,926,309	746,884	2,904,808
Arch3	2	939,298	3,926,309	800,249	3,090,618
Arch4	1	220,112	590,993	191,984	515,792
Arch4	2	220,112	590,993	179,535	458,798
Arch5	1	189,641	1,165,882	150,477	923,324
Arch6	1	541,908	2,021,510	377,306	1,326,183
Arch6	2	541,908	2,021,510	541,908	2,021,510
Arch7	1	629,094	1,940,696	529,827	1,618,812
Arch8	1	140,866	789,257	133,130	570,627
Arch9	1	533,459	1,538,938	449,486	1,259,069
Arch9	2	533,459	1,538,938	405,730	1,152,362
Arch10	1	622,818	1,934,612	460,117	1,334,911
Arch11	1	753,891	866,941	451,836	480,068
Arch12	1	341,856	506,512	232,024	287,600

A.3.4 Transition pathways annual GHG emissions

	Agriculture emissions (MtCO2e)			LULUCF emissions (MtCO2e)			Total emissions		
Archetype	2021	2035	2050	2021	2035	2050	2021	2035	2050
Arch1	0.6	0.6	0.4	8.3	6.7	1.3	8.9	7.3	1.7
Arch2	1.3	1.0	0.5	3.3	2.6	0.7	4.7	3.6	1.2
Arch3/path 1	3.5	3.3	2.9	-0.8	-0.6	-2.3	2.6	2.7	0.7
Arch3/path 2	3.5	3.4	3.2	-0.8	-0.7	-2.1	2.6	2.6	1.1
Arch4/path 1	0.9	0.9	0.8	0.1	0.1	-0.6	1.0	1.0	0.2
Arch4/path 2	0.9	0.9	0.8	0.1	0.1	-0.9	1.0	0.9	0.0
Arch5	0.8	0.7	0.6	-0.4	-0.3	-1.1	0.4	0.4	-0.5
Arch6/path 1	1.9	1.7	1.4	-0.9	-0.8	-4.9	1.0	0.9	-3.5
Arch6/path 2	1.9	1.9	1.9	-0.9	-0.8	-2.2	1.0	1.1	-0.2
Arch7	2.4	2.3	2.1	-0.5	-0.5	-2.4	1.9	1.9	-0.3
Arch8	0.5	0.4	0.4	-0.5	-0.5	-0.6	-0.1	-0.1	-0.3
Arch9/path 1	3.4	3.4	3.3	0.1	0.2	-1.8	3.6	3.6	1.5
Arch9/path 2	3.4	3.4	3.1	0.1	0.3	-0.8	3.6	3.7	2.3
Arch10	3.6	3.5	3.2	1.9	2.1	0.4	5.5	5.6	3.7
Arch11	2.4	2.1	1.6	0.8	0.6	-0.6	3.2	2.8	1.0
Arch12	1.1	0.9	0.8	0.8	0.5	0.0	1.8	1.4	0.9

A.4.0 Ecosystem Service Metrics Figures

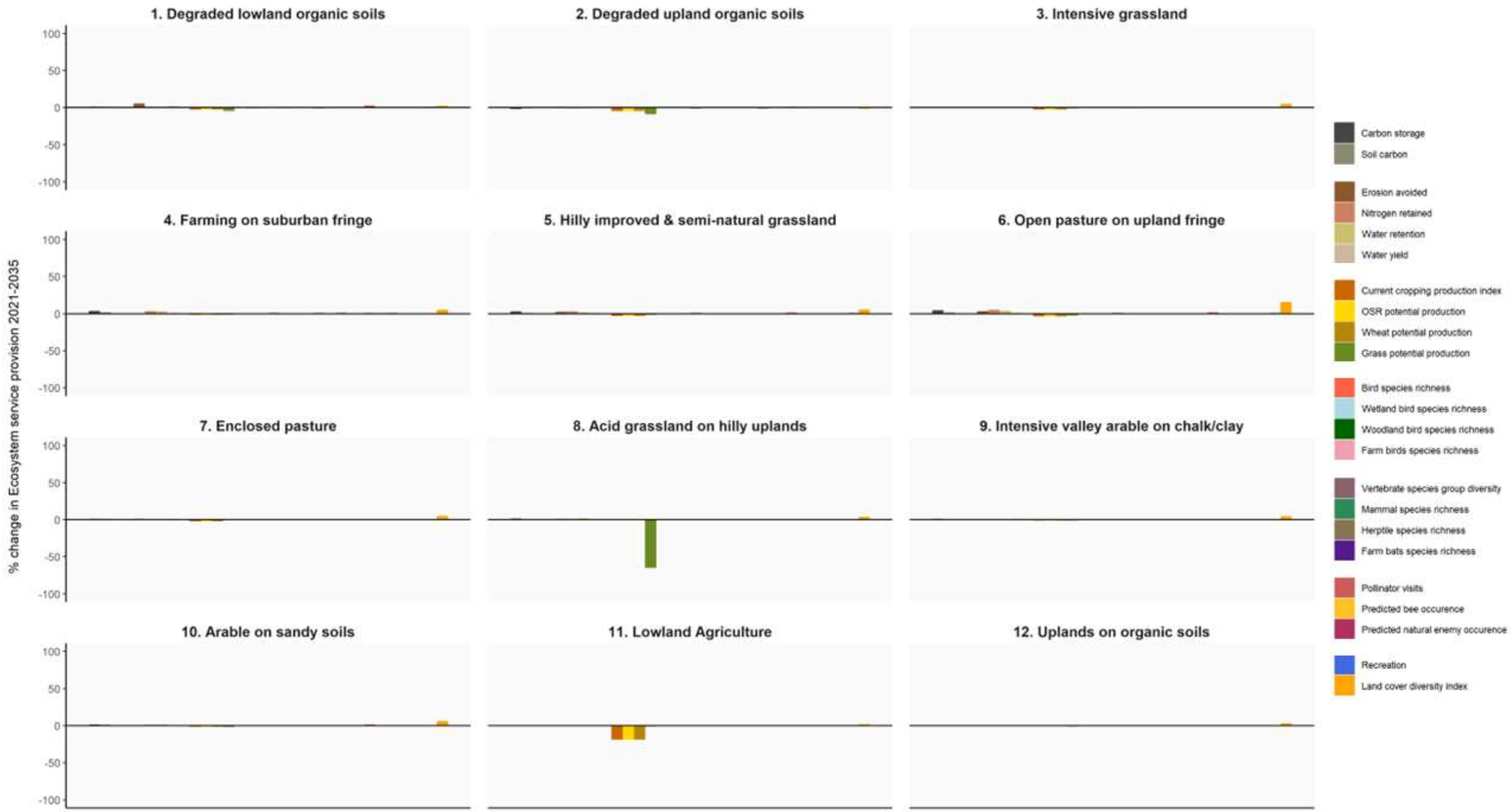

Figure A1. The relative percentage change in ecosystem services within each archetype between 2021 and 2035, under baseline change pathways.

As with figure 18, Ecosystem services which have not been possible to calculate for certain archetypes are not included i.e. all run-off and invertebrate species richness services, pollination and recreation for: Northern Irish Archetypes 11 and 12; arable production archetypes for Archetype 8 (as this archetype has no arable land).

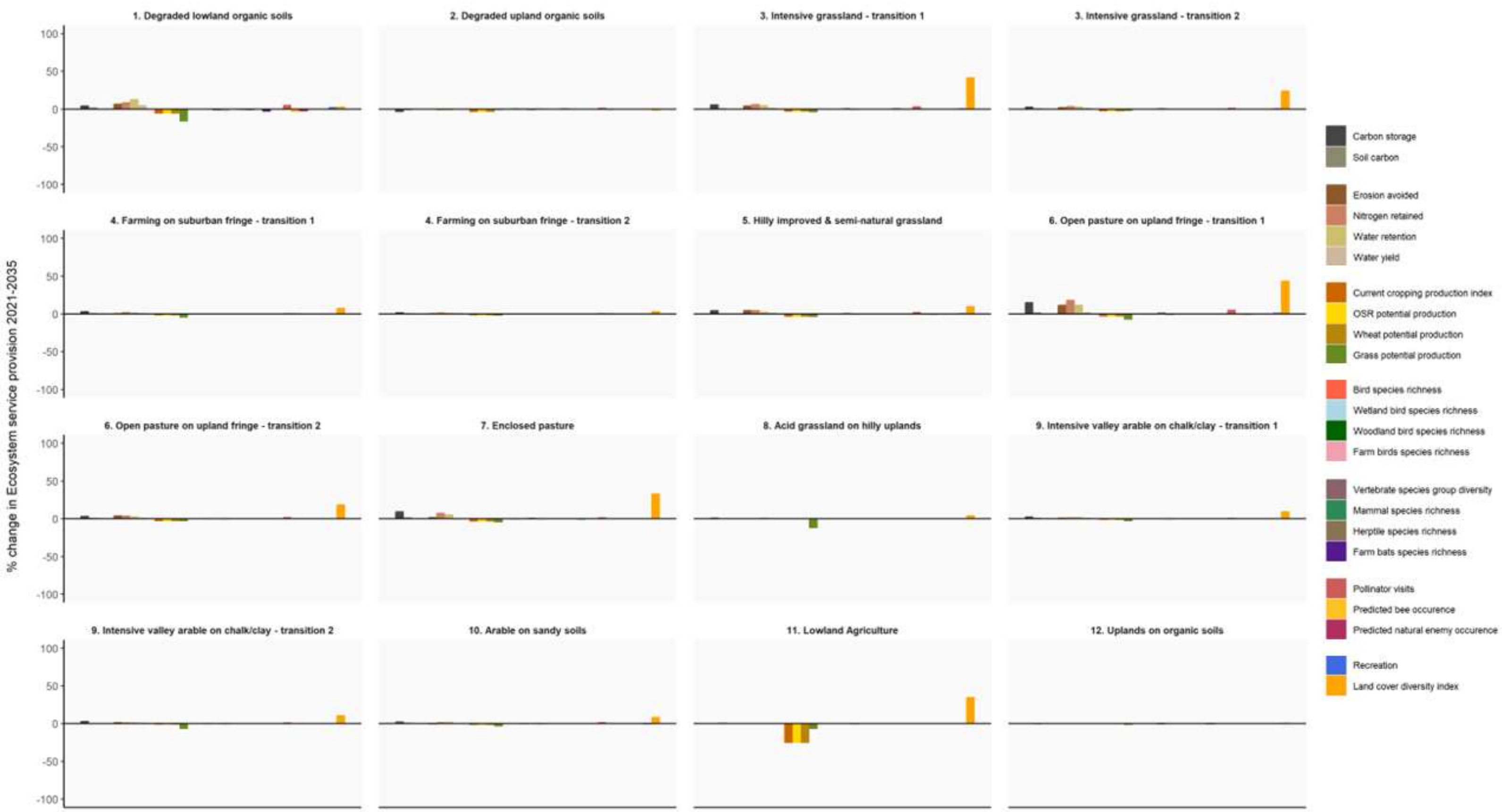

Figure A2 The relative percentage change in ecosystem services within each archetype between 2021 and 2035, under transition pathway pathways (encompassing baseline change).

As with figure 18, Ecosystem services which have not been possible to calculate for certain archetypes are not included i.e. all run-off and invertebrate species richness services, pollination and recreation for: Northern Irish Archetypes 11 and 12; arable production archetypes for archetype 8 (as this archetype has no arable land); and grass potential production for Archetype 8, as this archetype has <1 km^2 of improved grassland in 2050.

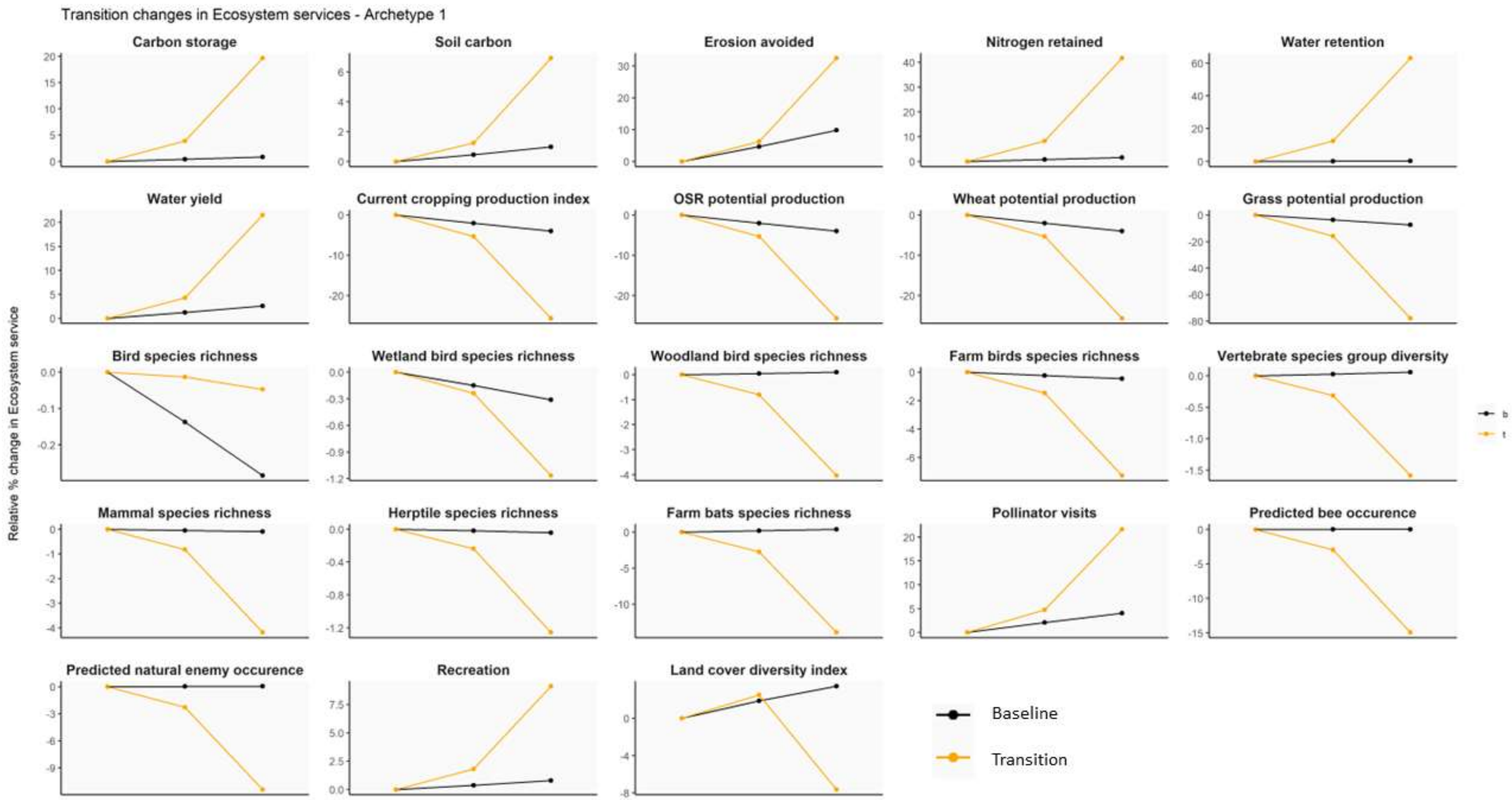

Figure A3 Relative percentage change in ecosystem service provision across all archetypes under baseline (black) and transition (orange) pathways, from 2021 to 2035 and 2050, for Archetype 1.

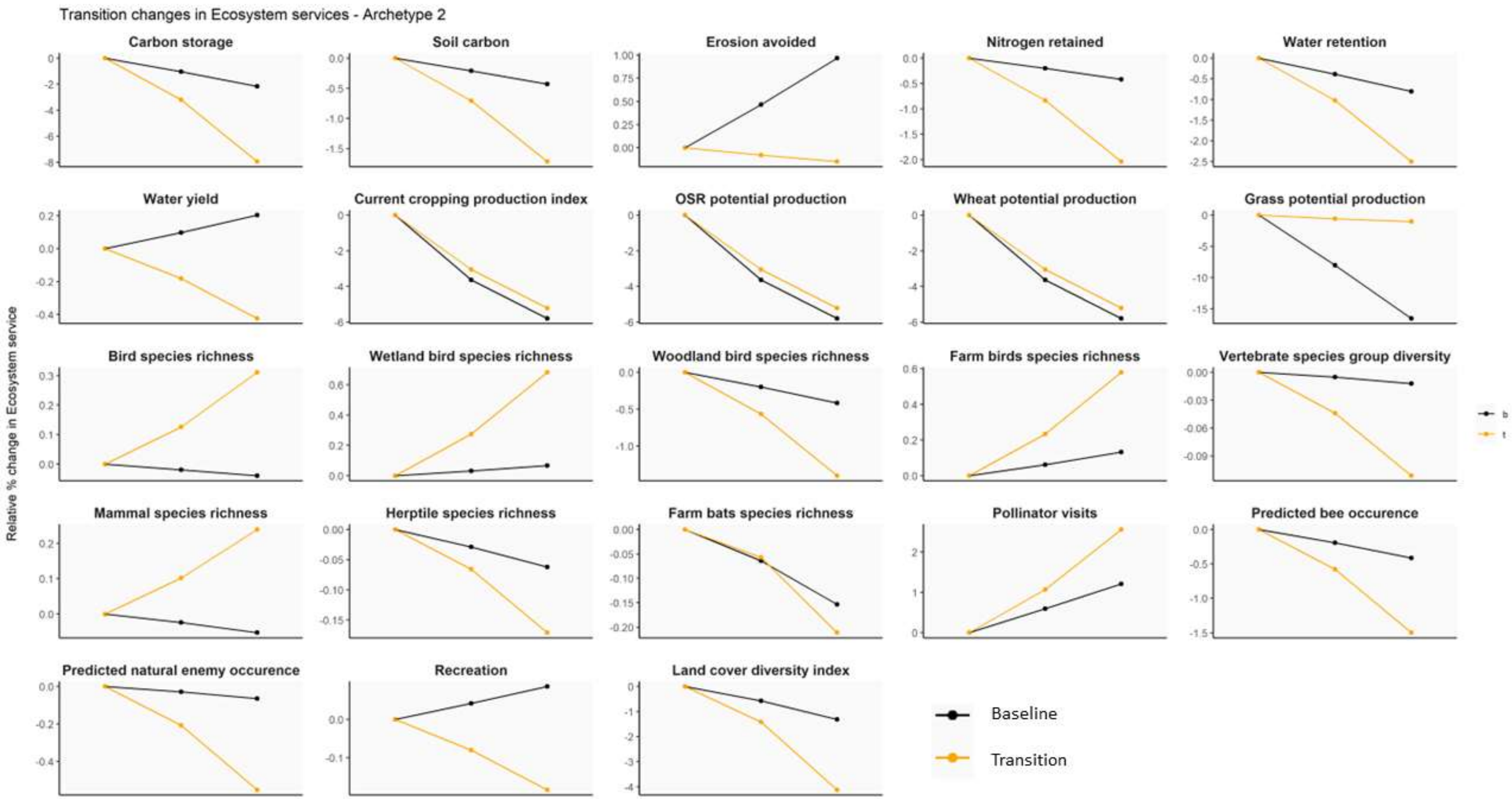

Figure A4 Relative percentage change in ecosystem service provision across all archetypes under baseline (black) and transition (orange) pathways, from 2021 to 2035 and 2050, for Archetype 2.

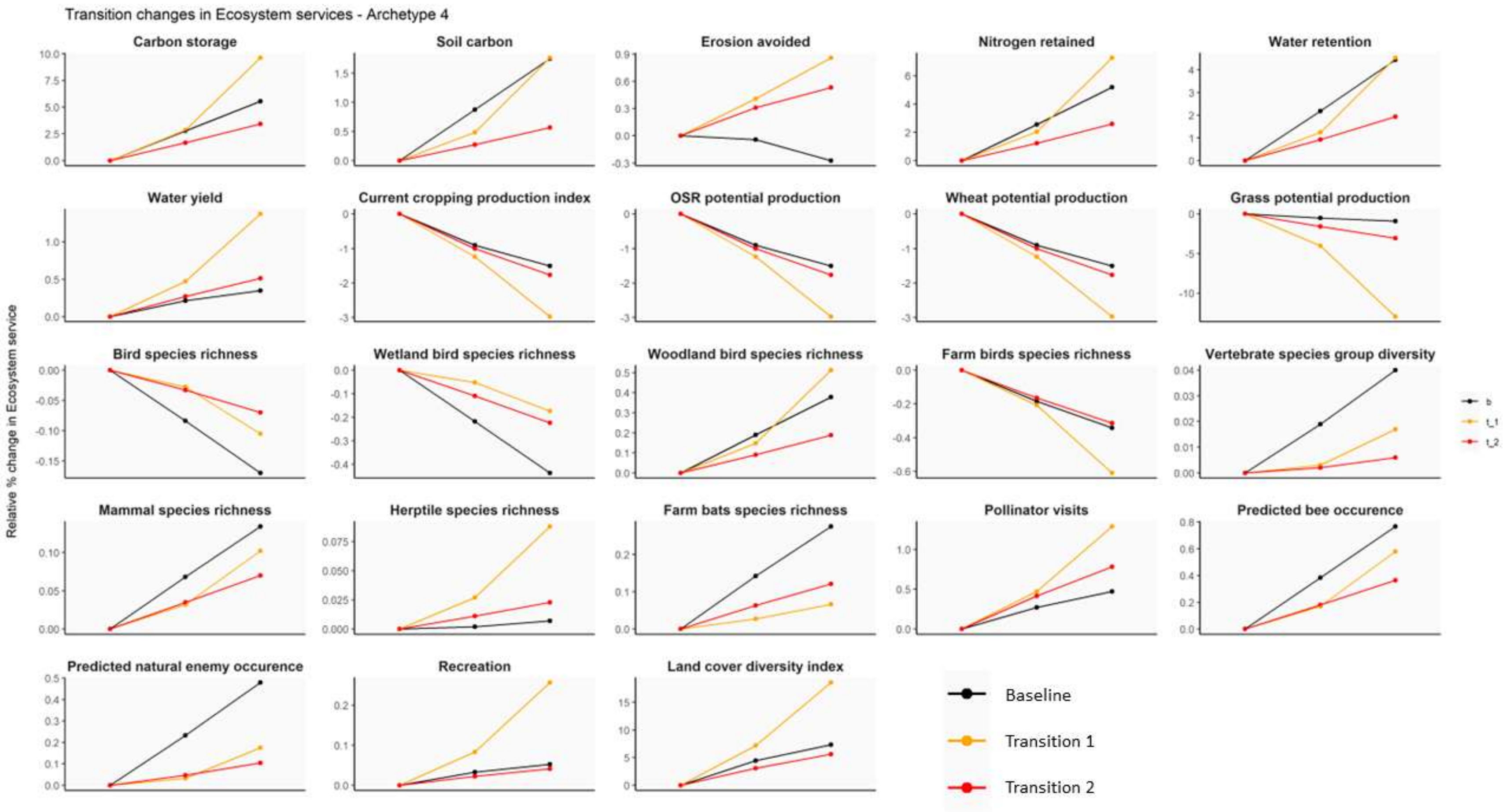

Figure A5 Relative percentage change in ecosystem service provision across all archetypes under baseline (black) and transition (orange and red) pathways, from 2021 to 2035 and 2050, for Archetype 4.

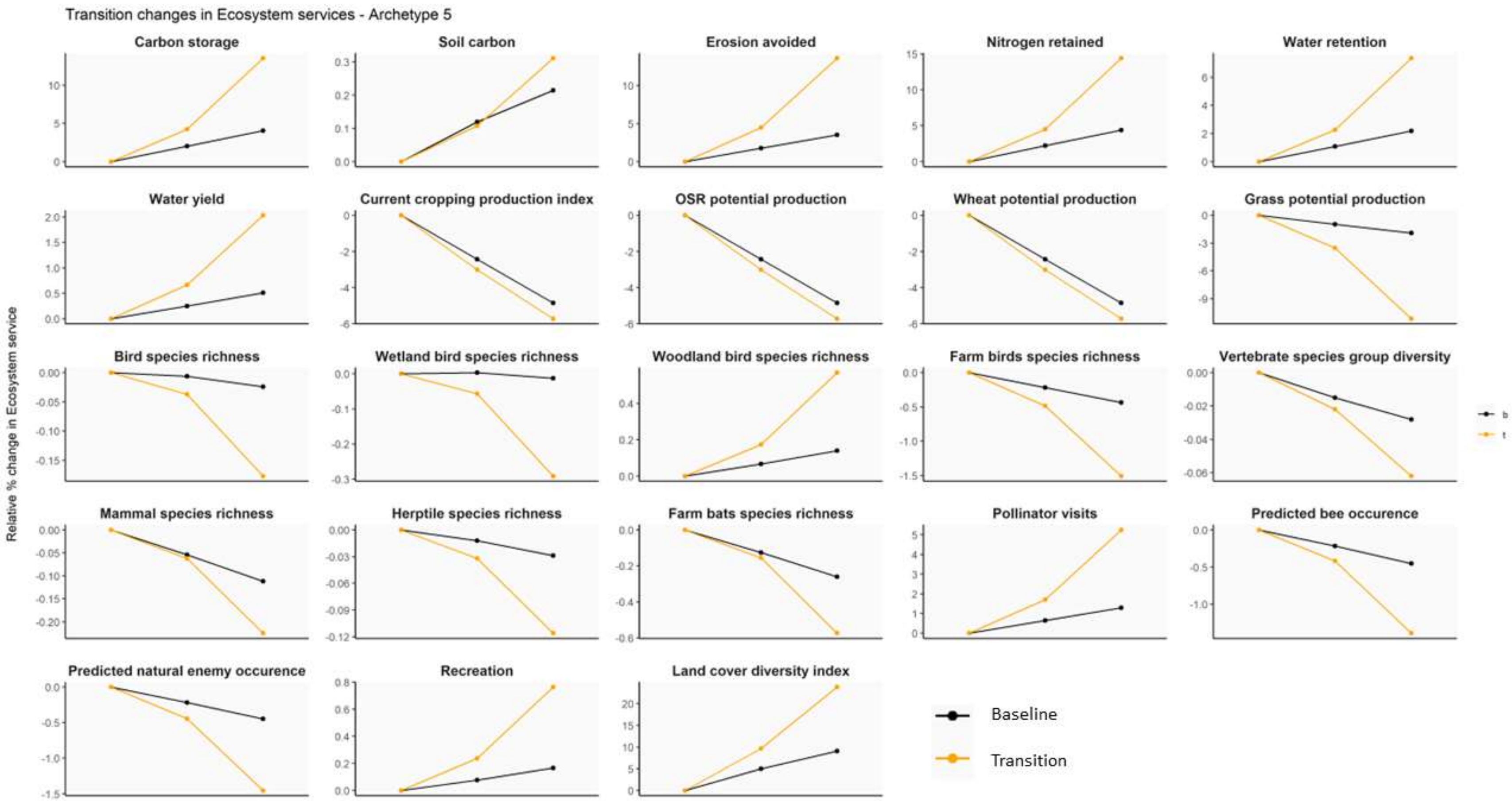

Figure A6 Relative percentage change in ecosystem service provision across all archetypes under baseline (black) and transition (orange) pathways, from 2021 to 2035 and 2050, for Archetype 5.

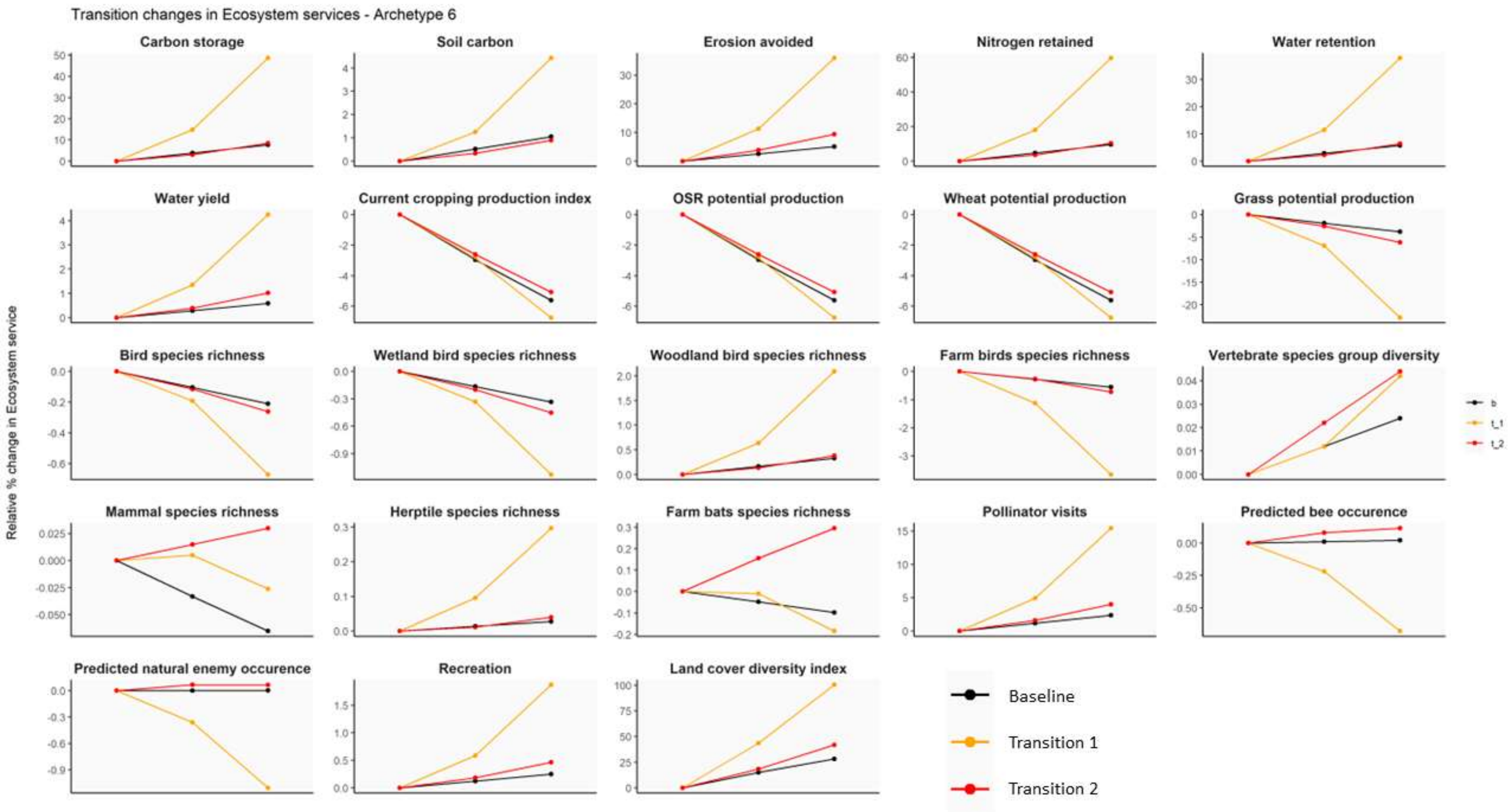

Figure A7 Relative percentage change in ecosystem service provision across all archetypes under baseline (black) and transition (orange and red) pathways, from 2021 to 2035 and 2050, for Archetype 6.

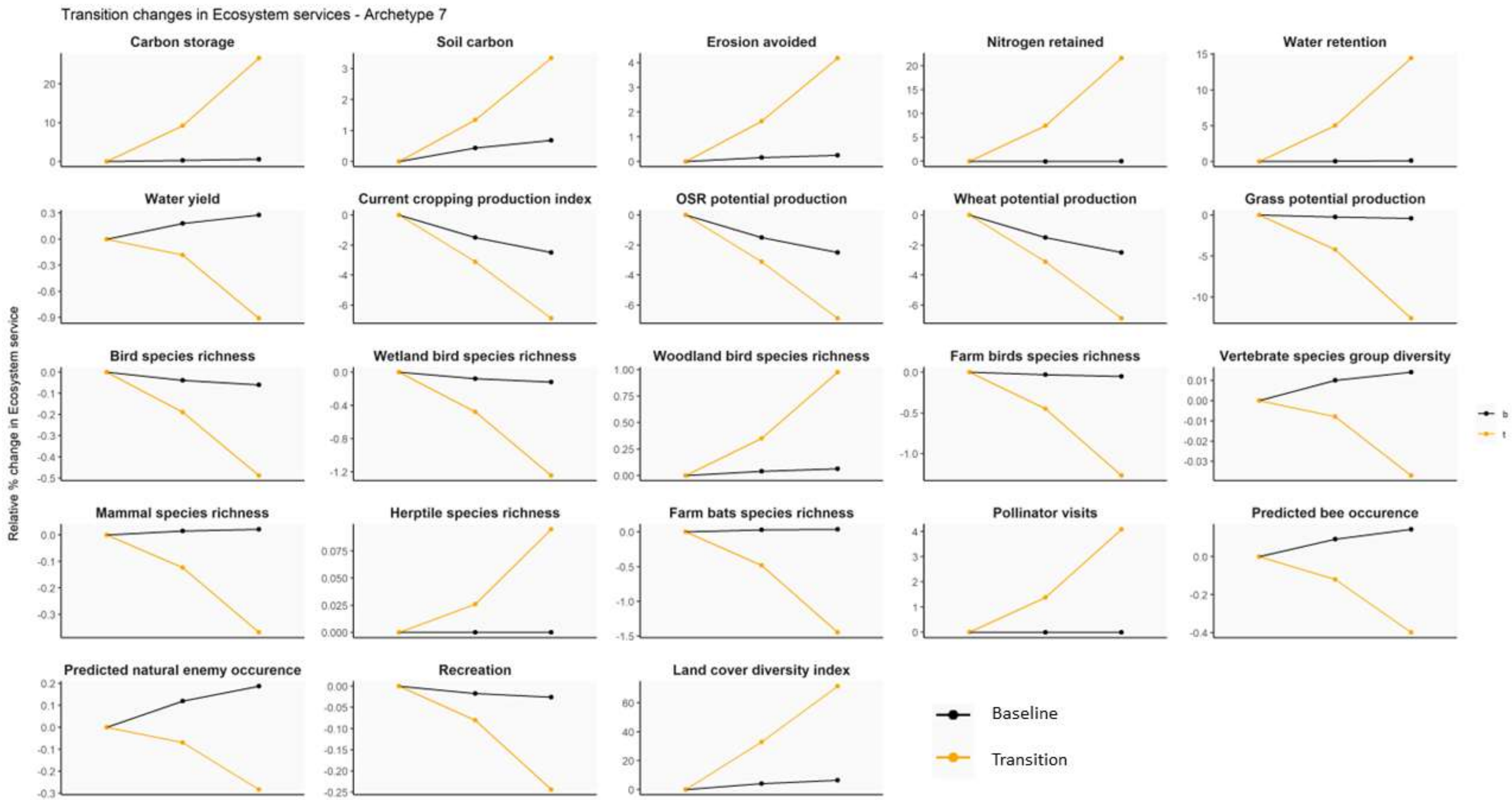

Figure A8 Relative percentage change in ecosystem service provision across all archetypes under baseline (black) and transition (orange) pathways, from 2021 to 2035 and 2050, for Archetype 7.

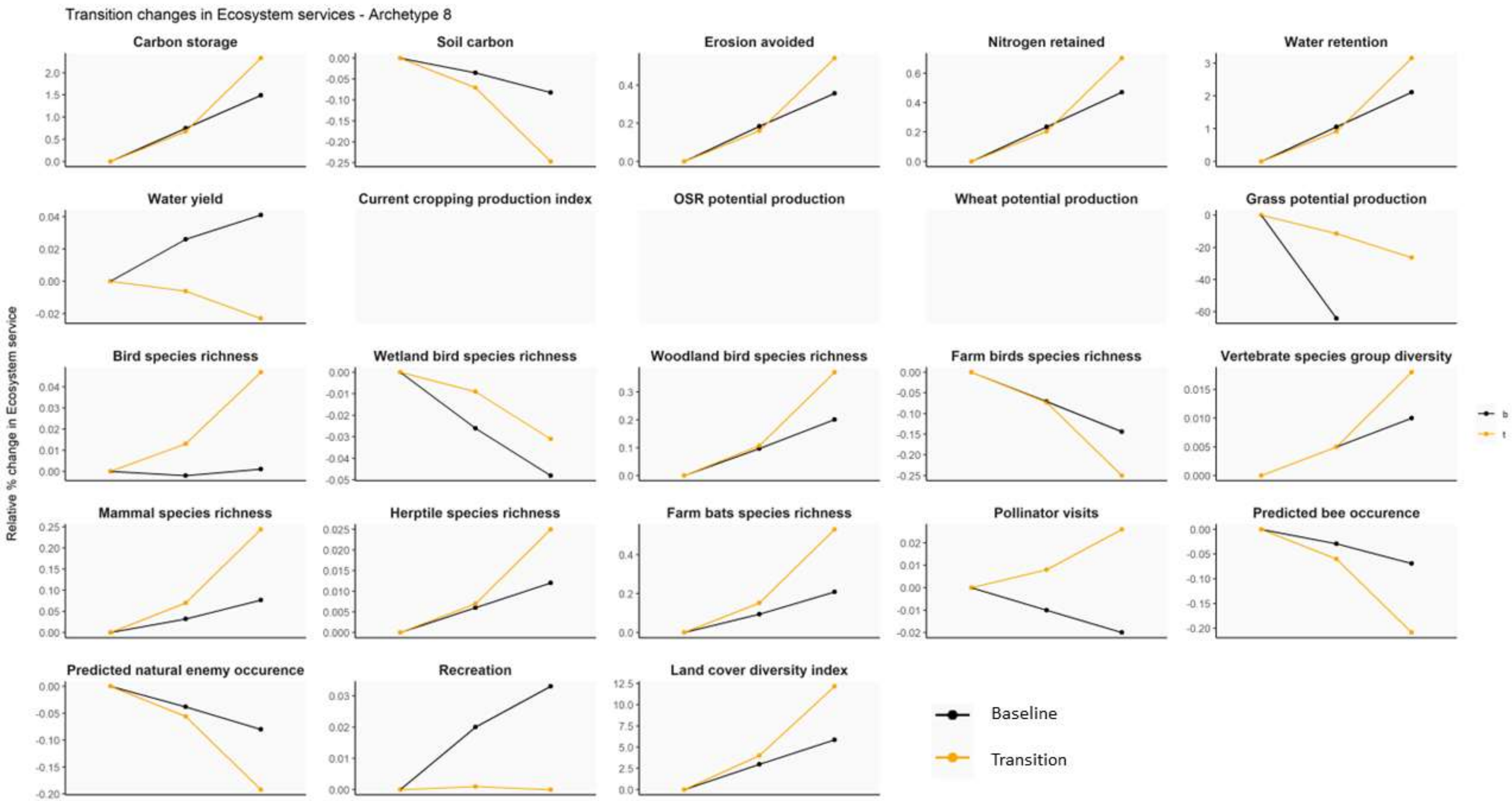

Figure A9 Relative percentage change in ecosystem service provision across all archetypes under baseline (black) and transition (orange) pathways, from 2021 to 2035 and 2050, for Archetype 8. Archetype 8 had no arable land and therefore arable production services were not calculated.

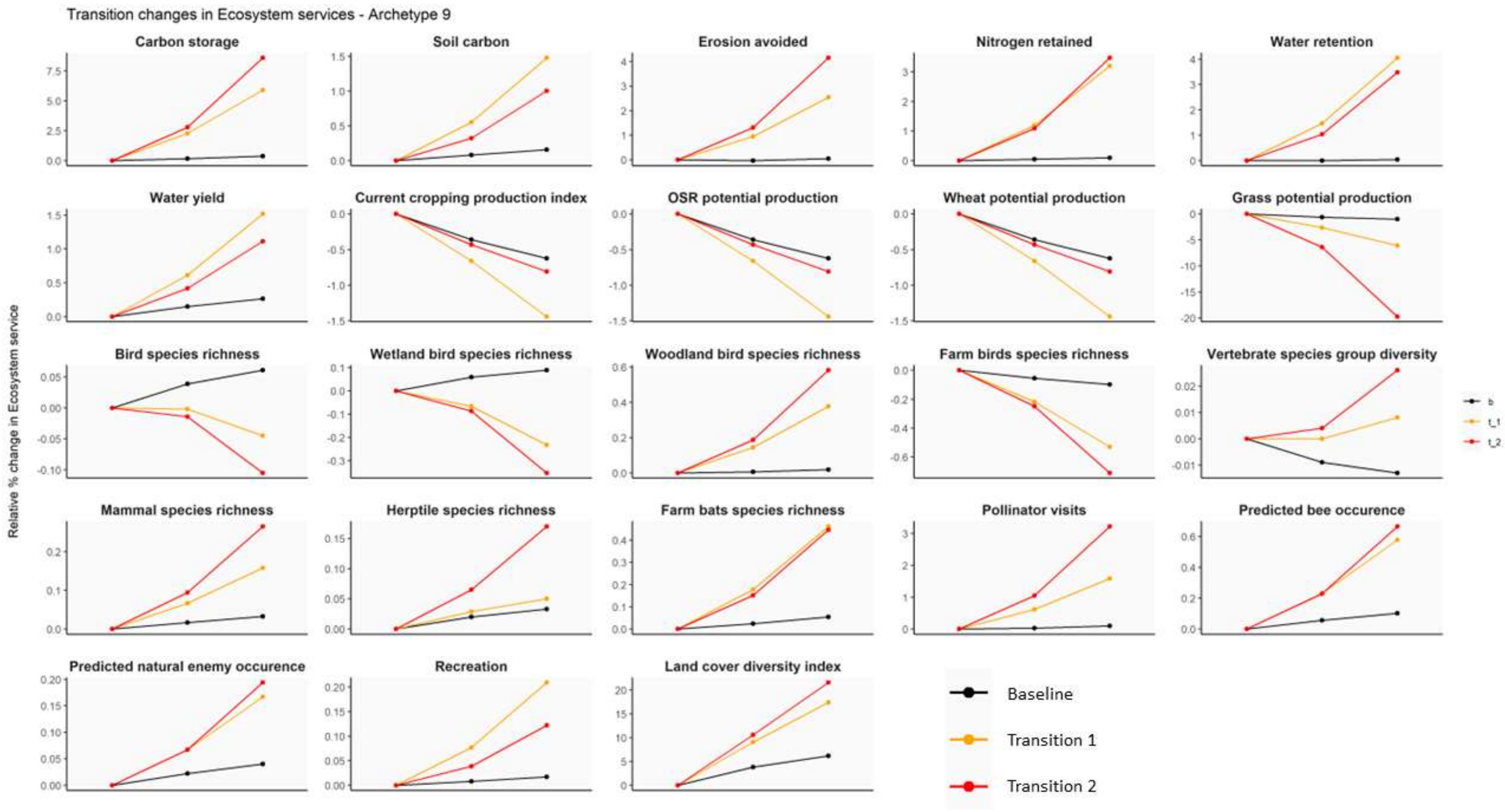

Figure A10 Relative percentage change in ecosystem service provision across all archetypes under baseline (black) and transition (orange and red) pathways, from 2021 to 2035 and 2050, for Archetype 9.

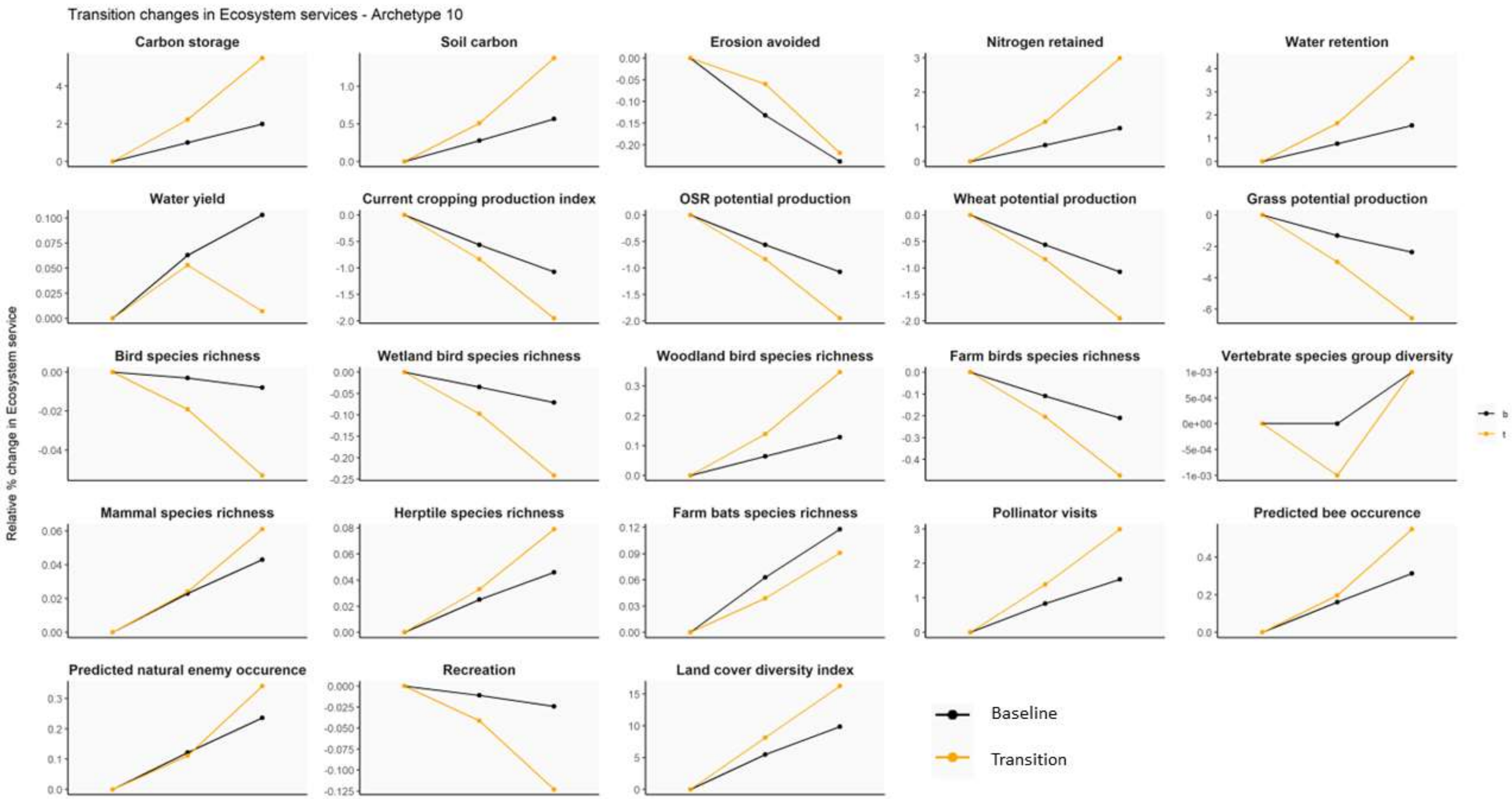

Figure A11 Relative percentage change in ecosystem service provision across all archetypes under baseline (black) and transition (orange) pathways, from 2021 to 2035 and 2050, for Archetype 10.

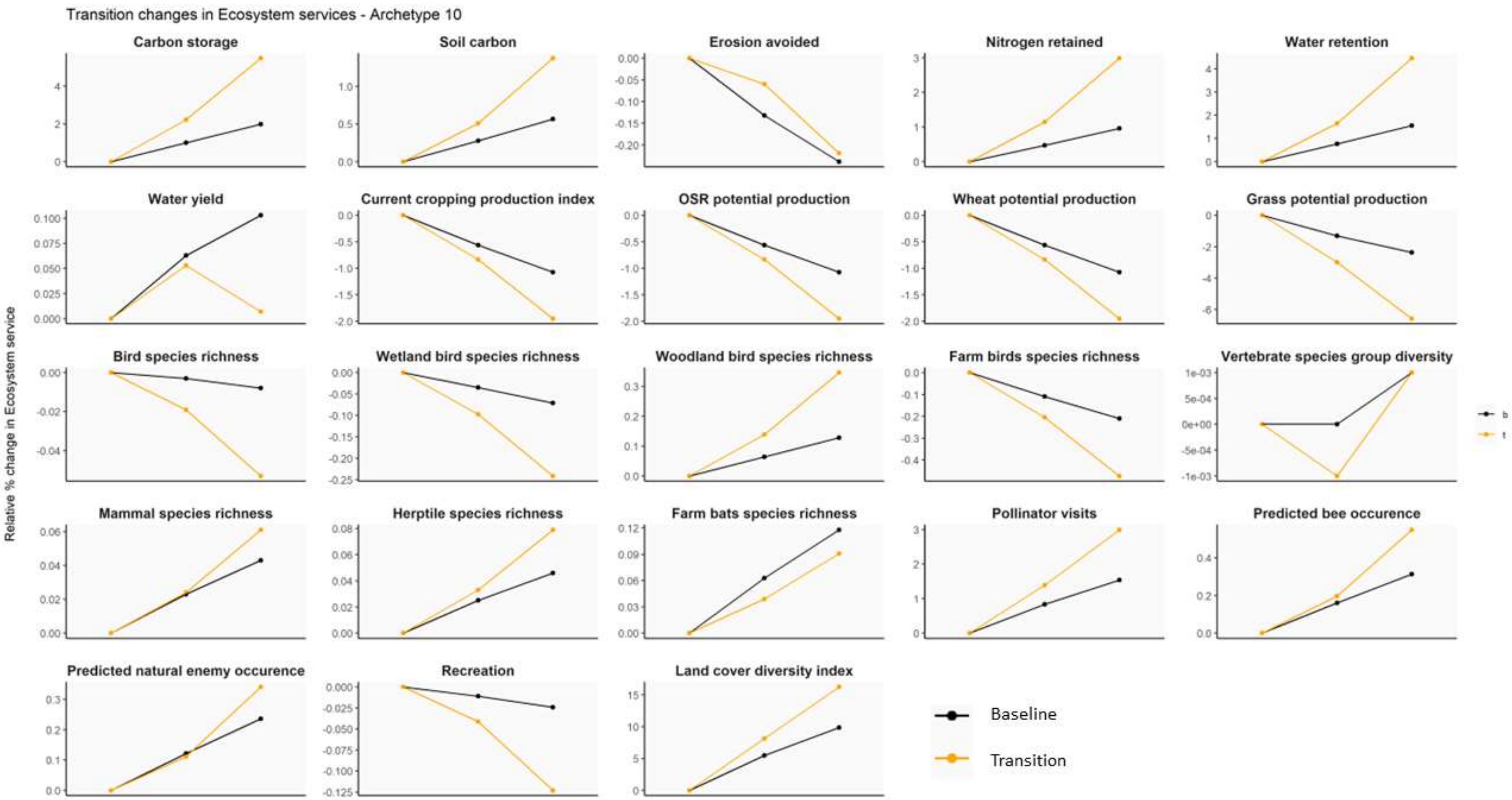

Figure A12 Relative percentage change in ecosystem service provision across all archetypes under baseline (black) and transition (orange) pathways, from 2021 to 2035 and 2050, for Archetype 11. Services with blank plots were unable to be calculated for Northern Ireland due to lack of data coverage.

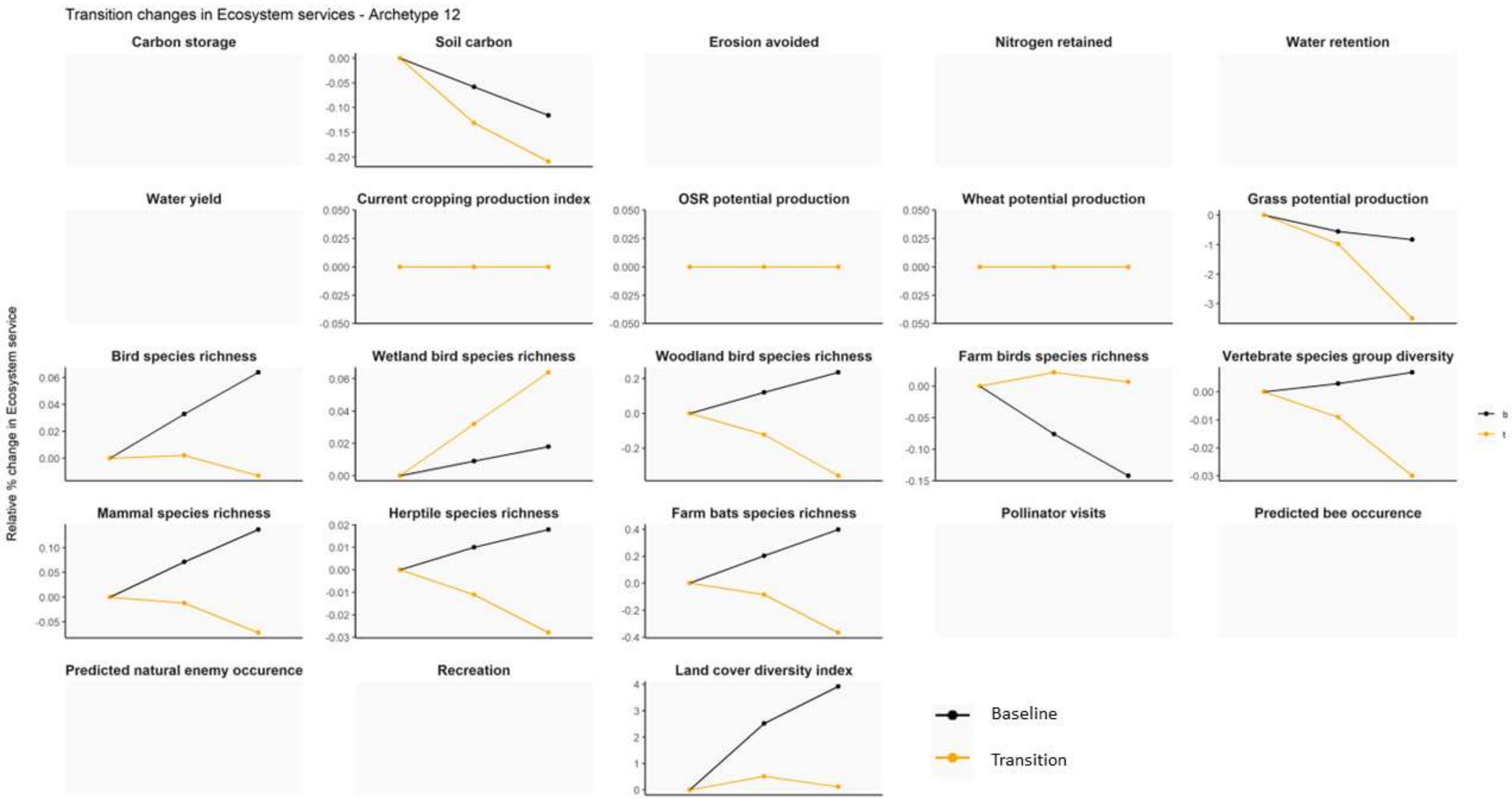

Figure A13 Relative percentage change in ecosystem service provision across all archetypes under baseline (black) and transition (orange) pathways, from 2021 to 2035 and 2050, for Archetype 12. Services with blank plots were unable to be calculated for Northern Ireland due to lack of data coverage.

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