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Regenerative Farming in the Protected Landscapes of York and North Yorkshire

Baseline and Action Plan

Final Report for

Yorkshire Dales National Park Authority

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fera Original thinking... applied

Cumulus

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Foreword

In 2022, staff from the five Protected Landscapes (PLs) – National Parks and Landscapes – in North Yorkshire came together to explore how we could contribute to the drive for net zero. With agriculture as the dominant land use across these vast upland and lowland areas, together covering 46% of the York and North Yorkshire Combined Authority area, it was clear that the most effective approach was to focus on supporting changes in farming—delivering meaningful progress toward net zero while potentially helping farmers navigate the agricultural transition.

The York and North Yorkshire Combined Authority has adopted an ambitious *Route Map to Carbon Negative*, aiming to reach net-zero carbon emissions by 2034 and achieve a carbon-negative position by 2040. Similarly, Lancashire County Council aspires to reach net zero in the early 2040s. At a national level, the Government's Protected Landscapes Targets and Outcomes Framework (PLTOF) sets a goal for all Protected Landscapes to be net zero by 2050.

There is increasing recognition of the role that regenerative farming can play in building carbon stores in soils and grasslands, whilst also reducing farm emissions. However, in the five PLs, we lacked baseline data on farming emissions and an understanding of how a move toward regenerative farming practices might affect these figures.

We were therefore delighted to receive support from the **Net Zero Fund** at York and North Yorkshire Combined Authority (YNYCA) to commission this report. Cumulus and Fera have modelled current and future emissions from farming and estimate that agriculture in these landscapes currently emits just over **1 million tonnes of carbon dioxide equivalent per year (1,013,444 tCO2e/year)**. The main sources of these emissions are:

- **Livestock farming** (sheep, cattle, and dairy) – primarily due to methane emissions – which accounts for **626,000 tCO2e/year**;
- **Fertiliser use** to enhance productivity, releasing nitrous oxide emissions equivalent to **223,800 tCO2e/year**;
- **Energy use**, including petrochemicals and fuel for machinery, as well as lighting and heating for livestock housing and dairy operations.

This report also examines the impact of a **100% shift to regenerative farming** in these areas. It estimates that such a transition would reduce emissions by nearly **25%**, bringing them down to **762,771 tCO2e/year**. This shift would involve:

- Adjusting livestock numbers – reducing sheep and dairy cattle while increasing the number of beef cattle;
- Reducing fertiliser and bought-in feed, relying more on grass forage;
- Cutting 'tractor miles' by minimising fertiliser applications and grass cutting;
- Increasing rotational grazing to improve soil health and grass production;

- Reducing the need for livestock housing in winter, lowering energy costs for lighting and heating, and decreasing dependence on imported feed;
- Expanding hedgerow and woodland/tree planting.

Research shows that regenerative farming not only reduces emissions but also delivers wider benefits, including improved biodiversity, healthier soils, and better water quality. Furthermore, enhanced soil health and increased tree and hedge cover will contribute to **carbon sequestration**, potentially capturing an additional **158,400 tCO2e/year in soils** and **22,000 tCO2e/year through tree planting**.

The staff of the five Protected Landscapes have long supported a shift towards more nature-friendly and regenerative farming. The **Farming in Protected Landscapes** (FiPL) programme has played a crucial role in funding initiatives such as the **Pasture and Profit Programme**, which has helped over 70 farms adopt regenerative practices. It has also provided grants for equipment such as electric fencing and cattle handling kits. Some of these pioneering farmers are featured as case studies in this report, with further examples available online via each individual PL's FIPL pages.

The completion of this project marks an essential first step in understanding and advancing agriculture's contribution to net zero in these landscapes. We are keen to build on this momentum, accelerating the transition to regenerative farming across the Protected Landscapes. This is a vital contribution that these landscapes – and the farming sector as a whole – can make to reducing carbon emissions, strengthening rural economies, and enhancing nature recovery.

Fred Constantine Smith, Project Manager

On behalf of:

- Forest of Bowland National Landscape
- Howardian Hills National Landscape
- Nidderdale National Landscape
- North York Moors National Park Authority
- Yorkshire Dales National Park Authority

1 Executive Summary

Regenerative agriculture is attracting interest from across the private, public and non-profit sectors, from producers and retailers to researchers and politicians. There are major benefits to regenerative agriculture, including improved soil health, increased resilience against extreme weather events (excess rain and drought), improved river water quality and biodiversity, as well as economic benefits of increased resilience against input price volatility.

This report analyses the contribution that regenerative farming in five Protected Landscapes (PLs) could make to net zero targets in the York & North Yorkshire Combined Authority area. **The analysis shows that a 100% uptake of regenerative farming would reduce the overall Greenhouse (GHG) emissions of farming in all five PLs combined by an estimated 24.7%**.

The five PLs include:

- Forest of Bowland National Landscape
- Howardian Hills National Landscape
- Nidderdale National Landscape
- North York Moors National Park
- Yorkshire Dales National Park

Given the PLs' rural nature, farming represents a high proportion of GHG emissions (e.g. farming represents 60% of all emissions in the Yorkshire Dales). Much of the land area consists of large expanses of moorland, characterised by 'upland farms', with predominantly sheep and cattle grazing, with the exception of the Howardian Hills. The Howardian Hills is a more mixed agricultural landscape, dominated by cereals and some general cropping, with permanent pasture on the steeper slopes and in small fields around villages.

The **aims** of this work were to estimate the current emissions from farming in these PL areas, to estimate the potential for reducing these emissions and increasing carbon storage and sequestration through the adoption of regenerative practices, and to prepare an Action Plan in collaboration with the steering group of how the five Protected Landscape Organisations (PLO) could support a transition to regenerative farming in their areas. The Action Plan is set out in a separate document.

What does Regenerative farming mean in an upland context?

Regenerative ('regen') agriculture focuses on a set of broad practices that aim to enhance soil health and reduce negative environmental and social impacts. There are many different definitions and descriptions of regenerative farming in usage, with none specifically related to upland farming.

We have looked in detail at how regenerative principles can be practically applied on different farm types, and what outcomes have been evidenced in the literature. Much of the literature around regenerative agriculture is focused on arable systems, but four of the five PLs are primarily managed under livestock systems.

The key characteristics of regenerative agriculture in this context include:

- Maximising forage production by improving soil health and natural nutrient cycles;

- Maximising forage utilisation, through proactive grazing strategies and livestock enterprises which are best suited to forage-based systems;
- Improving feed-conversion efficiency by investing in livestock genetics, health and welfare, and devising strategies to minimise routine treatments with anthelmintics (e.g. anti-worming), ectoparasite chemicals, and antibiotics;
- Increasing the diversity of browse and forage available to livestock, providing shade and shelter for livestock, and enhancing biodiversity and landscape, by investing in more diverse swards, planting trees and agroforestry;
- Minimising inputs of synthetic mineral nitrogen and plant protein imports and aligning stocking rates closer to the natural carrying capacity of the land.

In this report, we consider in detail how regenerative principles are practically applied in **farm types** most often found in the five PLs, and what outcomes have been evidenced in the literature. These farm types are:

- Less Favoured Area (LFA) grazing livestock farms
- Lowland grazing livestock farms
- Dairy farms
- Cereal and general cropping farms

The results

The baseline emissions findings are in line with figures from the National Atmospheric Emissions Inventory (NAEI). **The analysis shows that a move to regenerative farming would reduce the overall GHG emissions of farming in all five PLs combined by an estimated 24.7% (or 250,673 tCO2e/year), from the baseline of 1,013,444 tCO2e/year to 762,771 tCO2e/year** (Table 7-7). The total emissions reduction for the four upland PLs only, excluding the Howardian Hills, is estimated to be 25.5%. Emissions reductions range from 16.3-39.8% reduction for the four upland landscapes, and a 7.3% reduction for the Howardian Hills.

The modelling estimated the emissions reductions for crops and grazing land at 41.4% and the reductions for livestock at 17.4%, resulting in an overall reduction from the baseline to a '100% regen' scenario of 24.7%. A reduction in inputs of synthetic mineral nitrogen reduces nitrous oxide emissions; this together with a reduction in imported feed requires the alignment of stocking rates closer to the natural carrying capacity of the land, contributing to a reduction in methane emissions from livestock.

The reduction in livestock emissions varies considerably by PL and this is directly linked to the changes in livestock numbers. For the four upland PLs, reductions would be largely driven by adjusting livestock numbers, as a reduction in inputs would lower the number of animals that can be fed by the forage produced on the farm. This has already been happening to some extent, driven by high input prices. The literature clearly advocates optimising a mix of sheep and cattle to achieve ecological objectives. This would mean reducing the number of dairy cattle and using a more dual-purpose breed, reducing the number of sheep, and incorporating more beef cattle.

For the Howardian Hills, regenerative cereal production would integrate sheep into the crop rotations to increase fertility, build soil organic matter, and reduce crop pests and disease.

This would mean an increase in livestock numbers on cereal farms, resulting in an increase in livestock emissions, offsetting to some extent the emissions reductions from the land. The overall reduction in GHG emissions in the Howardian Hills would therefore be relatively small. However, the wider benefits from improved soil health, water quality and biodiversity could be significant.

The additional sequestration from the planting of more trees and hedges is estimated at just over 22,100 tCO2/year (2.2% of baseline emissions) from an additional planting on 3,772 ha of permanent grassland (Table 7-11).

The potential for sequestration of carbon in soils was calculated separately, using a different methodology, showing estimated additional sequestration of 158,437 t/CO2e year (see Table 7-12).

The majority of these results were derived by creating a model to estimate the changes in GHG emissions from a transition to regenerative farming practices in the PLs. The model drew on a variety of datasets to assess key agricultural and land use factors contributing to GHG emissions across the five PLs, and emissions factors based on national estimates adjusted for the farm practices within the PLs (see Section 5 for more detail).

Discussion

Regenerative farming improves resilience and generates important environmental benefits, including a reduction in GHG emissions. However, regenerative farming practices alone will not reduce emissions from agriculture to net zero.

We have taken a process-based approach to defining best practice regenerative agriculture, which results in a range of positive outcomes, rather than trying to optimise one specific public-policy objective (i.e. reducing GHG emissions). It has been informed by the literature, feedback from farmer engagement, and case study examples (see Appendix 2).

While many of the regenerative practices we have modelled could lead to long-term improvements in farm economics (as highlighted in Chris Clark's report 'Less is more'[1]), there may be economic/commercial challenges to their adoption and implementation. At the farm level, there may be large sunk capital costs and overheads which militate against significant changes in farming system; for example, we model a change from high-output specialist dairy cows to more dual-purpose breeds and beef animals, better suited to extensive grass-based systems, which dairy farmers may not feel able to switch to under current contracts and market conditions.

There may also be practical challenges to some of the changes we have modelled. For example, we have modelled a shift towards more cattle, and fewer sheep, on LFA grazing farms as much of the literature points to the role of cattle in best practice regenerative farming in the uplands: they are better suited to utilising coarser forage than sheep, it is practically easier to mob graze cattle, and the way they graze results in a more varied sward structure and greater sward diversity. However, we are conscious of the challenges associated with this, such as additional labour and regulatory requirements, as well as the risks relating to managing cattle.

There are many different permutations of regenerative farming, which could potentially result in different emissions figures. In particular, different assumptions around changes in fertiliser inputs and livestock numbers could have a significant impact on modelled emissions.

Section 6 of this report outlines the benefits to soil health and wider environmental, economic and societal outcomes arising from regenerative farming. Further research will be required to better understand how to optimise food production, emissions and these other benefits.

Finally, it must be noted that there are other important habitats and interventions that could sequester and store additional carbon, in particular new woodlands and restored peatland (these are outside the scope of this work).

Recommendations for further research:

- Integrating the findings of this work with other recent work on land use targets and emissions pathways in the North York Moors and other PLs (e.g. recent analysis undertaken on the sequestration potential from restoring moorlands, heathland, peatlands, and wetland), and the work recommended below.
- Baselining soils, using a data set called NATMAP Carbon which shows soil carbon stock totals (and potential uplift) produced for the individual PLs, to see how these figures would compare with the soil carbon stock estimates we produced using the approach above.
- Emissions baselining and monitoring of regenerative systems at an individual farm level, to build the evidence base around specific regenerative practices and the implications for GHG emissions and food production.
- Exploring more fully how GWP* affects GHG emissions with the increased uptake of regenerative practices across the PLs
- Baselining the carbon sequestration of existing hedgerows. This study calculated only the increase in carbon sequestration as a result of planting more hedges and trees under the regenerative scenario. Baselining could be achieved through access to better data and additional analysis.

A separate Action Plan proposes a programme of interventions that could support farmers on their ‘regenerative journey’.

2 Introduction and aims

This report is produced for the Yorkshire Dales National Park Authority on behalf of a partnership of the five Protected Landscapes ("PLs") located in North Yorkshire. It is supported by funds from the York & North Yorkshire Combined Authority's Net Zero Fund. The Lancashire area of Forest of Bowland is supported by Lancashire County Council Climate Action funding. The research establishes the contribution that a transition to regenerative farming in these protected landscapes could make towards the drive for net zero targets in the York & North Yorkshire Combined Authority area. The accompanying Action Plan sets out how a transition to more regenerative farming could be supported in the Protected Landscapes.

The five PLs are: Forest of Bowland National Landscape, Howardian Hills National Landscape, Nidderdale National Landscape, North York Moors National Park, Yorkshire Dales National Park. Appendix 1 provides further context of farming in these PLs.

The aims of this work are to:

1. Estimate the current emissions from farming in these Protected Landscape areas (i.e. establish a baseline)
2. Estimate the potential for reducing these emissions and increasing carbon storage and sequestration through the adoption of regenerative practices.
3. Prepare an Action Plan in collaboration with the steering group of how a transition to regenerative farming could be supported in the five PLs.

3 Approach

The overall approach undertaken during this project included:

- Inception and scoping
- Literature review (the findings from the literature review are primarily set out in Section 6 where we describe regenerative farming practices; the references are listed as endnotes in Appendix 4)
- Development of an emissions model and data collation to calculate a baseline
- Definition of regenerative practices by main farm type, together with development of model farms and 'pen portraits' and integration of findings into the emissions model.
- Analysis of findings and scenario analysis (see Appendix 3).
- Nine regenerative farming case studies (see Appendix 2 – attached separately).
- Two farmer meetings and a farm advisor meeting
- Production of an Action Plan
- Steering Group and Advisory Group meetings
- Reporting

The methodology for assessing the emissions baseline and the regenerative scenarios are set out in detail in Section 5 below.

4 Scope

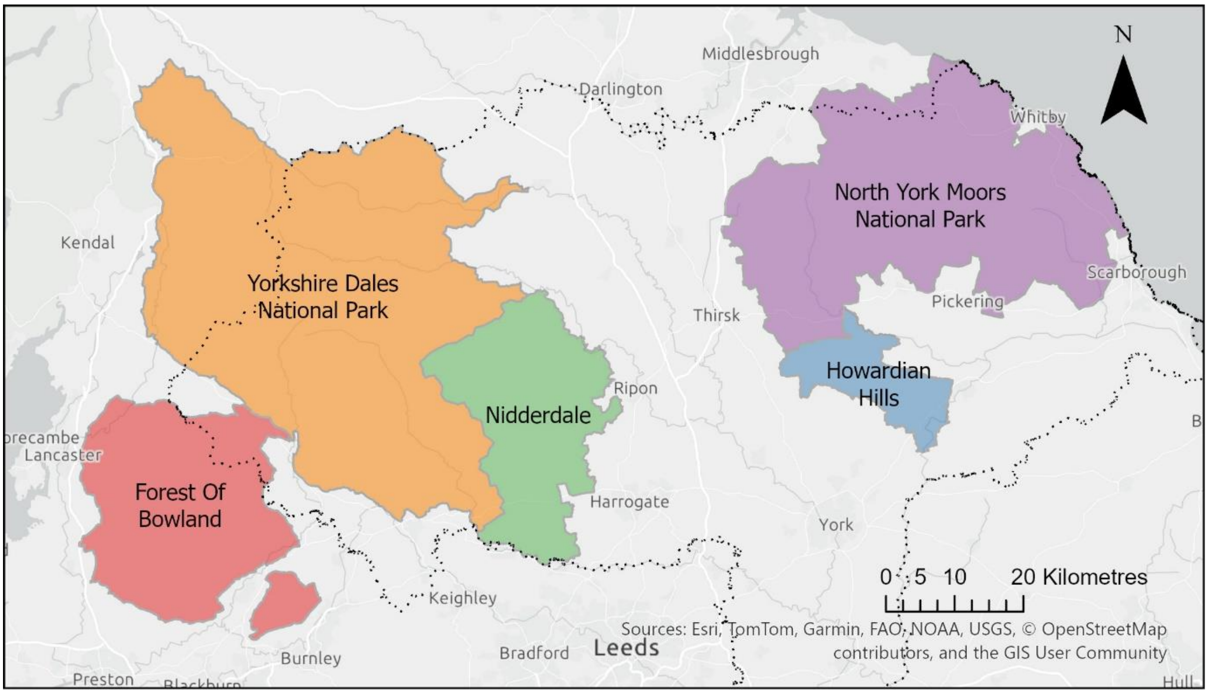
The scope of the project covers the following:

- Geographic scope;
- Temporal scope;
- Emissions scope, including organisational focus and value chain boundaries.

4.1 Geographic scope

The research covers the five Protected Landscapes which are wholly or partially within the North Yorkshire Combined Authority area. The five PLs are shown on the map in Figure 4-1. The proportion of the North Yorkshire Combined Authority area designated as a Protected Landscape is 45.8%; and this would increase to 48.8% if one were to include the Yorkshire Wolds which is being considered for designation as an Area of Outstanding Natural Beauty / National Landscape[1]. Further background and statistics on the Protected Landscapes by size (in ha), farm type, number of holdings and number of livestock are included in Appendix 1.

Figure 4-1: Map of the five Protected Landscapes wholly or partly in North Yorkshire (dotted line indicates boundary for North Yorkshire Combined Authority)



The focus of the research is on farming and farmland within the five PLs. This includes arable land, temporary grassland, permanent grassland, farm woodland and other non-agricultural land within farm holdings. It includes sole right rough grazing (land subject to the exclusive right to graze rough pasture or moorland) but – due to data limitations – not common rough

[1] Protected Landscape coverage would be even higher - 50.4% - when taken as a percentage of the North Yorkshire County Council area, as opposed to the Combined Authority area.

grazing. Peatland / peatland restoration and commercial forestry are also excluded. Additional planting of hedges under regenerative farming is included. Further detail on types of land use covered by the emissions model and analysis is included in the methodology in Section 5.

4.2 Temporal scope

The initial baseline emissions for year 2022 are estimated using data from: 2022 for the crop data; 2021 for the livestock data: and 2021 for the emissions data. These represent the most recent data available for each dataset. To allow consistency between baseline and regenerative agriculture comparisons, a second set of estimates were subsequently made using crop and livestock data from 2021. The Action Plan is for the short to medium term (5 years), with the potential to extend for a further 5 years.

4.3 Emissions scope

4.3.1 Organisational focus

The focus of the research is the farming operations on land within the five PLs, and in particular, how regenerative farming practices can change GHG emissions as a whole. The assessment is undertaken from the farmers' perspective, and the support they require to transition, and the role that the Local Authorities, Protected Landscape Organisations and others can play in this.

4.3.2 Value chain boundary

When performing an assessment of GHG emissions and carbon sequestration the scope of the assessment is split into three classes. Scope 1 emissions relate to direct operations by an organisation. Scope 2 emissions relate to upstream emissions from energy usage and Scope 3 emissions relate to emissions external to a business both upstream and downstream in the supply chain.

For this project, a comprehensive life cycle analysis (LCA) (such as specified in ISO 14040-44) of conventional and regenerative farming systems was not undertaken. Instead, the assessment focused on how Scope 1 and some key Scope 2 and Scope 3 GHG emissions would change as a result of regenerative farming practices. These regenerative farm practices are expected to involve changes to livestock numbers, management and housing; changes to tillage practices; introduction of cover cropping; changes to agrochemical usage; and changes to farm enterprise types and to the choice of crops within farm enterprises.

Scope 1 (Direct) emissions included carbon dioxide emissions from fuel used by machinery during agricultural operations, nitrous oxide emissions from the application of nitrogenous fertilisers and manures/excreta, and methane emissions from livestock. Carbon sequestration by farm woodlands also fall into the Scope 1 assessment. Scope 2 (Upstream energy) emissions included carbon dioxide emissions from off-site generation and distribution of energy. Scope 3 (Upstream materials) emissions included emissions from energy used in the production of agro-chemicals and the fuel used in their transport. Scope 3 (Downstream) emissions from the transport, processing and retail of agricultural goods produced within the PLs are excluded from the scope of the assessment.

Some Scope 3 elements (e.g. the change in emissions linked to a lower level of production of concentrate feed used in the PLs) have also been covered in narrative (see Section 5).

Carbon sequestration in soils was not included in the model, but this was calculated separately (see Section 5).

5 Methodology

The methodologies for assessing the emissions baseline and the regenerative scenarios are set out in detail below.

A variety of datasets were used to develop a representative assessment of the key agricultural and land use factors that are contributing the GHG emissions across the five PLs (see Section 5.1). The data was collated into a single **'GHG emissions analysis'** MS Excel document with each tab presenting individual PL and a total aggregated to cover the whole focus area.

The emissions factors were based upon national estimates of emissions adjusted for the farm practices within the PLs. Carbon tool kits were not used for this assessment. There are many farm calculator toolkits on the market, which are all materially different in the standards and protocols they aligned to, their coverage of different farm enterprises, and their transparency, rigour, consistency and functionality. However, these toolkits are designed for single farm assessments and the licencing is not conducive to landscape scale applications.[2]

Emissions factors were applied to the farm enterprises and land uses and integrated into the GHG emissions analysis. Section 5.2 and 5.3 explain the methodology for the base line analysis and the regenerative scenarios in more detail. The model is designed to consider emissions at the Protected Landscape scale, so defining the combination of enterprises for individual farms is not relevant as the model calculates total emissions for each enterprise across all farms, or all farms of a particular farm type, in each Protected Landscape.

For this report an 'enterprise' refers to a set of farm business processes related to the production of a single type of farm goods. Each crop type is considered a separate enterprise alongside the management of land to produce temporary or permanent grassland. Different types of livestock production are considered separate enterprises and are considered separately from the temporary and permanent grazing land which they rely on. Therefore, it is possible for a farm not to have grazing land of its own but still have livestock or for a farm to have a grassland enterprise without any livestock of its own. Woodlands are also considered an enterprise as, although in most cases farm woodlands are not currently considered to contribute financially to the farm, they provide multiple ecosystem services and may in the future contribute to farm income through carbon, biodiversity or nutrient neutrality credits.

5.1 Data sources used

5.1.1 Land use data

For the initial baseline estimates, land use was based on the Rural Payment Agency (RPA) Crop Map for 2022, and land use codes were grouped to give farm enterprises. Additional open datasets were used to calculate the areas of land with specific designations or characteristics, and to re-classify important habitats, for example, heath, bog, woodland from the Living England Map from Natural England.

The emissions model is based principally on the RPA Crop Map of England (CROME) 2022. This covers agricultural land registered with the RPA actually inside the boundaries of the protected landscape. It includes 15 main crop types, grassland, and non-agricultural land covers, such as Woodland, Water Bodies, Fallow Land and other non-agricultural land. Non-agricultural areas are defined as land covers that do not fall under the category of agricultural production.

The RPA dataset/emissions model includes:

- Farm woodland
- Grazed heather, heathland, moorland – under either ‘permanent grassland’ (moorland grassland) or ‘non-agricultural’ (moorland other habitats - e.g. wetland, dwarf shrub heath and bracken).

but excludes:

- Hedges
- Common land (but see notes and ‘Livestock’ below)
- Commercial forestry

In order to compare the emissions under the regenerative scenarios to a baseline, it was necessary to create and analyse a series of model farms using land use and livestock statistics from the Defra June Survey of Agriculture 2021. It must be noted that there is a difference between the RPA data and the June Survey data. The RPA data is restricted to agricultural land registered with the RPA actually inside the boundaries of the PL. The June Survey data is all land associated with commercial holdings where the business location is within the PL. This can include land outside of the PL but registered to the holding. In theory neither dataset should include common land, in practice there is little bit of overlap.

5.1.2 Soil data

While there is much academic evidence on the soil health and other environmental benefits of regenerative farming, there is very little quantitative evidence of the effect of regenerative farming on soil carbon emissions and sequestration.

It was not possible to estimate and integrate changes in soil carbon into the emissions modelling used in the project due to limitations in data available, although we have differentiated between organic and mineral soils, and differences in management practices, within the modelling. Building a separate model to estimate changes in soil carbon to replicate the method used in the National Inventory was not feasible within the timeframe and budget of the project, and licencing restrictions precluded the use of NSRI and other data. Instead, our approach used a 1km open dataset from the Food and Agriculture Organisation (FAO) containing precalculated soil carbon stock and sequestration rate estimates for England; these have been calculated by NSRI for the FAO Global Soil Sequestration Potential Map (GSOCseq).

To estimate soil carbon sequestration under the baseline and regenerative agriculture scenarios, a separate spatial analysis was performed using the FAO dataset. This enabled us to produce estimates of soil carbon stocks for each of the five PLs for the baseline and for the regenerative scenarios where carbon inputs are increased. The soil carbon estimates are an average across all land uses so it is not possible to identify the impact from specific land use changes. The dataset provides a set of estimates for carbon stocks under 20 years of sustainable soil management at 5%, 10% and 20% increased carbon inputs. We used the 20% uplift to represent the change in carbon sequestration under the regenerative agriculture scenarios, scaled by the proportion of uptake in the scenarios. The 20% uplift figure was used to try to get as close as possible to the 4 in 1000 (4 per mille) sustainable soils initiative target for an annual increase in soil carbon in agricultural soils. The 20% increase in inputs is likely to be below the required uplift in carbon inputs as studies such as Martin et al.[3] have found that a greater than 20% uplift is required to achieve this target.

This approach gave indications for both the current carbon stock, and the uplift arising from regenerative agriculture. This analysis was undertaken separately (and not incorporated into our model) as the estimates do not relate directly to the changes in activities under regenerative agriculture proposed within this report, but we do show the figures alongside the emissions model outputs in later sections.

5.1.3 Livestock data

Livestock data used in the model comes from the Defra Survey of Agriculture and Horticulture - June 2021, which is the best we have. It relates to commercial holdings and should cover livestock grazed on in bye land, sole grazing intake and moorland, and shared grazing i.e. the June Survey data should capture livestock linked to the 'home farm' wherever it is grazed.

5.1.4 Emissions data

The sources of information for the emissions data and analysis include (but are not limited to):

- IPCC Emission Factors Database
- Defra GHG conversion factors
- Defra GHG Platform Reports (Defra projects AC0114-AC0116)
- Natural England Carbon Storage and Sequestration by Habitat (NERR094)
- Establishing a field-based evidence base for the impact of agri-environment options on soil carbon and climate change mitigation. Final Report for Natural England Project RP04176 (Defra project reference LM0470)

5.2 Methodology for assessing the baseline

For the assessment of the baseline for carbon sequestration and GHG emissions we split the agricultural enterprises into three groups:

1. Cropping and grazing land (i.e. land use)
2. Livestock (i.e. livestock numbers)
3. Forestry

Within each group, the methodology to calculate the carbon storage and GHG emissions is consistent across the enterprises making up that group.

Cropping and grazing land

This group of enterprises covers land uses to produce crops or grassland to support grazing livestock. Carbon sequestration is not considered for the baseline assessment of the cropping and grazing land on mineral soils as it is assumed that the soil carbon storage is in equilibrium and removal of biomass by harvesting or grazing means no change in above-ground carbon storage in biomass. For cropping and temporary grassland on organic soils it is assumed that disturbance of the organic soil causes carbon losses (as CO_2 from oxidation of soil carbon).

The majority of the modelling for cropping and grazing land involves estimating emissions from management inputs in the production of the crops or grass. These are split across emissions of carbon dioxide (CO_2; Table 5-1) and nitrous oxide (N_2O; Table 5-2).

Table 5-1: CO_2 emission factors for crops and grassland

Source	Unit
Fertiliser manufacture	t CO_2/t fertiliser produced
Pesticide manufacture	t CO_2/kg pesticide produced
Fuel usage	t CO_2/1000l
Limestone production	t CO_2/t limestone produced
Liming	t CO_2/t limestone applied
Cultivation of organic soil	t CO_2/ha/yr

Table 5-2: N_2O emission factors for crops and grassland

Emission Source	Unit
Direct emissions from fertiliser application	t N_2O/t nitrogen applied
Indirect emissions for leached fertiliser nitrogen	t N_2O/t nitrogen leached
Indirect emissions for volatilised and redeposited fertiliser nitrogen	t N_2O/t nitrogen deposited
Direct emissions from spreading manure	t N_2O/t nitrogen applied
Indirect emissions for leached manure nitrogen	t N_2O/t nitrogen leached
Indirect emissions for volatilised and redeposited manure nitrogen	t N_2O/t nitrogen deposited
Direct emissions from crop residues	t N_2O/t nitrogen in residues
Indirect emissions from nitrogen leached from crop residues	t N_2O/t nitrogen leached from residues
Cultivation of organic soils	t N_2O /ha/yr

For each enterprise, the management inputs in Table 5-3 are specified based on national or locally derived data. In addition, a set of coefficients is used to convert the reported units to those used by the emission factors has been identified.

Table 5-3: Management inputs for crops and grazing land

Management Input	Unit
Straight nitrogen fertiliser (Ammonium Nitrate)	t N/ha
Compound nitrogen fertiliser (NPK)	t N/ha
Manure application	t/ha
Pesticides	kg active ingredient/ha
Fuel usage	l/ha
Limestone	t/ha
Crop Residues	t/ha

Livestock

This group of enterprises is defined by emissions associated with the management of livestock. Livestock numbers for each PL come from the estimates made from the June Survey 2021. The types of livestock in each enterprise are given in Table 5-4. Livestock are also assigned to the land use supporting them.

Table 5-4: Livestock enterprises in the North Yorkshire Protected Landscapes

Livestock Enterprise	Livestock Types
Dairy	Dairy cows
Beef	Beef cows
Other Cattle	Calves Other Cattle
Pigs	Breeding Pigs Other Pigs
Sheep	Breeding Ewes Lambs Other sheep

The livestock management inputs are given in Table 5-8 and, as with the cropping/grazing calculations, a set of coefficients has been defined that allow the conversion of the management inputs and livestock population data into the units used by the emission factors. The different GHG emission factors are given in Tables 5-5 (CO_2), 5-6 (N_2O) and 5-7 (CH_4).

Table 5-5: CO_2 emission factors for Livestock

Emission Source	Unit
Electrical Energy Use	t CO_2/kWh

Table 5-6: N_2O emission factors for Livestock

Emission Source	Unit
Direct emissions from grazing	t N_2O/t nitrogen excreted
Indirect emissions for leached excreta nitrogen	t N_2O/t nitrogen leached
Indirect emissions for volatilised and redeposited excreta nitrogen	t N_2O/t nitrogen deposited
Direct emissions from housing	t N_2O/t nitrogen excreted

Table 5-7: CH_4 emission factors for Livestock

Emission Source	Unit
Excreta	t CH_4/head
Managed manure	t CH_4/head
Enteric	t CH_4/head

Table 5-8: Management inputs for Livestock

Management Input	Unit
Electrical Energy Use	kWh/head

Livestock feed

Scope 1 emissions of bought-in feed are captured through the livestock numbers and emissions from those, but the emissions factors are based on conventional systems. In regenerative systems, which are forage-based, concentrates would make up a much smaller percentage of animal feed intake. This would logically help to reduce the emissions associated with livestock, all other things being equal. However, the picture is complicated, because livestock production cycles may take longer in forage-based systems and production output is also reduced; this makes it more effective from an emissions per unit perspective to reduce livestock numbers and maintain existing feed practices than to change feed and have a larger herd (see Box 1 below). Therefore, we assume feed related emissions per head do not change between the conventional and regenerative scenarios.

Box 1: IPCC livestock feed and production data (IPCC, 2019)[4]

The IPCC values for dairy cattle emissions for Eastern Europe and Oceania, where the diets are more forage based, have reduced emissions per head compared to Western Europe (down from 126 kg CH_4 head^{-1} yr^{-1} to 93 kg CH4 head^{-1} yr^{-1} for Eastern Europe and Oceania). However, this is accompanied by average milk yield reductions from 7,410 kg head^{-1} yr^{-1} to 4,000 kg head^{-1} yr^{-1} and 4,400 kg head^{-1} yr^{1-} respectively for Eastern Europe and Oceania.

While the impact of the composition of livestock feed is incorporated within the way the emission factors for livestock are calculated, we do not have a good understanding of the carbon footprint of the livestock feeds themselves which will depend on the feed type and source of materials used in the manufacture of the feed. Therefore, Scope 3 emissions directly associated with production and transport of feed are excluded.

Woodland

Following the approach that Natural England have used in their report on carbon storage and sequestration by habitat (NERR094), we assess farm woodland as being equivalent to a Sycamore, Ash and Birch woodland with 1.5m spacing, Yield Class 6 with no thinning (as it is native woodland). Carbon sequestration (t CO_2/ha) values are taken from the Woodland Carbon Code calculation spreadsheet with the average carbon sequestration calculated for stands across age classes between 30 and 80 years old (Table 5-9).

Table 5-9: CO_2 emission factors for Forestry

Emission Source	Unit
Biomass Carbon Sequestration	t CO_2/ha

The baseline assumes that all cells identified as 'trees and scrub' within RPA parcels are in a farm woodland enterprise. As with the cropping/grazing enterprises we assume that soil carbon in farm woodlands has reached an equilibrium and therefore carbon sequestration in biomass is the only change in carbon storage needing to be accounted for in the baseline.

Hedges

Under the regenerative scenario, we have assumed the area of farm woodland doubles, up to a maximum of 5% of the total farm area. This increase in farm woodland could take the form of hedgerows or woodland blocks - we do not differentiate - but the effect would be the same. We have assumed that any tree planting takes place on permanent pasture.

Peatland

Peatland is identified separately using the peat soils dataset, so it is not a separate land use. Cropland and temporary grassland have additional emissions for the area on peat soils.

We have considered whether moorland/heathland/peatland/wetland restoration is part of regenerative farming actions or is out of scope. For normal farmers, we feel that it would be 'special', i.e. requiring special funding via Landscape Recovery or other public/private funding, as opposed to part of the 'usual' regenerative transition on farm. It would also require a different treatment than the emissions model we have, which is based on changes in inputs, stocking densities etc.

Our view is that peatland restoration would be 'in addition' to regenerative farming and generally would require additional activity and incur additional costs that would be funded separately. In most cases it requires specialist interventions, such as re-wetting and re-profiling of peat hags, which go above and beyond what would normally be considered regenerative farming practices.

5.2.1 Analysis, Testing, verification and aggregation

The methodology for calculating carbon sequestration and GHG emissions is implemented using MS Excel spreadsheets. Each Excel spreadsheet contains separate sheets holding data on the land use for an area of interest (a PL or farm), the scale of different agricultural enterprises within the area of interest (linked to land use) and the management inputs related to each of the enterprises. The workbook also contains worksheets that act as look ups for conversion coefficients and GHG emission factors to allow the GHG and carbon sequestration estimates to be calculated in a way that is comparable with UK national inventory methods. Finally, there are two worksheets to calculate emissions and sequestration on an enterprise and total area basis. The management inputs and conversion coefficients worksheets were populated with data derived from national datasets, with the assumption that these can be updated with locally derived values if they become available.

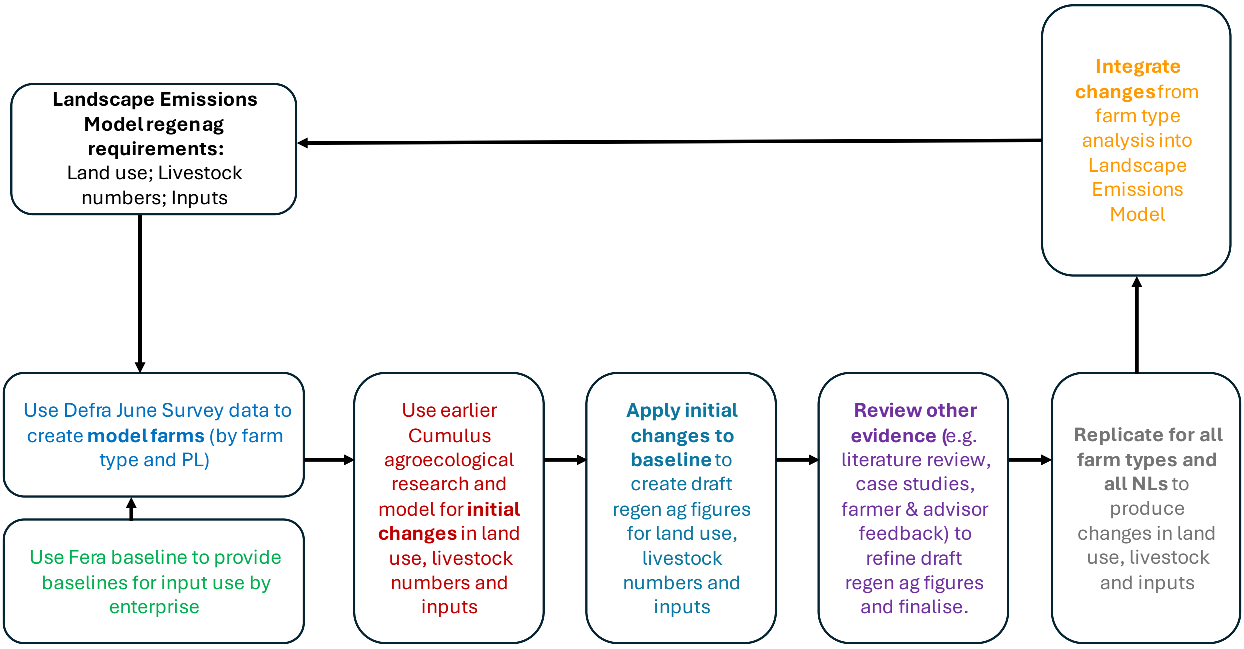
The model was sense checked using the land use and agricultural enterprise information for the Forest of Bowland National Landscape (NL) to make sure that the formulas were working properly. Once we were satisfied that the formulas were operating as expected, a workbook was populated with the national data on land use and agricultural enterprises for 2021 to compare with the official GHG inventory estimates for agriculture (see Figure 5-1). Once this comparison validated that the spreadsheet was able to reproduce estimates that generally agrees with the national inventory, copies of the spreadsheet were created with the information for each of the PLs. The baseline estimates are summarised in Section 7.1.1.

The land use and enterprise data have been derived for each PL and for individual farm types present in each PL. For each PL, a workbook has been produced to calculate a baseline estimate of emissions for all agricultural activities (PL estimates) as well as individual workbooks to calculate emission estimates for baseline and regenerative agriculture scenarios for each farm type in each PL (FT estimates). The outputs of these workbooks were also used to calculate estimates for emissions on an enterprise basis (EE estimates).

5.3 Methodology for assessing the regenerative scenarios

The emissions model described in Section 5.1 is used for calculating the GHG emissions and sequestration for both the baseline and the regenerative farming scenarios. However, to arrive at the regenerative farming figures, a separate analysis has to be carried out to arrive at the changes in land use, livestock numbers and inputs arising from the regenerative transition. Figure 5-1 summarises the approach used to estimate the regenerative farming changes and integrating these into the emissions model.

Figure 5-1: Approach to estimating regenerative agriculture changes and integrating these into the emissions model



The emissions model sets out three key areas that drive GHG emissions:

- Land use change
- Livestock numbers
- Input rates and amounts

These three key areas provided focus for analysing the changes in emissions arising from a transition to regenerative farming.

The analysis considers the regenerative farming transition at the 'farm level' as opposed to the landscape level. This has the advantages of us being able to draw on available literature and data on the regenerative transition which is generally at the 'farm level' and us then being able to share this with farmers, and obtain feedback, using recognisable farming systems, enterprises and practices.

To this end, we developed a set of 'model farms' for each PL. This included the following main farm types:

- LFA grazing livestock
- Lowland grazing livestock
- Dairy
- Cereals
- General cropping
- Mixed

For each model farm, we produced a conventional version and a regenerative version, with the difference being the main changes in land use, livestock and inputs arising as the farm goes through the regenerative transition. These included:

- % changes in land use
- % changes in livestock numbers
- % changes in inputs

Each model farm was built using area, land use and livestock number data from the Defra June Survey 2021. This data is available by farm type and by PL. This, together with input data from the main emissions model, was used to create the conventional version of each model farm.

The changes arising from the regenerative transition were derived from a variety of documents and data. The initial changes in land use, livestock numbers and inputs were primarily based on a previous, formative report 'The Economics of a Transition to Agroecological Farm' carried out by Cumulus for the Soil Association in 2022.[5]

The initial changes were then supplemented by data and information from:

- A review of other previous agroecological/regenerative farming research carried out by Cumulus for Soil Association and WWF.
- A literature review focused on regenerative farming relevant to the North of England (see Section 6, and references at the end of the appendix)
- Nine local regenerative farming case studies produced alongside this project. (Appendix 2 – attached separately).
- A sample of carbon footprints carried out for farms across the PLs.
- Farm Business Survey data and reports for Yorkshire & Humberside and surrounding regions, and agricultural budgetary data from publications such as ABC[6] and Nix[7].
- Feedback from two farmer meetings and one farm adviser meeting held towards the end of the project.

The model farm data was accompanied by a 'pen portrait' produced for each model farm, describing the shift from conventional to regenerative farming. This was supported by a review of contextual information relating to farming in each PL. The pen portraits on the regenerative farming practices and supporting evidence can be found in Section 6.

Model farms were produced initially for one farm type (LFA grazing livestock) in one PL (Forest of Bowland) prior to replicating the approach for all farm types in the same PL. Once proof of concept was established, this process was replicated for the other PLs.

The results - in terms of percentage changes in land use, livestock numbers and inputs by farm type - were then re-aggregated to create equivalent changes at landscape scale for the PL for inclusion with the main emissions model

The research then calculated the overall scale of change based on a number of different scenarios, e.g. 25% of agricultural land area in PLs converting to regenerative agriculture, 50% converting and 75% of land converting, again based on the specific farmed landscapes of the five PL areas.

5.4 Emissions model limitations

The emissions model developed for this project takes a coefficient-based approach to estimating emissions from agricultural practices. It is based on the values from national agricultural management statistics and emission factors used in the National Atmospheric Emissions Inventory (NAEI) meaning that the values used are representative of the whole of the UK which may be slightly different to what representative regional values for North Yorkshire may be. However, the land use, crop areas and livestock numbers have been extracted for the individual protected landscapes and therefore those model inputs are specific to the protected landscapes. The model is also limited by how the NAEI is structured, with some agricultural emissions being incorporated other emission sources in other sectors (e.g. transport, land use change, energy production). Where it has been reasonable to bring emission factors in from these other sectors we have done so, however in some cases it is not possible to disaggregate the agricultural emissions within other sectors (for instance emissions for the transportation of goods to and from farms).

We have not been able to include all emissions from livestock feed as explained in Section 5.2. The impact of the composition of livestock feed is incorporated within the way the emission factors for livestock are calculated and are therefore included. However, the emissions directly associated with production and transport of feed are excluded. This would be a future development for the model.

For carbon sequestration under land use change, the NAEI used a modelling approach rather than a coefficient-based approach which means that we cannot replicate that part of the national methodology. Instead, we are relying on a precalculated soil carbon model created by NSRI/Cranfield University that uses a set uplift in carbon inputs across all agricultural land uses in a 1km grid cell. This use of the precalculated model means that we cannot link the specific regenerative agriculture outcomes used to calculate the emissions reductions to a change in soil carbon storage. The values given only provide an estimate of the increase in soil carbon storage, and therefore we do not have information on changes in emissions associated with the increased carbon inputs. It is possible that while soil carbon storage in increased, a proportion of the increased carbon inputs could also be released as emissions meaning the net sequestration with the change in inputs may be lower than purely converting the change in soil carbon storage to CO2e.

Carbon sequestration in soils

The IPCC Tier 2 methodology for assessing carbon sequestration from land use change is designed around habitat change such as conversion of cropland to grassland or grassland to forest. The UK has moved from the Tier 2 country specific emission factor approach to a Tier 3 approach which uses a dynamic soil carbon model that takes in information such as soil types, temperature, hydrology, and carbon inputs to provide an estimate for the change in carbon storage for the UK as a whole. This means that we are unable to convert the National Inventory approach into a simple coefficient-based approach to soil carbon sequestration for use in the model developed here. Instead, we are using the values calculated for the FAO Global Soil Sequestration (GSOCseq V1.0.0) map which is created using the RothC model applied to a 30 arcsecond (approximately 550m x 925m at the latitude of North Yorkshire) grid of soil type and land use. The map includes data for the current and future estimates of soil carbon stocks under a Business as Usual (BAU) scenario after 20 years. It also provides estimates for the relative change in carbon sequestration rate from the BAU estimate for uplifts in soil carbon inputs of 5%, 10% and 20%. For each PL, the soil carbon stock and sequestration rates for the agricultural areas (land registered with the RPA) within the PL were extracted from the datasets, and the soil carbon stock change stock change and average sequestration rates for each PL were calculated for each of the carbon input uplift values.

Comparison of GWP100 vs GWP*

The most commonly used way of standardising GHG emissions is to express each gas with respect to global warming potential (GWP) of CO_2 over a 100 year period with respect to a single pulse of emissions. This is referred to as the GWP100. Other similar metrics are the GWP20 which standardises with respect to the global warming potential of carbon dioxide over a 20 year period and GWP500 which standardises over a period of 500 years. For methane the IPCC Assessment Report 5 (AR5) estimate for GWP100 is 28, but the GWP20 value for methane is 84, demonstrating the importance of specifying an appropriate time period to assess impact over. These are static measures assuming a comparison of two pulses of emissions at the same time, one of CO_2 and one of the GHG of interest, for a predetermined period.

More recently a new methodology, called GWP*, has been proposed by researchers at Oxford University. This is a dynamic method for calculating the global warming impact of a timeseries of GHG emissions with reference to a single equivalent pulse of CO_2. This method has been proposed to address the fact that some GHGs are much more reactive than CO_2 in the atmosphere and have much shorter lifespans over which they influence warming. These short-lived climate pollutants (SLCPs), most important of which is methane, have a different warming profile over time than long-lived climate pollutants such as CO_2 and N_2O.

Generally, the GWP* method applied for 100 years of emissions predicts lower values for GWP, under decreasing or slightly increasing emissions, than estimated using GWP100. But GWP* produces higher values for warming potential if emissions increase more rapidly. The point of cross over depends on how quickly the GHG degrades in the atmosphere, and for methane this cross over occurs at approximately a 1% annual increase in emissions. In the scenarios described in this report, GWP* would likely produce lower total CO_2e values for reduced methane emissions under regenerative practices in the Forest of Bowland, Nidderdale, North York Moors and Yorkshire Dales, but higher CO_2e values for the Howardian Hills where methane emissions are expected to significantly increase due to increased livestock numbers.

6 Regenerative farming practices

6.1 Defining 'regenerative' farming

Regenerative agriculture is attracting interest from across the private, public and non-profit sectors, from producers and retailers to researchers and politicians. There are potentially significant benefits to regenerative agriculture; we explore these in more detail at sections 6.3.4–6.6.4 below, with reference to peer-reviewed studies and data, but in summary they include:

- improved soil health,
- animal health and welfare improvements,
- greater resilience against extreme weather events
- water quality improvements
- more biodiversity
- economic benefits of increased resilience against input price volatility.

Despite this, no universally agreed definition of the term 'regenerative agriculture' exists. There are many different definitions and descriptions in usage; the literature review undertaken during this project shows that scholars and practitioners are generally using one of three broad definitions: process-based definitions (e.g., use of cover crops, the integration of livestock into the arable rotation, and reducing or eliminating tillage); outcomes-based definitions (e.g., to improve soil health, to sequester carbon, and to increase biodiversity); or a combination of the two[8]. The problem is that these alternative definitions can be mutually exclusive: if an outcome-based definition is agnostic as to the processes that generate those outcomes, this is potentially in conflict with a definition that is based on process. A lack of clarity around the meaning of the term creates challenges for a research project like this, where we are seeking to test claims about its adoption and impacts. It is therefore important for us to carefully define what we mean by regenerative agriculture in the context of this project, with particular reference to livestock grazing in the English Uplands – a scenario not well covered by research to date.

The purpose of this project is to establish the contribution that a transition to regenerative agriculture in the five Protected Landscapes could make towards the drive for Net Zero in the York & North Yorkshire Combined Authority area. Across the public sector, from international to local levels, governments are exploring the possibilities for regenerative agriculture to contribute to climate action plans. Internationally, a Special Report on 'Climate Change and Land' by the Intergovernmental Panel on Climate Change listed regenerative agriculture as a "sustainable land management practice" focused on ecological functions that "can be effective in building resilience of agro-ecosystems" (IPCC, 2019, p. 389)[9]. At a more local level, there are many instances from across the UK and elsewhere of local and municipal governments exploring the potential for regenerative agriculture to help achieve local sustainability goals (The Climate Reality Project, 2020)[10] . However, empirical evidence of the contribution that regenerative agriculture could make towards the drive for Net Zero is hard to come by.

Whilst the public-policy objectives of the five Protected Landscapes are clear – to de-carbonise farming in the drive for net zero, whilst also supporting nature recovery, climate change adaptation, and the viability of their farming communities – it is farmers who are key to delivery. A farmer-focused approach is (almost by definition) process-based, and for this reason our working definition of regenerative agriculture is "**farming systems and field operations that minimise soil disturbance (don't disturb the soil, keep the soil surface covered, and keep living roots in the soil); use diverse rotations and a range of crops; and integrate grazing livestock**". These key principles are those adopted by the Groundswell forum[11] and align with the definitions of regenerative agriculture used by Giller et al (2021)[12]; Magistrali et al (2022)[13] Schreefel et al (2020)[14], and others. However, much of the literature around regenerative agriculture is focused on arable systems, but the Protected Landscapes are primarily managed under livestock systems. We therefore looked in more detail at how regenerative principles can be practically applied on different farm types, and what outcomes have been evidenced in the literature (references of the literature review are included as an appendix at the end of the report). The key characteristics of regenerative agriculture in this upland context have been summarised in Section 6.2 below.

The intended outcomes from following these principles include: reducing GHG emissions; building soil carbon; improving soil heath and biology; enhancing farm-scale nutrient use efficiency; and restoring biodiversity.

6.2 Defining regenerative livestock systems in the Protected Landscapes

We started this chapter with a working definition of regenerative agriculture as **"farming systems and field operations that minimise soil disturbance (don't disturb the soil, keep the soil surface covered, and keep living roots in the soil); use diverse rotations and a range of crops; and integrate grazing livestock'".** We have gone on to look in more detail at how regenerative principles can be practically applied on different farm types, and what outcomes have been evidenced in the literature (detail in Section 6.3 – 6.6). Much of the literature around regenerative agriculture is focused on arable systems, but the Protected Landscapes are primarily managed under livestock systems.

The key characteristics of regenerative agriculture in this context include:

- **Maximising forage production by improving soil health and natural nutrient cycles;**
- **Maximising forage utilisation, through proactive grazing strategies and livestock enterprises which are best suited to forage-based systems;**
- **Improving feed-conversion efficiency by investing in livestock genetics, health and welfare, and devising strategies to minimise routine treatments with anthelmintics, ectoparasite chemicals, and antibiotics;**
- **Increasing the diversity of browse and forage available to livestock by investing in more diverse swards, planting trees and agroforestry;**
- **Minimising inputs of synthetic mineral nitrogen and plant protein imports.**

Below, we consider in more detail how these principles are practically applied in different farming contexts, and what outcomes have been evidenced in the literature. These have been informed by (a combination of) the literature, observed farm practices, as well as from farm case studies (Appendix 2 – attached separately) and feedback from farmer engagement. We follow the UK farm classification system[15], but focus on those farm types most often found in the 5 Protected Landscapes:

- Less Favoured Area (LFA) grazing livestock farms
- Lowland grazing livestock farms
- Dairy farms
- Cereal and general cropping farms

For each farm type, we consider the following:

- Change in farming system
- Change in enterprises
- Changes in management practices
- Regenerative outcomes

SUMMARY TABLES OF THE ASSUMPTIONS FOR THE FOUR FARM TYPES ARE INCLUDED IN SECTION 6.8., TABLE 6-2, TABLE 6-3, TABLE 6-4, AND TABLE 6-5.

To enable the emissions modelling, we had to define a set of regenerative principles and practices for each farm type. However, we recognise that these would not suit every farm or farmer. In farming, there is a wide spectrum of practices which are loosely called regenerative farming, and many farms are 'in transition' rather than arrived at a specific end point as is illustrated by the case studies (see Section 6.7 and Appendix 2).

6.3 Less Favoured Area grazing livestock farms

Grazing Livestock farms are classified as farms with more than two-thirds of their total Standard Output produced by cattle and sheep (excluding holdings classified as dairy). A farm is classified as "LFA" if more than 50% of its total area is in the EC Less Favoured Area (see the maps showing LFA land in the PLs in Appendix 1).

We set out below the various ways in which LFA grazing farms might adopt principles of regenerative agriculture. For practical examples of how these principles are applied, please refer to Case Studies 4, 5, 6 and 9.

6.3.1 Change in farming system

The overall system-level changes that we would expect to see in LFA grazing farms are as follows:

- A move towards more grass-based systems, in which the majority of forage resources come from permanent grasslands[16]; Many upland farms have done this already.
- A move towards low-input or closed-nutrient systems, in which synthetic mineral nitrogen inputs and plant protein imports are halted or minimised[17, 14]. Since the price rises in 2020, many upland farms drastically reduced their nitrogen fertiliser applications.

- A reduction in livestock numbers to adjust to the natural carrying capacity of the land

6.3.2 Change in enterprises

A shift from sheep towards cattle

In general, moving away from conventional LFA grazing to regenerative grazing would precipitate a shift away from sheep and towards more cattle: cattle are generally better able to utilise the coarser forage resources that are available over a longer period[18,19]. Sheep are more selective in their grazing and require a higher percentage of Digestible Dry Matter than cattle[20].

Breeding versus store enterprises

The LFA grazing farm will rely on enterprises that are best suited to low-input, outdoor systems, and which maximise forage utilisation. We would expect to see less maintenance/keeping or finishing of dairy-cross stores, which would typically rely on supplementary concentrate feeding, and more suckler-based enterprises: the native-bred suckler cow is better suited to grass-based systems and will produce a calf that can finish off grass[21].

6.3.3 Changes in management practices

We would expect to see some or all of the following changes in management practices:

Grassland management

Forage production and utilisation is maximised by proactive grazing strategies. The precise strategy is context-specific, and will depend on the location / grassland habitat / weather / soil conditions, but might include mob grazing (high density, short duration, tall grass grazing, with long rest periods); deferred grazing (setting aside pastures in summer to allow for areas to be grazed overwinter); bale grazing (where fodder bales are pre-arranged on pasture to support outwintering cattle); and creep grazing (where young livestock access higher quality pasture by dipping below electric fencing)[22]. Giving livestock access to more varied herbage, and the greater variety of vitamins, minerals and nutrients that comes from this, may be an important part of the grazing strategy.

Breed selection

The regenerative LFA grazing farm relies on breeds that:

- maximise forage utilisation;
- are suited to low-input, outdoor systems
- are hardy, to withstand upland weather conditions and low management inputs;
- are bred for resistance to gastrointestinal parasites, reducing use of anthelmintic treatments;
- are able to eat coarser forage resources that are available over a longer period (i.e. they are 'browsier' breeds);

In practice this will often mean hardy native breeds developed specifically for conditions in the uplands[23]. Our case studies feature Luings, Galloways, and native-bred Angus cattle.

Traditional upland sheep breeds include the Swaledale, Scottish Blackface, and Herdwick, but there is also a trend towards more white-faced or composite breeds and the introduction of New Zealand genetics. Case Studies 5, 6, and 9 provide good examples of the sort of changes we might expect to see on LFA grazing farms.

Housing

The need for livestock housing is minimised under a regenerative LFA grazing system. The system is characterised by:

- earlier turnout in spring and later housing in autumn / all-year-round outdoor system
- maximising forage utilisation, and minimising the need for bought-in fodder or concentrate feed

In summary, livestock are at pasture at all times when conditions allow. By contrast, conventional, intensively raised cattle may be housed from the point of weaning, and a minority of conventional, early-lambing flocks may be housed until after lambing, notably those with lowland breeds. While it is true that almost every farmer wants to minimise the length of time cattle are housed, stocking rates in a regenerative system are matched more closely to the natural carrying capacity of the land with the specific objective of minimising housing. Of course, this will also be dependent on location, soil conditions and weather conditions.

Agroforestry

Agroforestry is often cited as a core regenerative agriculture activity (e.g. Giller et al 2021[12], Magistrali et al 2022[13]). Regenerative LFA grazing systems are likely to incorporate areas of open woodland or scattered trees at low density in a matrix of grazed grassland, heathland and/or woodland floras. Carefully integrating trees into livestock systems can boost production, improve animal health and welfare, and provide wider environmental benefits, including carbon sequestration[24,2526] Stock graze beneath the trees, which provide shade, shelter, improve soil quality, improve water infiltration, and reduce water-logging and erosion.

However, tree planting needs to be very carefully considered, not least because of potential impacts on - for example - the archaeological landscape, or breeding waders. The Sustainable Farming Incentive (SFI) currently provides two actions supporting agroforestry. The options on offer will be expanded through 2025 with the new Countryside Stewardship Higher Tier (CSHT) scheme offering an additional four agroforestry actions. At this stage, we anticipate only a relatively modest increase in woodland on LFA grazing farms; however, this may change as the new actions are rolled out and farmers and advisers become more familiar with them.

6.3.4 Regenerative Outcomes

Some of the outcomes from adopting these changes, which are evidenced in the literature, include:

- Proactive grazing strategies lead to higher grass yields, with research suggesting around 20% more grass is grown in a rotational grazing system[27] than continuous (set-stocked) grazing systems.

- Reducing output (and hence stock numbers) to a level where stock are grazed only on the farm's naturally available grass (i.e. without artificial fertilisers) – known as 'Maximum Sustainable Output' - can increase profitability through significant savings of variable costs.[28]
- The benefits of mob grazing on soil organic matter and animal performance have not been widely studied in scientifically robust experiments, and this gap in scientific knowledge is reflected in the literature. We can find no peer-reviewed papers quantifying the effects of mob grazing on soil organic matter in the UK prior to 2017. However, since then there have been some individual case studies, such as Zaralis and Padel's (2017)[29] case study on a mixed dairy/arable farm in the Cotswolds. In this study, soil samples following the introduction of mob grazing were compared with historic data on the organic matter content from three different fields, and they found that soil organic matter increased by 10-15% per annum over a 3-8 year period. These results indicate a potentially significant increase in soil organic matter arising from mob grazing.
- Management of important grassland habitats. Longer rest periods found in mob grazing and holistic planned grazing can allow grasses and flowers to set seed, leading to increased plant diversity, and invertebrates and bird life in turn[30]. (This is not to say that mob grazing is suitable for all grassland habitats; the grazing regime needs to be tailored to the grassland).
- Higher omega-3 content of meat from grass-fed beef and lamb.[31]
- Animal health and welfare benefits. Cattle and sheep housed indoors are more susceptible to certain diseases, and cannot self-medicate and source minerals as well as the alkaloids, terpenes, sesquiterpene lactones and phenolics which may be available in forage-based systems, particularly biodiverse pasture and silvopasture.[32]
- Limiting food-feed competition and reducing the environmental footprint of plant-based imports. The efficiency of LFA grazing systems is low if we just look at energy (the conversion of solar energy into plant then animal biomass), but it becomes high if we consider that they make use of what humans cannot eat.
- Off-farm, there is reduced fossil fuel use and energy consumption associated with the manufacture of inorganic fertilisers and pesticides[33]. In general, the risk of nitrate pollution is lower with extensive and low intensity cattle (and sheep) production systems compared to intensive systems[34].
- Potential reductions in antibiotic use to treat bacterial diseases and respiratory diseases which are more common while animals are housed.
- Decreased use of machinery to tend grassland sward, leading to lower fuel use and carbon emissions, and less soil compaction when fertilising/ cutting grass and spreading slurry/FYM
- Improving health can reduce emissions intensity per unit output by improving feed conversion ratios and fertility and reduce mortality, all of which can increase growth rates and milk yields[35,36]
- As noted by W R Teague (2018)[37] in the Journal of Animal Science: "With appropriate management of grazing enterprises, soil function can be regenerated to improve essential ecosystem services and farm profitability. Affected ecosystem services include carbon sequestration, water infiltration, soil fertility, nutrient cycling, soil formation, biodiversity, wildlife habitat, and increased ecosystem stability and resilience".

A SUMMARY OF THE ASSUMPTIONS FOR OUR MODEL FOR THE REGENERATIVE LFA GRAZING LIVESTOCK FARM TYPE IS INCLUDED IN SECTION 6.8 TABLE 6-2.

6.4 Lowland grazing livestock farms

Lowland grazing livestock farms are those farms with more than two-thirds of their total Standard Output produced by cattle and sheep (excluding holdings classified as dairy) which lie outside the EC Less Favoured Area designation.

Many of the on-farm actions described above for LFA grazing livestock farms would also be seen on lowland grazing livestock farms. We focus below on the changes that are specific to lowland grazing livestock farms.

6.4.1 Change in farming system

One of the most obvious differences between LFA and lowland grazing livestock farms is the area of land dedicated to temporary grass, fodder crops and general cropping. The average (conventional) lowland grazing livestock farm in the Farm Business Survey has approximately 20% of its land area dedicated to temporary grass, fodder crops and general crops. In a transition to regenerative agriculture, we would expect to see more diverse herbal leys, less maize, and longer rotations on this portion of the farm which is not in permanent grassland. The system overall would be more forage-based and livestock would be outdoors at all times when conditions allow.

Case Studies 1, 2 and 3 offer practical examples of how regenerative practices have been adopted on lowland grazing livestock farms.

6.4.2 Change in enterprises

Sheep versus Cattle

Lowland grazing livestock farms are likely better suited to continuing with sheep in a regenerative system than their LFA counterparts. The availability of temporary grassland and croppable land offers more opportunities for sheep to maximise forage and fodder utilisation with minimal inputs. Indeed, it may be easier to integrate sheep into the arable rotation without negatively impacting soil structure than cattle. Cattle and sheep can be rotated on the grassland, in order to maximise grass utilisation and manage parasite burdens. Overall, then, we would not expect to see the same shift away from sheep towards cattle which might be seen on the regenerative LFA grazing livestock farm.

Less intensive finishing of cattle and lambs

Certain finishing enterprises are not well suited to regenerative lowland grazing livestock farms. The traditional cereal-based system for finishing cattle, with animals housed throughout the production period and fed on a barley concentrate and straw based ration, would not be considered a regenerative enterprise. The same goes for feeding concentrates in order to finish store lambs. The aim of the regenerative lowland grazing farm is to finish animals at grass or on forage crops. This implies lower overall stocking rates on the regenerative lowland grazing livestock farm, but an end product which has added value. The meat could then be labelled and marketed as 'grass fed'.

6.4.3 Changes in management practices

We would expect to see many of the same practice changes described for the LFA grazing livestock farm, with the following additional changes more likely to be seen in a lowland setting:

Use of diverse herbal leys and integration with the arable rotation

Lowland grazing livestock farms are characterised by a higher percentage of temporary grassland than LFA grazing livestock farms. Temporary grassland is defined as land that's been in grass or other herbaceous forage for five years or less. It occurs either as part of a grass-arable rotation system or in grasslands subject to frequent re-seeding. The regenerative farmer will look to incorporate perennial herbs and legumes into temporary grass swards when re-seeding, in addition to the common grasses and clovers[38]. Furthermore, these temporary herbal leys will feature more frequently in the arable rotation of a regenerative lowland grazing livestock farm[39]. This has the effect of lengthening the rotation and provides more opportunities to build soil organic matter and natural fertility. We look in more detail at regenerative arable rotations below at section 6.6. Case Study 3 provides an example of how these changes can be applied in practice.

Genetic improvements

According to the UK Climate Change Commission's independent research[40], selective breeding for beneficial genetic traits offers the most cost-effective pathway to lower carbon emissions from livestock systems. The genetic traits that a regenerative lowland grazing livestock farm might select for include: feed-conversion efficiency – see, for example, Genus's SimAngus breeding programme[41]; low methane emissions – see, for example, the CIEL's 'Breed for CH4nge' programme[42]; resistance to gastrointestinal parasites; and wool-shedding in sheep, which mitigates the need for chemical agents to prevent flystrike[43]. As Mason et al[44] point out, reducing emissions intensity per unit output may be achieved by increasing yield while emissions per animal stays the same, reducing emissions per animal while yields stay the same, or a combination of reduced emissions per animal and increased yield.

6.4.4 Regenerative Outcomes

Scholars and practitioners have reported the following outcomes from adopting these regenerative actions on lowland grazing livestock farms, in addition to those set out in section 6.3 above:

- The benefits of moving away from finishing cattle indoors on maize silage, and therefore taking maize out of the arable rotation on the lowland grazing livestock farm, were noted in a 2016 ADAS report[45]: maize production is associated with significant amounts of surface runoff, sediment, phosphorus and nitrate losses to water, and the risk of soil degradation is high due to trafficking when soils are wet; it can lead to depletion of soil organic carbon; and it results in relatively low levels of biodiversity.

- It is possible to finish cattle within 22 months on lowland farms using predominantly grazed grass and fodder beet over the winter, with minimal reliance on cereals or other bought-in concentrates and no housed period; however, excellent grassland management is key to achieving this, rotational grazing is required to deliver high grass yields, and soils must have a good nutrient status[46].
- Enhanced sward diversity increases pasture productivity and resilience; the inclusion of legumes build fertility through N fixation; deeper rooting species confer drought tolerance; and plant trace mineral and secondary metabolite content improve livestock health[47].
- Incorporating a ley phase into the arable rotation builds fertility for following arable cash crops, breaks arable weed lifecycles, and provides high-quality livestock forage[48].
- Permanent cover of forage plants is highly effective in reducing soil erosion, whilst ruminants consuming only grazed forages under appropriate management may result in more carbon sequestration than emissions[49]. We cite the research of Zaralis and Padel (2017) above, which suggests increases in soil organic content of 10-15% per annum under mob grazing over a 3-8 year period.
- Genetic selection for low methane production could cumulatively reduce emissions from sheep production by 1–2% per year; 10–20% after 10 years[50].
- Rotational grazing is an important strategy for managing gastrointestinal parasites in sheep and helps mitigate the risk of anthelmintics resistance.

A SUMMARY OF THE ASSUMPTIONS FOR OUR MODEL FOR THE REGENERATIVE LOWLAND LIVESTOCK GRAZING FARM TYPE IS INCLUDED IN SECTION 6.8, TABLE 6-3.

6.5 Dairy farms

Dairy farms are defined in the UK Farm Classification system[51] as holdings on which dairy cows account for more than two thirds of their total Standard Output.

Many of the on-farm actions described above for grazing livestock farms would also be seen on dairy farms. We focus below on the changes that are specific to dairy farms.

6.5.1 Change in farming system

A regenerative dairy system is likely to be characterised by:

- Grass-based, ‘New Zealand-style’, grazing. New Zealand style dairying is a pasture-based system that involves a number of practices, including seasonal calving and rotational grazing.
- Lower inputs, in which synthetic mineral nitrogen inputs and plant protein imports are minimised;
- Spring block calving, which makes the most efficient use of available grass, minimising winter feed requirements while the cows are dry.

6.5.2 Change in enterprises

Dairy-bred beef enterprises

Conventional dairy farms often rely on high yielding, high genetic merit dairy cows, which have been selected for increased milk yields to the detriment of carcass conformation. Selecting instead for cows that maximise forage utilisation, with less of a narrow focus on milk yields, offers greater genetic potential for beef production. Calves from such 'dual-purpose' breeds will finish more quickly (particularly in forage-based systems) and have better carcass traits. For this reason, the regenerative dairy farm is likely to be more multi-functional (i.e. beef and dairy) than single enterprise conventional dairy farms[52].

6.5.3 Changes in management practices

Regenerative dairy practices follow many of the same principles applicable to grazing livestock farms, but we describe below what this looks like for dairy farms specifically:

Grassland management

Proactive grazing management is key to maximising milk production from forage. Mob grazing will help to maximise forage utilisation. Perennial herbs and legumes will be incorporated into the farm's temporary grass swards, and these temporary herbal leys will feature more frequently in the arable rotation.

Housing

Year-round housing, which is not uncommon in conventional dairy systems, is generally considered incompatible with regenerative dairying. The emerging norm within the sector is that for a dairy farm to be considered regenerative, grazing is a prerequisite[53]. As a general principle, livestock will be at pasture at all times when conditions allow. However, farmer engagement over the course of this project has highlighted the practical limitations on this principle. Year-round grazing is not realistic in many situations, owing to ground conditions and increasingly wet winters.

Breeding

Regenerative farmers would tend to select for breeds that maximise milk production from forage. As with beef cattle, certain breeds are better than others at utilising grass. High-yielding, high genetic merit dairy cows are generally 'high maintenance' animals, requiring regular prophylactic veterinary treatments and high energy concentrated feeds to meet their potential[54]. Such breeds may be unable to fulfil their potential performance under low-input, forage-based feeding systems[55].

Milking regime

The milking regime on a regenerative dairy farm will need to be adapted to lower inputs and concentrate feeds[36]. Overall, milk yields will be lower from forage-based systems: cows fed primarily on grazed grass will produce less milk than dairy herds on concentrate-based Total Mixed Ration (TMR) diets. However, cutting concentrate costs can help drive profitability in this system – see, for example, the AHDB's Strategic Dairy Farms project[56].

Crop diversity

With cows at grass for longer and lower overall stocking rates, the regenerative dairy farm is likely to grow less maize for silage and incorporate more herbal leys into its arable rotation or temporary grassland. Cultivations overall will be reduced, helping to minimise soil disturbance and maintain soil cover.

Agroforestry

Trees and hedges are important parts of regenerative systems. They take carbon from the atmosphere and store it safely deep in the soil, cycle nutrients which feed other plants, animals and fungi, which go on to nourish the soil further, and reduce dependence on chemical fertilizers[57]. Trees and hedges increase and diversify habitats and can enhance animal welfare. Trees planted in shelterbelts have been found to improve the productivity and resilience of grazing enterprises[58].

6.5.4 Regenerative Outcomes

Some of the outcomes we would expect to see from the adoption of these regenerative actions on dairy farms include:

- Reduced risk of risk of nutrition-related complaints such as subacute ruminal acidosis (SARA), which is associated with grain-fed diets.
- Lower levels of lameness, hoof pathologies, hock lesions, mastitis, uterine disease and mortality compared with cows on continuously housed systems, according to reviews by Arnott (2014)[59], Tikofsky (cited by Pasture for Life, 2018)[60] and Charlton and Rutter (2017)[61] .
- With spring block calving, winter feed requirements (and costs) will be considerably reduced because the cows are dry. Producers won't need to make as much silage and there won't be as much slurry to handle. This helps to drive down GHG emissions through lower fuel consumption, and can improve soil health and soil carbon sequestration.
- With less slurry to store and manage, the risk of water pollution is much reduced.

A SUMMARY OF THE ASSUMPTIONS FOR OUR MODEL FOR THE REGENERATIVE DAIRY FARM TYPE IS INCLUDED IN SECTION 6.8, TABLE 6-4.

6.6 Cereal and general cropping farms

The UK Farm Classification system treats cereal and general cropping farms as separate business types, but the sort of regenerative practices we would expect to see on these farms are often relevant to both. Cereal farms are defined as holdings on which cereals and combinable crops account for more than two thirds of their total Standard Output; general cropping farms are defined as holdings on which arable crops (including field scale vegetables) account for more than two thirds of the total Standard Output, excluding holdings classified as cereals.

6.6.1 Change in farming system

The system-level changes we would expect to see on regenerative cereal and general cropping farms include:

- Minimising tillage. Practices that may be used in a 'min-till' system include direct drilling, zero tillage, and controlled traffic farming.
- Integrating livestock into the arable rotation. Practically, this can be done by using cover crops as grazeable ground cover between cash crops, or by using temporary grassland / herbal leys within the rotation.

- Minimising or avoiding the use of artificial fertilisers and pesticides. This may or may not involve formal organic conversion, but will likely involve organic practices, such as companion cropping and integrated pest management, diverse crop rotations, and building soil fertility through biological nutrient cycles. Where artificial fertiliser is still applied, practices such as foliar nitrogen applications and precision farming will help to optimise inputs.

Case Studies 1, 2, 7 and 8 offer practical examples of how some of these changes have been applied on farms.

6.6.2 Change in enterprises

The makeup of enterprises on a regenerative cereal and general cropping farm might change as follows:

Less combinable cropping

Lengthening the rotation to include more herbal leys and greater crop diversity would have the effect of reducing the area in combinable crops when averaged across the rotation. A reduction in feed wheat and feed barley production would be consistent with reduced demand for animal feeds, as livestock are moved to forage-based systems.

Greater crop diversity

Besides herbal leys, the regenerative rotation might include more novel break crops to increase diversity, built fertility and break pest lifecycles. Beans and peas are likely to feature more often.

More spring-based cropping

Traditional winter crop-heavy rotations are likely to be replaced with a much more spring-based regime, to maximise the benefits of cover crops.

More livestock

Cereal and general cropping farms are likely to become more multi-functional, with the integration of livestock into the arable rotation resulting in an increase in stock numbers on these farms.

6.6.3 Change in management practices

The practice-level changes we would expect to see on regenerative cereal and general cropping farms include:

Min-till or No-till

Min-till practices reduce soil disturbance by using tines, cultivators and light discs instead of ploughing. No-till or zero-till practices rely on direct drilling to plant crops: no cultivation machinery is used. Min-till or reduced-till were amongst the most common regenerative practices identified by Magistrali et al (2022) in their review of farmer experiences in the north of England.

Controlled traffic farming

Controlled traffic farming (CTF) reduces soil compaction by limiting all farm machinery to fixed tramlines. This has the effect of reducing the area of the field being driven on during farming operations from 85% in a conventionally ploughed field to between 25% and 40% under CTF[62].

Cover crops

Cover crops are non-cash crops which provide potential benefits to a rotation. The term is often used to also encompass both catch crops (which 'catch' available soil nitrogen and prevent nutrient losses via run-off and leaching) and green manures (which improve nutrients and add fresh biomass for following crops). Typically, cover crops are grown over a single winter to cover bare soil or stubble between harvest and establishment of the following cash crop[63]. They offer an added benefit as forage for grazing livestock, which can help to recycle nutrients and make them more available to the following crop[64].

Herbal leys

Herbal leys are temporary grasslands made up of legume, herb and grass species. Leys can be a beneficial addition to an arable rotation, particularly to manage weed problems, such as black-grass, or to build soil fertility. They differ from cover crops in that they take the place of a cash crop for a period of at least one year. Four years is considered an optimal length for herbal leys in the rotation, to allow for root growth, soil fertility building and high species diversity. Sward diversity is key, with each species having different functions: legumes, such as clovers and vetches, build fertility by fixing nitrogen, while deep-rooters such as chicory break up compaction and improve soil structure. Herbal leys can also be a valuable source of forage for livestock, and grazing of herbal leys can help build fertility and soil organic matter.

Integrated Pest Management

Integrated Pest Management (IPM) is a coordinated strategy for preventing and controlling pests, weeds and diseases by integrating different biological, physical and chemical tools. Regenerative practices in the cereal / general cropping farmer's IPM 'toolkit' might include: companion cropping; creating habitats for natural crop pest predators; minimising the use of insecticides; and adding greater crop diversity or leys to lengthen the arable rotation.

Mulching, biochar, compost, compost teas, inoculation of soils

These are all means of building soil fertility through biological nutrient cycles. They may be used by regenerative cereal and general cropping farms to build soil organic matter, increase microbial abundance, and improve fungal:bacteria ratios, which assists in delivering nutrients more efficiently to plants[65].

Optimising inputs

Where agrochemicals are deemed necessary, the regenerative farmer will aim to optimise their effectiveness and reduce wasteful actions. This can be done by using data-driven precision technologies to apply inputs when and where they are most needed. Moving to foliar nitrogen fertiliser applications, for example, where nitrogen is applied to the leaf of the plant and absorbed into the interior of the leaf blade, can help reduce excess soil nitrogen and cut overall nitrogen use. Alternatively, controlled release fertilisers provide plant-available N more slowly and improve N use efficiency.

Agroforestry

The regenerative cereal / general cropping farmer will look for opportunities to integrate and manage more trees on the farm. Trees can provide benefits to crops, such as acting as windbreaks, lifting nutrients from deeper soil horizons, or reducing water runoff[66]. However, it is true that silvoarable systems are much rarer than silvopastoral systems: den Herder et al. (2016) estimate that 2,000 hectares exist across the UK, but examples remain small-scale and niche. These smaller systems are mostly trial plots, and few well established systems exist.

6.6.4 Regenerative Outcomes

Scholars and practitioners have reported the following outcomes from adopting these regenerative actions on cereal and general cropping farms:

- Controlled traffic farming can lead to increased yields of 12% to 15% in combinable crops[67].
- Reduced tillage practices have multiple positive outcomes for GHG emissions: it reduces direct carbon dioxide emissions from soil, can reduce leaching (thus reducing emissions from nitrogen fertiliser manufacturing) and reduces fuel use associated with cultivations.
- Trials by Velcourt and crop consultants Niab showed that foliar applications can replace a third tranche of soil-applied nitrogen, maintaining yields while reducing N inputs by about 30%[68].
- Cover crops can absorb excess N left over in the soil from the previous crop thus minimising the risk of 'excess' nitrogen in the soil to turn into N2O. If the cover crops are legumes, then they also reduce the need for N fertilisers in subsequent crop. If these fertilisers are synthetic, then there is the added benefit of reducing manufacturing emissions[69].
- Herbal leys have the effect of improving soil carbon and improving soil health, which helps to maintain arable yields in the long-term. They can also improve soil N content reducing need for N fertilisers (reduce N2O emissions from excess N and also nitrogen fertiliser manufacturing emissions if synthetic).

A SUMMARY OF THE ASSUMPTIONS FOR OUR MODEL FOR THE REGENERATIVE CEREAL AND CROPPING FARM TYPE IS INCLUDED IN SECTION 6.8 TABLE 6-5.

6.7 Case study findings

During July 2024, members from the project team visited 9 farms across the five PLs to meet tenants, landowners and land managers who had incorporated regenerative principles on their farm. They show the diversity of farms and farmers across North Yorkshire, in terms of size, tenure, and time in transition. They range from small family hill farms to large land holdings like Castle Howard. They include small starter farms with a small herd of cattle and sheep, to large upland livestock farms, as well as more mixed farms with arable integrated with (different types of) livestock.

Some of the farmers had been farming according to organic principles for many years, while others had been forced to make drastic changes to their farm in order to make the farm work financially. There were also those who had just started testing some regenerative practices on a small scale to see what works before they would decide rolling such practices out across their whole farm/estate. They were on 'a journey', which was different for every farm. All showed a great willingness to trial, learn and share their experiences.

There was a strong focus on (restoring) soil health and fertility. Many had introduced herbal ley rotation, while on arable land livestock had been integrated into arable rotations. Resource efficiency was key, reducing external inputs such as synthetic fertiliser. There were farmers who hardly used any inputs, and had lowered their stocking levels to adjust. Most livestock farmers tried to be self-sufficient in feed, but this was not always possible (due to extreme weather). Housing and over-wintering differed considerably between farms, depending on the type of livestock, type of soil and infrastructure available. Hardy breeds were better able to overwinter outside, and required lower inputs, and lower levels of intervention (e.g. calving, lambing) and management.

In terms of performance, the respondents stated the following:

- Reduction in input costs: a reduction in bought in N fertiliser and feed concentrates had made these farmers more resilient against input price rises
- Reduction in fuel use: a shorter period of housing animals reduced fuel use
- Price premium: farmers who were able to access supply chains that pay a premium for their product were able to increase revenues and become more profitable than those who supplied a commodity market
- Profitability: fixed costs - such as rent, labour, and machinery - still need to be covered by the total farm gross margin before arriving at a profit. It is entirely possible for a farmer to see enterprise gross margins improve by adopting regenerative practices, while at the same time fixed costs per unit of production increase. The greatest impact on profitability is achieved when fixed costs can also be reduced in line with the enterprise size. This may be possible with some fixed costs, such as labour or machinery (although it is rarely possible to reduce these smoothly or in small amounts at a time in proportion to the size of the enterprise), but it is much harder with the fixed cost of rent.
- Improvements in biodiversity: some mentioned the increase in biodiversity (e.g. invertebrates and birdlife), but there was no baseline or measurement of this.
- Reduction in emissions; while some of the farmers had carried out a carbon footprint assessment, there was no clear evidence of the impact of regenerative practices on emissions.

6.8 Applying regenerative practices to the model - 'Pen Portraits'

As regenerative agriculture offers a direction of travel rather than a set of rules, we have to make some assumptions about what 'conventional' and 'regenerative' farming means in the context of this study. This forms part of the analysis outlined in Section 6.2, where we explore the regenerative farming transition at 'farm level'. Each model farm comprises data and a 'pen portrait' describing the key characteristics of regenerative farming. It is impossible to model every different permutation of regenerative practices, with some farms going further and faster in their transition. We have therefore tried to define a theoretical ideal based on best practice, feedback from farmer engagement, and case study examples. The pen portraits provide examples of regenerative practices by farm type.

6.8.1 LFA grazing livestock farm

Our model for LFA grazing livestock farm has the following characteristics:

System

It is managed under a zero-input, grass-based system.

Enterprises

The enterprise makeup has shifted away from sheep towards cattle, and away from finishing/store cattle towards suckler cows. We assume a cattle: sheep ratio of 40:60.

Practices

- **Forage production** and utilisation is maximised through mob grazing and increased sward diversity. This has the effect of increasing grass yields by 20% over the baseline, which we assume to be a continuous (set-stocked) grazing system.
- **Stocking rates** are matched to the farm's naturally available grass (i.e. without artificial fertilisers) to deliver Maximum Sustainable Output[70]. We have calculated stocking rates for zero input permanent pasture at 0.69 GLUs/ha and for zero input temporary pasture at 0.86 GLUs/ha by extrapolating the average stocking rate on a lowland dairy farm (2 GLUs on 250kg N temporary pasture[7]) assuming a direct linear correlation between stocking rate and freshweight yield. This approach gives a calculated fresh weight grass yield of 15t/ha on zero input permanent pasture, and 18t/ha on zero input temporary pasture. We have then applied a 20% uplift to account for yield increases under proactive grazing strategies. Note that in some cases, this may actually result in an increase in stocking rates over the baseline. This can be explained by the fact that some farmers in the survey sample have uneconomic levels of stock on their land, and it does not necessarily reflect the performance of more economically rational farmers. Our model farm, meanwhile, assumes Maximum Sustainable Output, which is based on the optimum theoretical stocking rate.
- For sole right rough grazing, we have assumed a stocking rate of 0.25 GLUs/ha. This land use would cover rough grassland habitats as well as moorland and heather-dominated habitats, but the Defra land use statistics by farm type do not differentiate. For the purposes of our modelling, we have assumed this is poor quality grassland dominated by *Nardus stricta* or *Molinia caerulea*, and we have based the stocking rate on the guidelines for grazing semi-natural grassland published in the Farm Advisory Service's Technical Note on *Conservation Grazing for Semi-Natural Habitats* (2017)[71]. For heather-dominated moorland only, stocking rates would in reality be lower than 0.25 GLUs/ha.
- **Straight N fertiliser**: we assume none is applied.
- **Compound N fertiliser**: we assume none is applied.

- **Manure**: we have referred to the standard values tables published in Defra's NVZ guidance[72] and worked out the total N produced by livestock on the farm. We assume no manure is imported or exported.
- **Lime**: Anecdotal evidence from the case study farms suggests that farmers may apply more lime during the earlier years of their regenerative transition, in order to optimise soil pH and maximise crop N use efficiency, but over the longer term, once soil nutrient cycles are fully functioning and with the reduction of artificial fertiliser use, liming may not be so important – although the underlying geology will have a big impact on soil pH. On this basis, we have assumed no change in overall lime application rates.
- **Pesticides**: we assume that pesticide applications are half the baseline rate.
- **Fuel**: There is less tractor work on our model LFA grazing farm: less spraying, less fertiliser applications, less forage conservation (because grazing period extended); we have assumed a 30% decrease in fuel use overall.

Table 6-1: Livestock manure and N values

Stock class	Total N produced (kg/year)	FYM equivalent (freshweight basis)[73]
Dairy cow	77	12.8 tonnes
Beef cow	61	10.2 tonnes
Calves <1yr	30.4	5.1 tonnes
Other cattle	50	8.3 tonnes
Breeding ewes	7.6	1.1 tonnes
Lambs <1yr	1.2	0.17 tonnes
Other sheep	11.9	1.7 tonnes

- **Housing period:** we assume that the housing period for cattle is reduced to 4 months, from a baseline of 5.5 months. Sheep are outwintered and lamb outdoors, compared to the baseline where they are housed for 6 weeks in the run up to and during lambing.
- **Concentrate feeding**: we assume all feed is derived from the farm's naturally available grass, with no additional hard feed.

Land use

We have assumed the area of farm woodland doubles, up to a maximum of 5% of the total farm area. We have assumed this comes out of the area of permanent pasture. This may not be discrete woodland blocks; instead, it might include a mix of shelterbelts, hedgerows, in-field trees, orchards, and other agroforestry systems. We have made no changes to any other land uses which make up less than 1% of the farm area.

Table 6-2: Summary of our model LFA grazing farm assumptions

Feature	Conventional	Regenerative
System	Cattle housed for 5.5 months Supplementary feeding Maximising output	Cattle housed for 4 months; spring lambing / calving; grass-finishing systems
Livestock	Primarily sheep Primarily keeping / maintenance of bought-in stores	More cattle, less sheep More breeder-finisher enterprises, fewer dairy-bred stores
Stocking rate	Whole farm: 0.54 – 0.70 GLUs/ha	Permanent Pasture: 0.83 GLUs/ha Temp Pasture: 1.0 GLUs/ha Rough Grazing: 0.25 GLUs/ha Whole farm: 0.58 – 0.67 GLUs/ha
Straight N ferts	27 kg N /ha	None
Compound N ferts	26 kg N /ha	None
Manure	11.1 t/ha	2.6 – 10.9 t/ha based on number of livestock, assuming none imported / exported
Pesticides	0.03 – 0.62 t/ha	0.015 - 0.31 t/ha
Fuel	55.9 – 96.2 L/ha	30% reduction overall
Lime	0.12 – 0.15 t/ha	No overall change
Housing period	Cattle routinely housed for 5.5 months, sheep for 6 weeks	Cattle housed for 4 months
Farm woodland	1-3% of farm area	2-5% of farm area

6.8.2 Lowland grazing livestock farm

Our model for regenerative lowland grazing livestock farm has the following characteristics:

System

It is managed under a zero-input, forage-based system, with more diverse herbal leys, less maize, and longer rotations on that portion of the farm which is not in permanent grassland. This is reflected in the land use assumptions below.

Enterprises

We have assumed no change in the enterprise makeup: while cattle are better suited to regenerative grazing strategies on the grassland, sheep are better suited to grazing cover crops and fodder crops on the arable land.

Practices

- **Forage production** and utilisation is maximised through mob grazing. This has the effect of increasing grass yields by 20% over the baseline, which we assume to be a continuous (set-stocked) grazing system.
- **Stocking rates** are matched to the farm's naturally available grass using the approach outlined above for LFA grazing farms.
- **Straight N fertiliser**: we assume none is applied.
- **Compound N fertiliser**: we assume none is applied.
- **Manure**: we have worked out the total N produced by livestock on the farm as per Table 6-1 above.
- **Pesticides**: we assume that pesticide applications are half the baseline rate.
- **Fuel**: we assume a 30% decrease in fuel use.
- **Lime**: we assume no change in lime application.
- **Housing period**: we assume that the housing period for cattle is reduced to 4 months, from a baseline of 5.5 months. Sheep are outwintered and lamb outdoors, compared to the baseline where they are housed for 6 weeks in the run up to and during lambing.
- **Concentrate feeding**: we assume all feed is derived from the farm's naturally available grass, with no additional hard feed.

Land use

We have assumed the farm woodland area is increased to 5% of the total farm area, or, if the existing farm woodland area exceeds this, we have made no change. We have assumed any increase in the farm woodland area comes out of the area of permanent pasture.

We have made no changes to any other land uses which make up less than 1% of the farm area.

Where the croppable land makes up more than 1% of the farm area, we have assumed a longer arable rotation, comprising 4 years of herbal leys, followed by 3 arable crops (including one non-cereal crop, such as beans), and we have adjusted the areas of cereal and other arable crops accordingly.

Table 6-3: Summary of our model lowland grazing farm assumptions

Feature	Conventional	Regenerative
System	Supplementary feeding Maximising output	Zero-input, forage-based system, with more diverse herbal leys, less maize, and longer rotations on that portion of the farm which is not in permanent grassland.
Livestock	Primarily sheep Primarily keeping / maintenance of bought-in stores	No change in the livestock enterprises
Stocking rate	Whole farm: 1.03 – 1.29 GLUs/ha	Permanent Pasture: 0.83 GLUs/ha Temp Pasture: 1.0 GLUs/ha Rough Grazing: 0.25 GLUs/ha Whole farm: 0.65 – 0.79 GLUs/ha
Straight N ferts	27-73 kg N /ha	None
Compound N ferts	26-28 kg N /ha	None
Manure	11.1 t/ha	7.65 – 15.93 t/ha based on number of livestock, assuming none imported / exported
Pesticides	0.03 – 3.98 t/ha	0.015 - 1.99 t/ha
Fuel	55.9 – 115.6 L/ha	30% reduction overall
Lime	0.05 – 0.18 t/ha	No overall change
Housing period	Cattle routinely housed for 5.5 months, sheep for 6 weeks	Cattle housed for 4 months
Farm woodland	0.5 – 12% of farm area	5 – 12% of farm area

6.8.3 Dairy farm

Our model for a regenerative dairy farm has the following characteristics:

System

Grazed-forage based; spring block calving; more of a dual-purpose cow (e.g. British Friesian, Fleckvieh, Norwegian Red, Montbeliarde).

Enterprises

We assume that all dairy progeny are retained on the farm and carried through either as dairy replacements or as beef animals. Accordingly, we have matched the number of calves under 12 months old to the number of dairy cows (adjusted down by 3% to account for calf mortality). The 'other cattle' would comprise yearling replacements, and we have pegged the number of these cattle to the dairy herd at 20% (reflecting a replacement rate of 20%). We assume all other yearling animals are finished as beef animals.

We assume no sheep or other livestock on the farm. In conventional systems where cows are housed and there isn't a reliance on early spring grazing for milk production, there is an opportunity for sheep to graze off winter grass. However, our model regenerative farm assumes cows are at grass at all times when conditions allow, and our breed of cow is better suited at utilising all available grassland on the farm, so there isn't the same scope for a sheep enterprise.

Practices

- **Forage production** and utilisation is maximised through mob grazing. This has the effect of increasing grass yields by 20% over the baseline, which we assume to be a continuous (set-stocked) grazing system.
- **Stocking rates** are matched to the farm's naturally available grass using the approach outlined above for LFA grazing farms.
- **Croppable land** is managed under a long rotation comprising 4 years of herbal leys, followed by 3 arable crops (including one non-cereal crop, such as beans).
- **Straight N fertiliser**: we assume this is half the baseline rate.
- **Compound N fertiliser**: we assume this is half the baseline rate.
- **Manure:** we have worked out the total manure produced by livestock on the farm as per Table 6-1 above.
- **Pesticides:** we assume this is half the baseline rate.
- **Fuel:** we assume a 30% decrease in fuel use.
- **Lime**: we assume no change in lime.
- **Housing period:** we assume cattle are housed for 4 months.
- **Concentrate feeding**: we assume all feed is derived from the farm's naturally available grass, with no additional hard feed.

Land use

The croppable land area is divided in accordance with the rotation above as follows: 57% herbal ley / temporary grass; 29% cereals; 14% other crops (e.g. beans).

We have assumed the farm woodland area is increased to 5% of the total farm area, or, if the existing farm woodland area exceeds this, we have made no change. We have assumed any increase in the farm woodland area comes out of the area of permanent pasture.

Table 6-4: Summary of our model dairy farm assumptions

Feature	Conventional	Regenerative
System	Cattle housed for up to 6 months Supplementary feeding Maximising output	Zero-input grazed-forage based; spring block calving; more beef production, less narrow focus on milk. Cattle housed for 4 months.
Livestock		No sheep Dairy progeny are retained for beef
Stocking rate	Whole farm: 1.72 – 2.13 GLUs/ha	Permanent Pasture: 0.83 GLUs/ha Temp Pasture: 1.0 GLUs/ha Rough Grazing: 0.25 GLUs/ha Whole farm: 0.69 – 0.78 GLUs/ha
Straight N ferts	27-73 kg N /ha	13-47 kg N/ha
Compound N ferts	26-28 kg N /ha	13-14kg N/ha
Manure	11.1 t/ha	7.7 – 9.87 t/ha based on number of livestock, assuming none imported / exported
Pesticides	0.03 – 3.98 t/ha	0.015-1.99 t/ha
Fuel	55.9 – 115.6 L/ha	30% reduction overall
Lime	0.05 – 0.18 t/ha	No overall change
Housing period	Cattle routinely housed over winter months	Livestock at pasture at all times when conditions allow
Farm woodland	1 – 4% of farm area	5 % of farm area

6.8.4 Cereal and general cropping farm

Our model for a regenerative cereal and general cropping farm has the following characteristics:

System

- Min-till
- Long rotations
- Integrates livestock

Enterprises

In contrast to the cereal-heavy conventional baseline farm, the rotation on our model regenerative farm reflects the following principles:

- Shallow-rooted crops follow deep-rooted crops;
- Nitrogen-demanding crops follow nitrogen-fixing crops;
- Incorporating herbal leys into the rotation helps build soil fertility;
- More spring cropping allows the farmer to plant cover crops, which help build fertility and prevent nutrient leaching.

Where farms already have livestock, we have assumed a 4-year herbal ley, followed by 3-years arable production, including two cereal crops and one legume crop. However, it is not realistic for specialist cereals farms to follow this rotation: it would take too much land out of cereal production, while the fixed costs of cereal cropping remain, with the overall effect that net margin per ha is significantly reduced. We have therefore assumed a much shorter ley, and we have assumed that winter wheat remains a mainstay of the rotation given the financial reward. Our model farm rotation is as follows[74]:

Year 1: Herbal ley

Year 2: Winter wheat

Year 3: Winter oats, followed by a winter cover crop

Year 4: Spring beans

Year 5: Winter wheat, followed by a winter cover crop

Year 6: Spring barley under-sown with herbal ley

The increase in forage availability means our regenerative model cereal / general cropping farm can sustain a livestock enterprise. We assume sheep are grazed on the herbal leys and cover crops.

Practices

- **Long rotation**, incorporating a herbal ley, and a move towards more spring cropping so that cover crops can be planted between cash crops.
- **Forage production** and utilisation on the temporary grassland / herbal leys is maximised through mob grazing. This has the effect of increasing grass yields by 20% over the baseline, which we assume to be a continuous (set-stocked) grazing system.

- Stocking rates are matched to the farm's naturally available grass using the approach outlined above for the livestock farms.
- **Straight N fertiliser**: we assume this is half the baseline rate.
- **Compound N fertiliser**: we assume this is half the baseline rate.
- **Manure:** we have worked out the total N produced by livestock on the farm as per Table 6-1 above.
- **Pesticides:** we assume this is half the baseline rate.
- **Fuel:** we assume a 30% decrease in fuel use.
- **Lime**: we assume no change in lime.
- **Housing period:** we assume livestock at pasture at all times when conditions allow.
- **Concentrate feeding**: we assume all feed is derived from the farm's naturally available grass, with no additional hard feed.

Land use

The croppable land area is divided in accordance with the rotation above as follows: 50% winter cereals; 16.6% spring cereals; 16.6% other crops (i.e. spring beans); 16.6% herbal ley / temporary grass.

We have assumed the farm woodland area is increased to 5% of the total farm area, or, if the existing farm woodland area exceeds this, we have made no change. We have assumed any increase in the farm woodland area comes out of the area of permanent pasture.

We have made no changes to any other land uses which make up less than 1% of the farm area.

Table 6-5: Summary of our model cereal farm assumptions

Feature	Conventional	Regenerative
System	Conventional cereals	• Organic • Min-till • Long rotations • Integrates livestock
Livestock	Minimal livestock	Commercial sheep enterprise introduced
Stocking rate	N/A	Permanent Pasture: 0.83 GLUs/ha Temp Pasture: 1.0 GLUs/ha
Straight N ferts	27-73 kg N /ha	13.5-36.5 kg N/ha
Compound N ferts	26-28 kg N /ha	13-14 kg N/ha
Manure	11.1 t/ha	5.4 – 5.6 t/ha based on number of livestock, assuming none imported / exported
Pesticides	0.03 – 3.98 t/ha	0.015-1.99 t/ha
Fuel	55.9 – 115.6 L/ha	30% reduction overall
Lime	0.05 – 0.18 t/ha	No overall change
Housing period	N/A	Livestock at pasture at all times when conditions allow
Farm woodland	6 – 16% of farm area	6 – 16% of farm area

7 Results

7.1 Results for the five PLs

7.1.1 Baseline

The total baseline emissions for all five PLs combined was estimated at 1.013 million tCO2e/yr (GWP100). The total agricultural emissions figure for these five protected landscapes from the accredited official statistics[75] is 1.085 million tCO2e/yr

Table 7-1 below shows a comparison of official agricultural emissions estimates and totals modelled for each PL. The comparison shows that both sets of figures are closely aligned, albeit the project model estimates are slightly less than those made using the full NAEI. The differences in the estimates produced can be attributed to the differences in data inputs and methodologies used by the two models. The NAEI estimates provide us with a guideline to ensure that the project model predictions are reasonable, whereas the project model is designed to compare between estimates of emissions between conventional and regenerative farming practices, rather than fully replicating all the NAEI outputs.

Table 7-1: Comparison of official agricultural emissions estimates and totals for farm types modelled in each Protected Landscape

Protected Landscape	Official Estimate (kt $CO_2e\ yr^{-1}$)	Project Estimate (kt $CO_2e\ yr^{-1}$)
Forest of Bowland	254.21	220.93
Howardian Hills	42.03	39.54
Nidderdale	150.82	144.03
North York Moors	261.77	244.15
Yorkshire Dales	376.50	364.79

Table 7-2 below shows a breakdown of GHG contributions to total agricultural GHG emissions in each Protected Landscape, using the project model. The emissions baseline for the five PLs shows that methane emissions (CH_4) from ruminants are the biggest source of emissions (62%), followed by nitrous oxide emissions (29%). These results align with the UK as a whole, where methane from ruminants is the main GHG emitted (56%), followed by nitrous oxide from fertilisers (31%) and carbon dioxide predominantly from energy and fuel (13%), according to AHDB.[76]

The modelling has shown that nitrous oxide emissions results are very sensitive to the assumptions of fertiliser application rates (e.g. a change from 'low input' to 'zero input' grassland for sole rights grazing reduced nitrous oxide emissions significantly).

Table 7-2: Estimated breakdown of GHG contributions to total agricultural GHG emissions for the baseline in each Protected Landscape (% contribution in brackets)

Protected Landscape	Land Use CO_2 (kt CO_2)	Livestock CO_2 (kt CO_2)	Land Use N_2O (kt CO_2e)	Livestock N_2O (kt CO_2e)	Livestock CH_4 (kt CO_2e)
Forest of Bowland	13.98 (6.3)	0.94 (0.4)	33.69 (15.2)	17.20 (7.8)	155.13 (70.2)
Howardian Hills	6.47 (16.4)	0.26 (0.7)	17.61 (44.5)	2.47 (6.2)	12.73 (32.2)
Nidderdale	9.34 (6.5)	0.55 (0.4)	23.76 (16.5)	11.46 (8.0)	98.92 (68.7)
North York Moors	23.87 (9.8)	0.47 (0.2)	71.97 (29.5)	16.27 (6.7)	131.58 (53.9)
Yorkshire Dales	32.71 (9.0)	0.78 (0.2)	76.77 (21.0)	26.89 (7.4)	227.64 (62.4)
Total	**86.36 (8.5)**	**3.00 (0.3)**	**223.80 (22.1)**	**74.28 (7.3)**	**626.00 (61.8)**

7.1.2 Comparison of total emissions under baseline and 100% regen scenario

The baseline figures were compared with a regenerative farming scenario, starting with a hypothetical scenario of a full regenerative transition for all farms. We call this the ‘100% regen scenario’ (in the tables referred to as ‘RA’ for Regenerative Agriculture). The regenerative farming scenario was modelled based on the assumptions for each of the farm types (see Section 6,

Table 6-2, Table 6-3, Table 6-4, Table 6-5), recalculating the land use area and livestock numbers, and adapting the coefficients as described in the methodology in Section 5. The emissions for the individual PLs are explored in more detail in Section 7.7.2.

The total emission reduction across all five PLs is an estimated 24.7% (or 250,673 tCO2e/year), reducing the baseline of 1,013,444 to 762,771 tCO2e/year. Table 7-3 below shows a comparison of emissions across the PLs under the baseline and regenerative farming scenarios, and the resulting emissions reductions. The emission reductions are driven by a number of modelled changes in farm systems, enterprises and practices, but overwhelmingly they are driven by changes in land use and livestock numbers.

Table 7-3: Comparison of estimated total emissions for Protected Landscapes under the baseline and 100% regen scenarios, and resulting emissions reductions

Protected Landscape	Baseline (kt CO_2e yr^{-1})	100% Regenerative (kt CO_2e yr^{-1})	% Emissions reduction
Forest of Bowland	220.93	133.17	39.73
Howardian Hills	39.54	36.65	7.31
Nidderdale	144.03	86.64	39.84
North York Moors	244.15	200.97	17.69
Yorkshire Dales	364.79	305.34	16.30

Emissions reductions by farm type

The modelling estimated the emissions reductions for LFA grazing livestock farms at 15.8%, and for lowland grazing livestock farms at 22.1% - see Table 7-4 below. For dairy farming, the modelling estimated the emissions reductions at 56.4% (Table 7-5). Our model assumes a significant reduction in the dairy herd, as the regenerative dairy farmer switches from high-genetic-merit dairy cows to more dual-purpose breeds. The modelling estimated the emissions reductions for cereal farming at 12.9% (Table 7-6). We did not model a regenerative transition for the mixed farm type or general cropping farm type (with the exception of the Howardian Hills, where baseline data on general cropping was sufficient).

Table 7-4: Estimated emissions reductions by farm type: LFA Grazing and Lowland Grazing (tCO2e GWP100/yr)

	LFA Grazing			Lowland Grazing		
Protected Landscape	**Baseline**	**RA**	**% Reduction**	**Baseline**	**RA**	**% Reduction**
Forest of Bowland	120,092	87,908	27	8,139	5,699	30
Howardian Hills	n/a	n/a	n/a	4,561	2,371	48
Nidderdale	69,310	50,771	27	16,752	9,652	42
North York Moors	101,187	83,487	17	33,387	31,687	5
Yorkshire Dales	274,336	253,408	8	3,992	2,632	34
Total	**564,925**	**475,574**	**15.82**	**66,833**	**52,040**	**22.13**

Table 7-5: Estimated emissions reductions by farm type: Dairy and Mixed farming (tCO2e GWP100/yr)

	Dairy			Mixed		
Protected Landscape	**Baseline**	**RA**	**% Reduction**	**Baseline**	**RA**	**% Reduction**
Forest of Bowland	88,912	35,768	60	n/a	n/a	n/a
Howardian Hills	n/a	n/a	n/a	12,335	12,222	1
Nidderdale	49,766	18,015	64	4,383	4,388	0
North York Moors	39,141	18,144	54	40,603	40,304	1
Yorkshire Dales	75,790	38,632	49	n/a	n/a	n/a
Total	**253,609**	**110,559**	**56.41**	**57,321**	**56,914**	**0.71**

Table 7-6: Estimated emissions reductions by farm type: Cereal and General Cropping (tCO2e GWP100/yr)

	Cereal			General Cropping		
Protected Landscape	**Baseline**	**RA**	**% Reduction**	**Baseline**	**RA**	**% Reduction**
Forest of Bowland	n/a	n/a	n/a	3,791	3,791	0
Howardian Hills	11,364	9,920	13	4,026	4,883	-21
Nidderdale	n/a	n/a	n/a	3,814	3,814	0
North York Moors	19,085	16,596	13	10,751	10,753	0
Yorkshire Dales	n/a	n/a	n/a	10,670	10,670	0
Total	**30,450**	**26,516**	**12.92**	**33,052**	**33,911**	**-2.60**

Emissions reductions by ‘Crops and grazing land’ and ‘Livestock’

The modelling estimated the emissions reductions for crops and grazing land at 41.4% and the reductions for livestock 17.4%, resulting in overall reduction from the baseline to a ‘100% regen’ scenario of 24.7%. The total emissions reduction for the four upland PLs only, excluding the Howardian Hills, is 25.5%. Table 7-7 below shows the total emissions for the five PLs for crops and grazing land and for livestock. The percentage reduction differs per PL. All five PLs show a reduction in land use emissions (e.g. crops and grazing land). The reduction in livestock emissions varies considerably and this is directly linked to the changes in livestock numbers. The results for the individual PLs are further explored in Section 7.2.

Table 7-8 shows the estimated reduction in livestock emissions by livestock type and Table 7-9 provides changes in livestock numbers. These show a significant reduction in total sheep numbers and an increase in total cattle numbers. The change in cattle numbers reflects both a significant reduction in dairy cattle and an increase in beef cattle. The result is a 27.8% reduction in emissions from sheep, and an 11.9% reduction in emissions from cattle. This is explored further in the discussion in Section 7.4.

Table 7-7: Estimated total emissions from Crops and Grazing land and Livestock for the five PLs (tCO2e GWP100/yr)

	Crops and Grazing Land			Livestock			Total		
Total emissions (tCO2e GWP100/yr)	**Baseline**	**RA**	**% Reduction**	**Baseline**	**RA**	**% Reduction**	**Baseline**	**RA**	**% Reduction**
Forest of Bowland	47,666	24,853	47.9	173,268	108,312	37.5	220,934	133,165	39.7
Howardian Hills	24,083	15,988	33.6	15,459	20,665	-33.7	39,542	36,653	7.3
Nidderdale	33,095	19,768	40.3	110,930	66,687	39.9	144,025	86,455	39.8
North York Moors	95,838	67,379	29.7	148,317	133,592	9.9	244,155	200,971	17.7
Yorkshire Dales	109,477	53,681	51.0	255,311	251,661	1.4	364,788	305,342	16.3
Total	**310,158**	**181,669**	**41.4**	**703,286**	**580,918**	**17.4**	**1,013,444**	**762,771**	**24.7**

Table 7-8: Estimated changes in livestock emissions under a '100% regen' scenario

	Sheep		Cattle		Pigs		Total	
Total emissions (tCO2e/yr) for each Enterprise	**Baseline**	**RA**	**Baseline**	**RA**	**Baseline**	**RA**	**Baseline**	**RA**
Forest of Bowland	49,865	29,099	123,377	79,213	26	-	173,268	108,312
Howardian Hills	3,394	9,351	7,006	6,255	5,059	5,059	15,459	20,665
Nidderdale	30,420	18,981	79,860	47,095	650	610	110,930	66,687
North York Moors	42,999	40,449	103,450	91,337	1,867	1,807	148,317	133,592
Yorkshire Dales	120,509	80,558	134,755	171,104	47	-	255,311	251,661
Total	**247,188**	**178,437**	**448,448**	**395,004**	**7,649**	**7,476**	**703,286**	**580,918**

Table 7-9: Estimated changes in livestock numbers under a '100% regen' scenario

	Sheep		Cattle		Pigs		Total	
Livestock Numbers	**Baseline**	**RA**	**Baseline**	**RA**	**Baseline**	**RA**	**Baseline**	**RA**
Forest of Bowland	314,606	182,372	47,095	38,569	102	-	361,803	220,941
Howardian Hills	22,255	60,199	3,252	2,975	22,667	22,667	48,174	85,841
Nidderdale	191,956	119,209	31,876	23,021	3,029	2,864	226,861	145,094
North York Moors	267,302	251,207	45,623	45,905	8,685	8,475	321,610	305,587
Yorkshire Dales	756,546	503,122	57,808	87,410	171	-	814,525	590,532
Total	**1,552,665**	**1,116,109**	**185,654**	**197,880**	**34,654**	**34,006**	**1,772,973**	**1,347,995**

Emissions reduction by gas

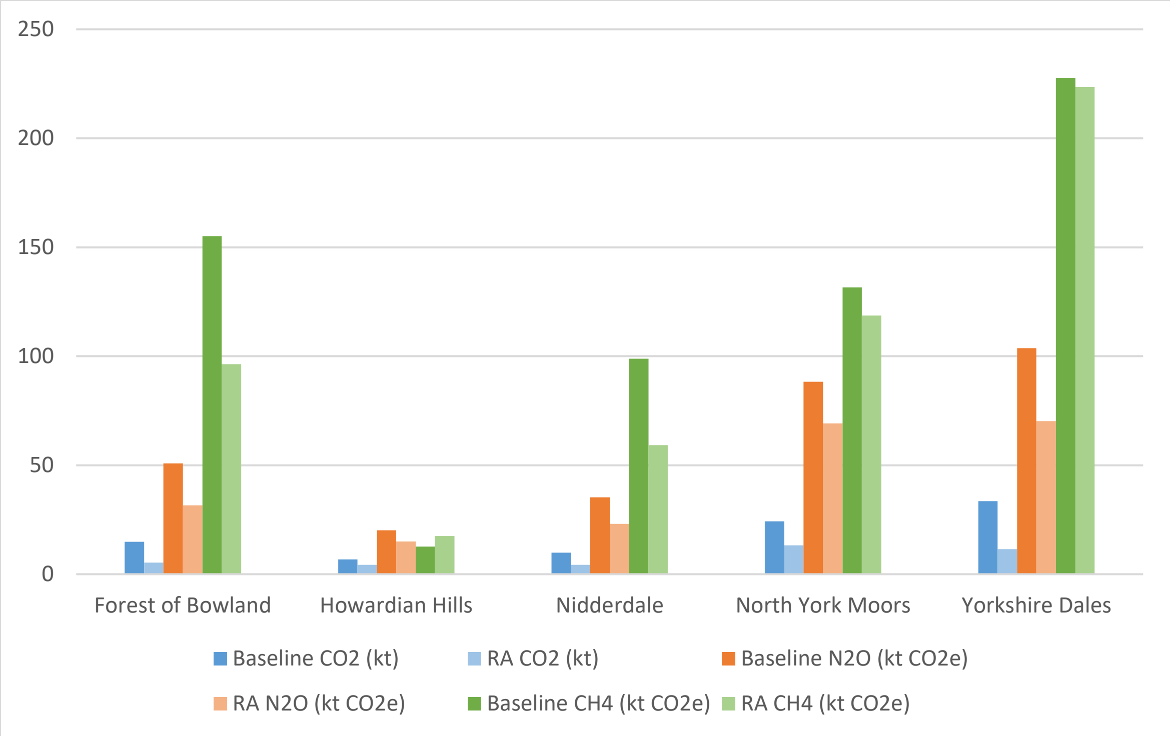
The emissions baseline for the five PLs shows that methane emissions (CH_4) from ruminants are the biggest source of GWP from emissions (62%), followed by nitrous oxide (N_2O) emissions (29%), as shows in Table 7-10 below. This pattern is generally mirrored within individual Protected Landscapes, with the exception of the Howardian Hills where the dominance of cropping over livestock results in N_2O emissions being the highest contributor to GWP of greenhouse gases emitted. Methane originates from enteric fermentation, mainly from cattle, and to a lesser extent from sheep, while nitrous oxide emissions originate from the application of nitrogenous fertilisers and manures/excreta.

Table 7-10: Estimated breakdown of GHG contributions to total agricultural GHG emissions for the 100% regenerative scenario in each Protected Landscape (% contribution in brackets)

Protected Landscape	Land Use CO_2 (kt CO_2)	Livestock CO_2 (kt CO_2)	Land Use N_2O (kt CO_2e)	Livestock N_2O (kt CO_2e)	Livestock CH_4 (kt CO_2e)
Forest of Bowland	5.18 (3.9)	0.14 (0.1)	19.67 (14.8)	11.87 (8.9)	96.31 (72.3)
Howardian Hills	3.97 (10.8)	0.26 (0.7)	12.02 (32.8)	2.94 (8.0)	17.47 (47.7)
Nidderdale	4.16 (4.8)	0.15 (0.2)	15.80 (18.2)	7.35 (8.5)	59.19 (68.3)
North York Moors	13.03 (6.5)	0.16 (0.1)	54.35 (27.0)	14.80 (7.4)	118.63 (59.0)
Yorkshire Dales	11.27 (3.7)	0.29 (0.1)	42.41 (13.9)	27.78 (9.1)	223.59 (73.2)
Total	**37.6 (4.9)**	**1.00 (0.1)**	**144.25 (18.9)**	**64.74 (8.5)**	**515.18 (67.5)**

Figure 7-1 below shows the break down by the different types of gases, converted into kt CO2e (kilo tonnes of CO_2 equivalents) in order to arrive at an overall total of emissions. The percentage contributions for the different GHGs are also slightly altered in the regenerative scenarios, with the contributions from CO_2 and N_2O reducing slightly (8.8% to 5.1% and 29.4% to 27.4% respectively) and the contribution from CH_4 increasing (61.8% to 67.5%). Generally, the emissions of each GHG are lower in the regenerative scenario than in the baseline. However, for the Howardian Hills there is a slight increase in methane emissions as livestock numbers are increased as a way to provide manures to replace synthetic fertiliser.

Figure 7-1: Estimated emissions by type of GHG Baseline vs '100% regen' scenario (ktCO2e)



During the farmer engagement workshop, it was pointed out that GWP 100 penalises cattle grazing for its methane emissions. In contrast, they favoured the use of GWP* which aims to model the impact of methane and compare the warming effect it has relative to CO_2 over time. However, where livestock remain, methane emissions continue. Our methodology is based on GWP 100, in line with IPCC guidance, the international body for assessment of climate change. As explained in Section 5.4, methane emissions initially have a more potent impact than under GWP100, but then drop to a very low impact, well below that from GWP100. This project has not modelled the decay of different gases over time.

Additional carbon sequestration of farm woodland under a '100% regen' scenario

The additional sequestration from the planting of more trees and hedges is estimated at just over 22,100 tCO2/year from an additional planting on 3,772 ha of permanent grassland, as shown in Table 7-11. This is equivalent to 2.2% of total baseline emissions. Sequestration figures are indicated by negative (-) emissions.

Table 7-11: Estimated carbon sequestration* from farm woodland (tCO2e GWP100/yr)

Total emissions (tCO2e/yr) from farm woodland			
Protected Landscape	**Baseline**	**RA**	**% Reduction**
Forest of Bowland	-9,009	-14,988	-66
Howardian Hills	-6,702	-6,702	0
Nidderdale	-6,275	-9,540	-52
North York Moors	-23,601	-29,086	-23
Yorkshire Dales	-16,909	-24,283	-44
Total	**-62,496**	**-84,599**	**-35**
Area (ha) of farm woodland			
Protected Landscape	**Baseline**	**RA**	**% Increase**
Forest of Bowland	1,537	2,558	66
Howardian Hills	1,144	1,144	-
Nidderdale	1,071	1,628	52
North York Moors	4,027	4,964	23
Yorkshire Dales	2,886	4,144	44
Total	**10,665**	**14,437**	**35**

**Please note that sequestration figures are indicated by negative (-) emissions.*

Additional soil sequestration under a '100% regen' scenario

Separately from the model, the project team also calculated the additional soil carbon sequestration that would result from regenerative farming; this is estimated to be 158,438 tCO2e/year (tC/year has been multiplied by 3.67 to arrive at tCO2e/year), shown in Table 7-12.

These figures for soil carbon sequestration were calculated completely separately from the model, using a different methodology. The methodologies are sufficiently different in their assumptions and in the nature of the underlying data that these should be represented separately from the model. Therefore, these figures should not be used in relation to the figures from our model (e.g., this soil carbon sequestration cannot be expressed as a percentage of the emissions baseline).

Table 7-12: Estimated soil carbon sequestration, assuming a 20% increase in soil carbon inputs (tC/yr and tCO2e GWP100/yr)

	PL Total (tC/yr)	% annual change in storage	Additional sequestration in tCO2e/yr
Forest of Bowland	7,722	0.3246	28,341.3
Howardian Hills	2,350	0.3392	8,625.7
Nidderdale	5,091	0.3200	18,682.8
North York Moors	8,485	0.3227	31,138.9
Yorkshire Dales	19,523	0.2902	71,648.9
Total	**43,171**	**0.3083**	**158,437.5**

7.2 Summary results for each PL

7.2.1 Forest of Bowland

Baseline emissions for the Forest of Bowland are estimated to be 220,934tCO2e/year. The '100% regen' scenario shows the greatest emissions reduction of 87,769tCO2e/year (39.7%) in absolute terms. Livestock emissions reduce by 37.5%, while land use emissions reduce by 47.9%. The emissions reductions associated with livestock are primarily driven by a reduction in livestock numbers. Our model assumes a 39% reduction in total livestock numbers across the PL, including an 18% reduction in cattle numbers and an associated 36% reduction in cattle emissions (driven by a significant reduction in the dairy herd, as the regenerative dairy farmer switches from high-genetic-merit dairy cows to more dual-purpose breeds) and a 42% reduction in the sheep numbers and emissions (as the regenerative LFA grazing farm transitions away from sheep towards beef cattle). The reduction in land use emission comes mainly from the emissions reductions from permanent grassland (99%) driven by removing the fertiliser inputs and reducing manure applications on permanent grassland for dairy, lowland and LFA grazing farm types.

The sequestration from additional tree and hedge planting represents 2.7% of Forest of Bowland's baseline emissions.

7.2.2 Howardian Hills

The Howardian Hills show a very different picture compared to the other four upland PLs. The Howardian Hills represent only 3.9% of the total baseline emissions for all PLs combined. It also has the lowest emissions per hectare, due to much of the land being used for cereal farming with high fertiliser inputs. The total emissions reduction for the Howardian Hills is only 7.3%, but this is made up of a 33.6% *reduction* in land use emissions and a 33.7% *increase* in livestock emissions. This is because our model reflects the integration of sheep into the cereal rotation, which has the effect of increasing livestock numbers and the emissions associated with them.

The farm types within the Howardian Hills already meet their overall 5% tree cover target, and therefore the model does not include additional tree planting. Please note that tree cover will not be evenly spread across the farms; some may include many trees and hedges, while others may not have any.

7.2.3 Nidderdale

Percentage wise, Nidderdale sees the greatest reduction in emissions of 39.8%, equal to a reduction in emissions of an estimated 57,386tCO2e/year. The adjustments we have made to the carrying capacity of the land in our model results in a significant reduction in livestock numbers, which in turn has a direct effect on emissions. The number of dairy cows is reduced by 74% resulting in a 75% reduction in dairy emissions (as the regenerative dairy farmer switches from high-genetic-merit dairy cows to more dual-purpose breeds). There is also a reduction in sheep numbers of around 38%, resulting in similar reduction in sheep emissions. Our model assumes that the number of beef cattle will increase, as will emissions associated with them, dampening some of those reductions in dairy and sheep emissions. Our model also shows a significant reduction in emissions from permanent grassland of 54%, again due to reducing or removing inputs of fertiliser and applied manures for livestock dominated farm types.

The sequestration from additional tree and hedge planting means additional sequestration equivalent to 2.3% of the Nidderdale's baseline emissions.

7.2.4 North York Moors

The North York Moors show an overall emissions reduction of 17.7% or an estimated 43,183 tCO2e/year. Modelled emissions reductions from livestock are lower for the North York Moors (9.9%) than in the Forest of Bowland (37.5%) and Nidderdale (39.9%), largely because lowland grazing farms – which comprise a relatively significant land use in the North York Moors, covering 9% of the PL, and being higher than the other PLs – have a baseline stocking rate which is already low, and lower than the other PLs. With the baseline stocking rate being much closer to the natural carrying capacity of the land (i.e. carrying capacity without artificial N), there is less scope for emissions reductions when transitioning to a regenerative system. Modelled emissions reductions in the dairy sector help to drive overall emissions reductions from livestock. Emissions from land use (mainly permanent grassland) reduce by 29.7%, mainly from reduced emissions from permanent grassland which represents 72% of the total reduction from land use change. As with the other PLs this is mainly due to reduced fertiliser usage. Manure applications go up on lowland grazing farms and down on the dairy and LFA grazing farm types, so there is some offsetting of the manure related emissions reduction on the permanent grassland of the dairy and LFA grazing farms by increased emissions from the manures on the lowland grazing farms.

The sequestration from additional tree and hedge planting means an additional sequestration equivalent to 2.2% of the North York Moors' baseline.

7.2.5 Yorkshire Dales

The Yorkshire Dales is the largest PL and has the highest emissions baseline (an estimated 364,788 tCO2e/year). The baseline emissions per hectare are similar to the Forest of Bowland. The reduction in emissions under the 100% regen scenario is 16.3% or 59,446 tCO2e/year. While our model shows emissions reductions being driven by reductions in sheep and specialist dairy cows, an increase in the beef herd tempers the scale of change overall. The good news is that baseline stocking rates on LFA grazing farms are already relatively low, and lower than the other PLs. With the baseline stocking rate being much closer to the natural carrying capacity of the land – which has been supported in the Yorkshire Dales and other PLs by significant agri-environment scheme participation over many years. However, this does mean that there is less scope for emissions reductions when transitioning to a regenerative system. This is amplified by the fact that LFA grazing farms make up the predominant land use in the Yorkshire Dales – so if the scope for emissions reductions in this farm type are low, it has a significant bearing on emissions reductions for the PL as a whole.

The sequestration from additional tree and hedge planting means an additional sequestration equivalent to 2.0% of the Yorkshire Dale's baseline.

7.3 Scenario analysis

There is currently uncertainty over the speed and degree of uptake of regenerative farming. The scenario analysis intended to model different degrees of uptake, to help inform the Action Plan, i.e. the levers that can be used to increase uptake of regenerative farming. The 100% Regen Scenario shows a 24.7% reduction. Figures for a 25% and 50% reduction are included in Appendix 3.

It may be that different sectors (farm types) transition at a different rate, but there is considerable uncertainty about this, as explored in the discussion below. Modelling this, is challenging and time consuming, and given the uncertainty, it is uncertain whether this would have further benefit.

7.4 Discussion

Regenerative farming provides major benefits including improved soil health, increased resilience against extreme weather events (excess rain and drought), improved river water quality and biodiversity, as well as economic benefits such as increased resilience against input price volatility.

The modelling shows that regenerative farming could also contribute to a GHG emissions reduction across all five PLs of an estimated 24.7% (or 250,673 tCO2e/year). This represents a 12% reduction in total agricultural emissions for North Yorkshire (2.066 kt CO_2e yr^{-1}) and 4.4% reduction in total emissions for North Yorkshire as a whole covering all parts of the economy and society (5714.16 kt CO2e yr^{-1} [77]). It is acknowledged that not all the reduction would go into the North Yorkshire budget as most of the Forest of Bowland and part of the Yorkshire Dales are outside of North Yorkshire. If the total reduction from regenerative farming is made proportionate to the area within North Yorkshire, then this represents a 3.2% reduction in total emissions for North Yorkshire.

These are significant contributions, although it is recognised that regenerative farming practices alone will not reduce emissions from agriculture to net zero and uptake of ‘best practice’ regenerative farming (as we have defined it) may be slow.

We have modelled the transition to a particular system of ‘best practice’ regenerative farming, and we have defined the characteristics of that system. These characteristics have been informed by the literature, feedback from farmer engagement, and the case studies produced as part of this project (see Appendix 2).

There are many different permutations of regenerative practice, which would potentially result in different emissions figures. In particular, changes to our assumptions about livestock numbers would have a significant impact on modelled emissions. We have taken a process-based approach to defining best practice regenerative agriculture, which results in a range of positive outcomes, rather than trying to optimise one specific public-policy objective (e.g. reducing GHG emissions). The danger in trying to optimise for a specific objective is that it can lead to perverse results. For example, one of the logical ways to make significant reductions in GHG emissions in the PLs would be to cease livestock production altogether, but this would simply off-shore food production and GHG emissions, decimate farming communities, and threaten important grassland habitats. On the other hand, if we were prioritising the reduction in GHG emissions per unit of production, and if we were agnostic as to the processes which generate this particular outcome, some highly intensive production systems would be favoured over more extensive grass-fed systems – with potential implications for grassland habitats, water quality, soil health, food quality and animal welfare.

While many of the regenerative practices we have modelled could lead to long-term improvements in farm economics, it is acknowledged that there may be economic/commercial challenges to their widespread adoption and implementation.

At the farm level, there may be large sunk capital costs and overheads which militate against significant changes in farming system; for example, we model a change from high-genetic-merit, high-output, specialist dairy cows, to more dual-purpose breeds and more beef animals better suited to extensive grass-based systems, but if the farmer has just invested in a new milking parlour then he/she is going to need to maximise milk production to drive down the fixed costs per litre of milk produced. While some farmers may achieve a premium for their produce based on their regenerative credentials, they may lose their unique selling point if the industry as a whole moves to more regenerative systems. Native-breed beef cattle, which are hardier and better at converting rough grazing, are also slower to mature, smaller, and do not meet some of the modern market requirements that continental or continental-cross breeds do. At the macro-economic level, some negative externalities arising from intensive agriculture – such as diffuse pollution – are largely borne by the taxpayer/public rather than the polluter, while many ecosystem services are undervalued because they are public goods; this tends to distort land-use decisions towards commodity production and against the supply of ecosystem services; regenerative farming delivers a much broader range of ecosystems services than conventional farming.

There may also be practical challenges to some of the changes we have modelled. For example, much of the literature points to the role of cattle in best practice regenerative farming in the uplands; they are better suited to utilising coarser forage resources than sheep, it is practically easier to mob graze cattle, and the way they graze results in a more varied sward structure and greater sward diversity. We have therefore modelled a shift towards more cattle, and fewer sheep, on LFA grazing farms. However, we are conscious of the practical implications associated with this, including: a higher labour requirement for cattle relative to sheep; animal health, welfare, and biosecurity issues particularly associated with cattle grazing; and risks associated with grazing cattle on land with open access and footpaths. These challenges can be overcome however with the selection of low maintenance hardy breeds, adjusting livestock numbers to the natural carrying capacity of the land and careful planning (see Case Studies 4, 5, 6 and 9 for example).

Given the above, farmers may take up only some of the regenerative practices that have been outlined, or only to some degree. For example, many farmers would try to reduce the amount of bought-in fertiliser, but not all would want to reduce it to zero. Livestock farmers would try to optimise forage production for their particular farm but may not be able to eliminate bought-in feed altogether (even if it is just due to fluctuations in weather). Arable farmers could be encouraged by supply chains to take an interest in regenerative practices to reduce the use of herbicides and pesticides to improve soil health and reduce negative environmental impacts.

While not all farmers may shift to regenerative farming, it can be anticipated that many more will. The case studies provide positive and inspiring examples of how farmers around the five PLs have taken up regenerative farming and are making it work to meet their own contexts, circumstances and objectives. There is also increasing interest in all things regenerative from both farmers and the public around the country, with growing support for the regenerative transition from farmer groups, supply chains, government schemes, financial organisations and NGOs. Existing and potential future support for regenerative farming is explored in more detail in the Action Plan accompanying this report.

While this work has focused primarily on regenerative farming in the PLs, it must be pointed out that there are other important habitats and interventions that could sequester and store additional carbon, in particular new woodlands and restored peatland.

8 Conclusions and recommendations

We have taken a process-based approach to defining best practice regenerative agriculture, which results in a range of positive outcomes, rather than trying to optimise a specific public-policy objective (e.g. reducing GHG emissions). It has been informed by the literature, feedback from farmer engagement, and case study examples (see Appendix 2).

This project has created a model to estimate the changes in GHG emissions from a transition to regenerative farming practices in the PLs. The baseline emissions figures are in line with the NAEI. The analysis shows that a move to regenerative farming would reduce the overall GHG emissions of all PLs combined by an estimated 24.7% or 250,673 tCO2e/year, ranging from 16.3-39.8% reduction for the four upland landscapes, and a 7.3% reduction for the Howardian Hills.

For the four upland PLs, these reductions would be largely driven by adjusting to the natural carrying capacity of the land, as a reduction in inputs (artificial fertilisers, bought in feed concentrates, such as soy) would lower the number of animals that can be fed by the forage produced on the farm. The literature clearly advocates optimising a mix of sheep and cattle to achieve ecological objectives. This would mean reducing the number of dairy cattle and using a more dual-purpose breed, incorporating more beef cattle and decreasing the number of sheep.

For the upland PLs, the emissions reductions associated with livestock are primarily driven by a reduction in livestock numbers. Our model assumes an overall reduction of the cattle herd across the PLs (driven by a significant reduction in the dairy herd, as the regenerative dairy farmer switches from high-genetic-merit dairy cows to more dual-purpose breeds) and a reduction in the sheep flock. The reduction in livestock emissions is tempered by a move away from sheep to more cattle in a regenerative scenario for these four PLs.

For the Howardian Hills, regenerative cereal production would integrate sheep into crop rotations to increase fertility and reduce crop pests and disease. This would mean an increase in livestock numbers on cereal farms and an increase in resulting livestock emissions. The percentage reduction in GHG emissions is therefore small.

The analysis shows an estimated increase in carbon *sequestration* of 22,100 t/CO2e/year under a regenerative scenario, as a result of planting additional trees and hedges (except for the Howardian Hills). Under the regenerative scenario, we have assumed the area of farm woodland doubles, up to a maximum of 5% of the total farm area (additional planting would take place on permanent grassland). The potential for sequestration of carbon in soils was calculated separately from our model, using a different methodology, showing an estimated potential uplift of 158,437 t/CO2e/year under a regenerative scenario.

However, there are many different permutations of regenerative practice, which would potentially result in different emissions figures. In particular, changes to our assumptions about livestock numbers would have a significant impact on modelled emissions.

As discussed, while there are economic/commercial and practical challenges associated with adopting regenerative practices, this report clearly outlines the benefits to soil health and wider environmental, economic and societal outcomes arising from regenerative farming. Further research will be required to better understand how to optimise food production, emissions and these other benefits.

Recommendations for further research:

- Integrating the findings of this work with other recent work on land use targets and emissions pathways in the North York Moors and other PLs (e.g. recent analysis undertaken on the sequestration potential from restoring moorlands, heathland, peatlands, and wetland), and the work recommended below.
- Baselining soil organic carbon levels, using a data set called NATMAP Carbon which shows soil carbon stock totals (and potential uplift) produced for individual PLs, and assessing the ability to sequester more carbon.
- Emissions baselining and monitoring of regenerative systems at an individual farm level, to build the evidence base around specific regenerative practices and the implications for GHG emissions. How to optimise regenerative farming systems so that they can drive down GHG emissions per unit of output. This is about more than farming at 'Maximum Sustainable Output (MSO)', or 'the Sweet Spot', as advocated by Nethergill Associates – although for some farms, there will be an overlap. Reducing or eliminating synthetic mineral nitrogen and plant protein imports are key characteristics of regenerative farming, and this will have the effect of reducing gross GHG emissions – but if it leads to lower levels of production, then emissions intensity per unit of output may actually increase. Most of the R&D around reducing emissions per unit of output, particularly through genetic advances, happens in conventional, intensive systems. Performance recording in regenerative upland livestock, and selecting for traits such as reduced methane emissions, resistance to parasites, wool-shedding, growth rates, etc., could help to crystallise significant reductions in emissions intensity for regenerative systems.
- Exploring more fully how GWP* affects GHG emissions with the increased uptake of regenerative practices across the PLs
- Baselining the carbon sequestration of existing hedgerows. This study calculated only the *increase* in carbon sequestration as a result of planting more hedges and trees under the regenerative scenario. Baselining could be achieved through access to better data and additional analysis.

A separate Action Plan proposes a programme of interventions that could support farmers on their 'regenerative journey'.

Glossary

Term	Definition/description
AHDB	Agriculture and Horticulture Development Board
AR	Assessment Report
BAU	Business As Usual
BNG	Biodiversity Net Gain
BPS	Basic Payment Scheme
CO_2	Carbon Dioxide
CO2e	Carbon Dioxide equivalent
CH_4	Methane
CROME	Crop Map of England
CS	Countryside Stewardship scheme
CSF	Catchment Sensitive Farming
CSHT	Countryside Stewardship Higher Tier
CTF	Controlled Traffic Farming
EE	Enterprise Emissions
ELM	Environmental Land Management scheme
FAO	Food and Agriculture Organisation
FiPL	Farming in Protected Landscapes Programme
FT	Farm Type
FYM	Farm Yard Manure
GHG	Greenhouse Gas emissions
GLU	Grazing Livestock Unit
GSOCseq	Global Soil Sequestration Potential Map
GWP	Global Warming Potential
Ha	Hectare
IPCC	Intergovernmental Panel on Climate Change
IPM	Integrated Pest Management
KPI	Key Performance Indicator
kt	Kilo tonnes
LCA	Life Cycle Analysis
LFA	Less Favoured Area
LR	Landscape Recovery
MSO	Maximum Sustainable Output
NAEI	National Atmospheric Emissions Inventory
N	Nitrogen
NL	National Landscape
N_2O	Nitrous Oxide
NSRI	National Soils Research Institute
NVZ	Nitrate Vulnerable Zone
PL	Protected Landscape

PLO	Protected Landscape Organisations
PLTOF	Protected Landscapes Targets and Outcomes Framework
RA	Regenerative Agriculture
RPA	Rural Payments Agency
SFI	Sustainable Farming Incentive
SLCP	Short-Lived Climate Pollutants
t	Tonnes
TB	Tuberculosis
TMR	Total Mixed Ration

Appendices

Appendix 1: Context of farming in the protected landscapes

The majority of the agricultural land in the PLs consists of 'LFA livestock farming' (with the exception of the Howardian Hills).

Less Favoured Areas (LFA)[78] are hill farming areas and are often referred to as 'upland farms', with predominantly sheep and cattle grazing. Agricultural activity has largely shaped the upland landscape, with natural characteristics such as geology, altitude and climate making it more difficult for hill farmers to compete. Figures A1-1 to A1-5 show the LFA status of agricultural land registered with the RPA in each PL.

Figure A1-6 and A1-7 show the dominance of LFA grazing livestock in number of holdings and land area for each of the National Landscapes (NL). For example, for the Yorkshire Dales, over 80% of holdings and farmed area is characterised as LFA grazing. Dairy farming exists in all the PLs (e.g. in the valleys of Forest of Bowland - although it is declining), but less so in the Howardian Hills.

Figure A1-8 shows the higher average farm size for LFA grazing livestock farms, dairy farms, and cereal farms (around 100 – 150ha), compared to lowland grazing livestock farms, say, which are relatively small (around 50ha). Average farm sizes vary by PL; for example, LFA grazing livestock farms in the Yorkshire Dales being significantly larger on average than those in other PLs (the figures shown exclude shared or commons grazing). Mixed farms vary in average size across the PLs.

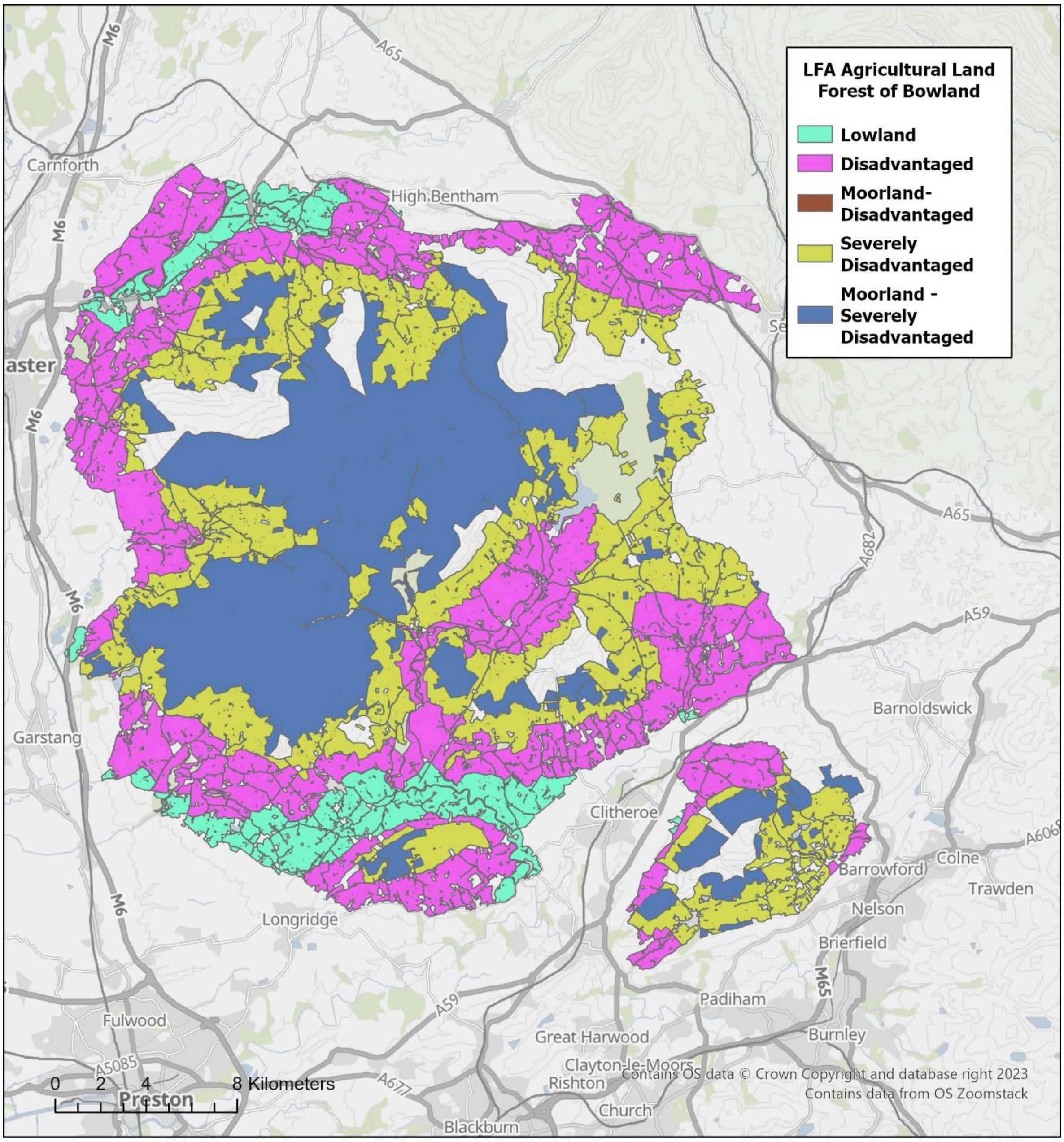
As might be expected given the above, sheep grazing dominates in terms of total livestock numbers in the PLs, except in the Howardian Hills, as shown in Figure A1-9.

Land use by farm type is also available from the Defra June Survey 2021, which is helpful for understanding the baseline for the regenerative farm transition. Figure A1-10 shows that, for LFA grazing livestock farms, permanent grassland averages 58-81% of farm area depending on the PL, and sole right rough grazing averages 14-36% (with Nidderdale having the highest percentage).

The Howardian Hills are very different from the other four PLs (Figure A1-2). It is a more mixed agricultural landscape, with 43% of land used for cereals (large farms) and 15% general cropping on the fatter land, and permanent pasture on the steeper slopes and in small fields around villages. Mixed farming accounts for 27%, while 6% of the land is used for pig farming.

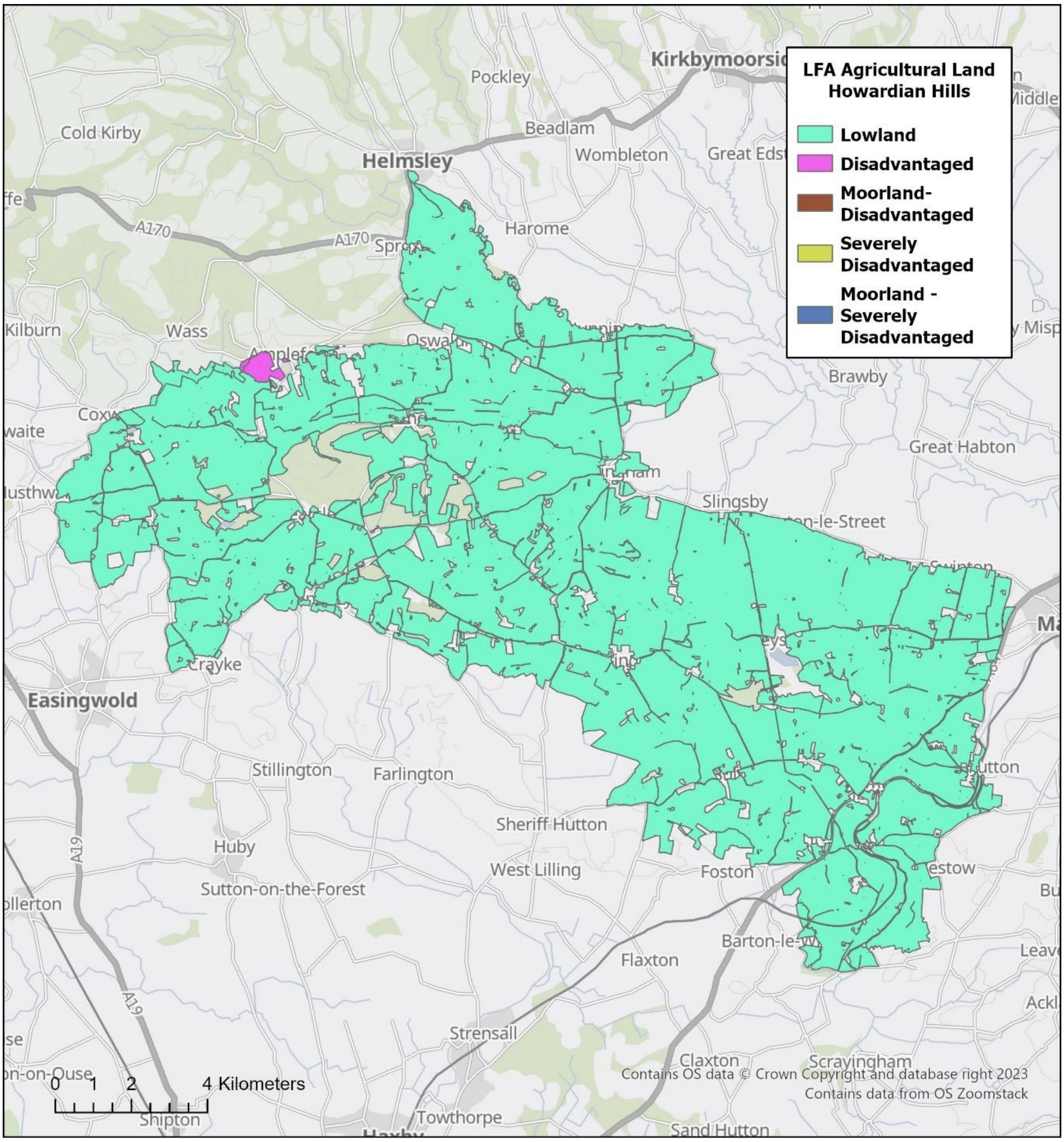
Table A1-1 provides the figures for the number of holdings, area (ha), number of livestock for each of the PLs.

Figure A1-1: Map of agricultural land in the Forest of Bowland NL registered with the RPA showing classification by LFA status



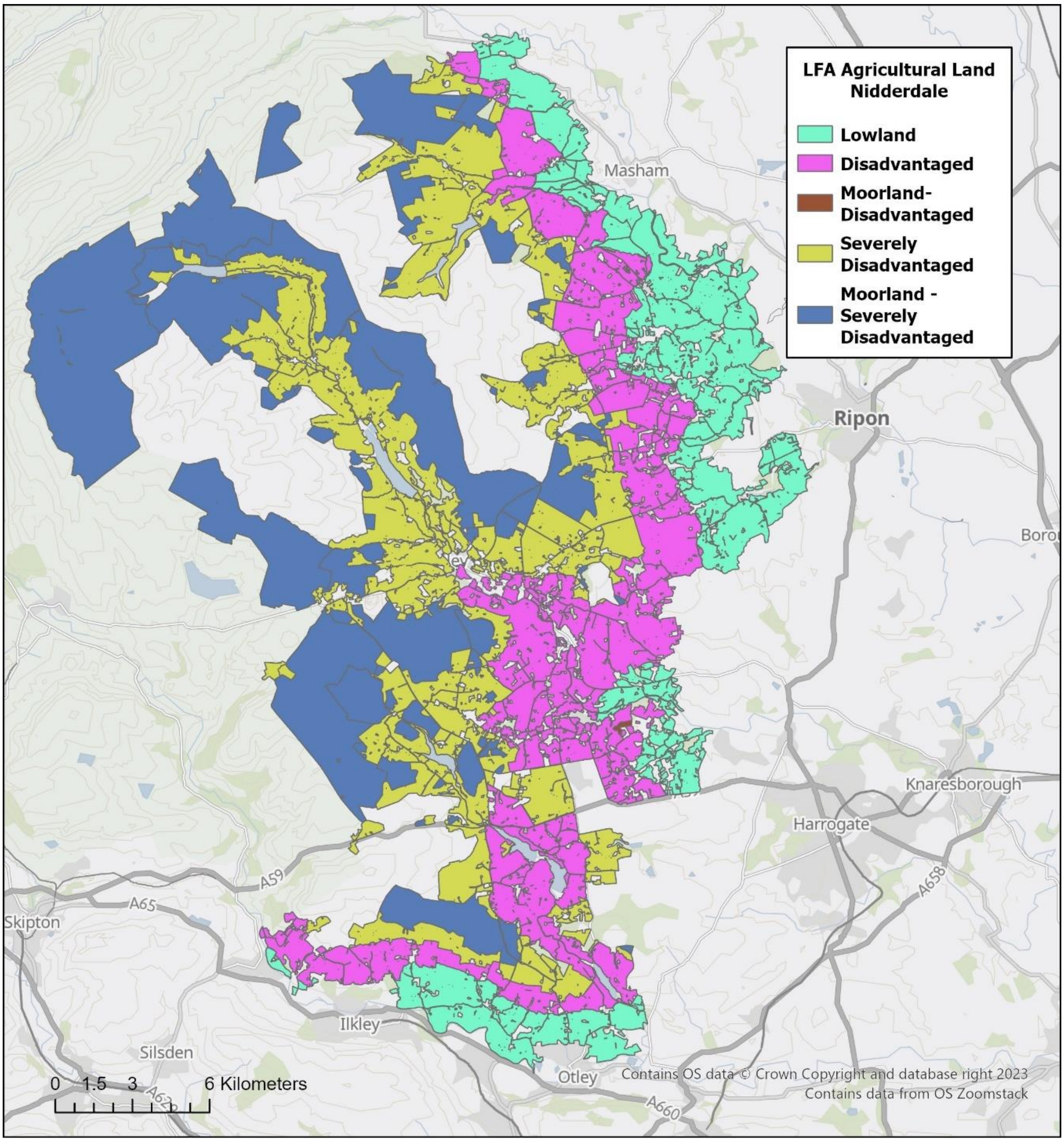
	Disadvantaged	Severely Disadvantaged	Moorland - Disadvantaged	Moorland - Severely Disadvantaged	Lowland	Total
Agricultural area (sq. km)	219.10	198.73	0.06	215.47	51.39	684.74
% of agricultural area	32.0	29.0	0	31.5	7.5	100.0
% of Protected Landscape	27.2	24.7	0	26.7	6.4	85.0

Figure A1-2: Map of agricultural land in the Howardian Hills NL registered with the RPA showing classification by LFA status



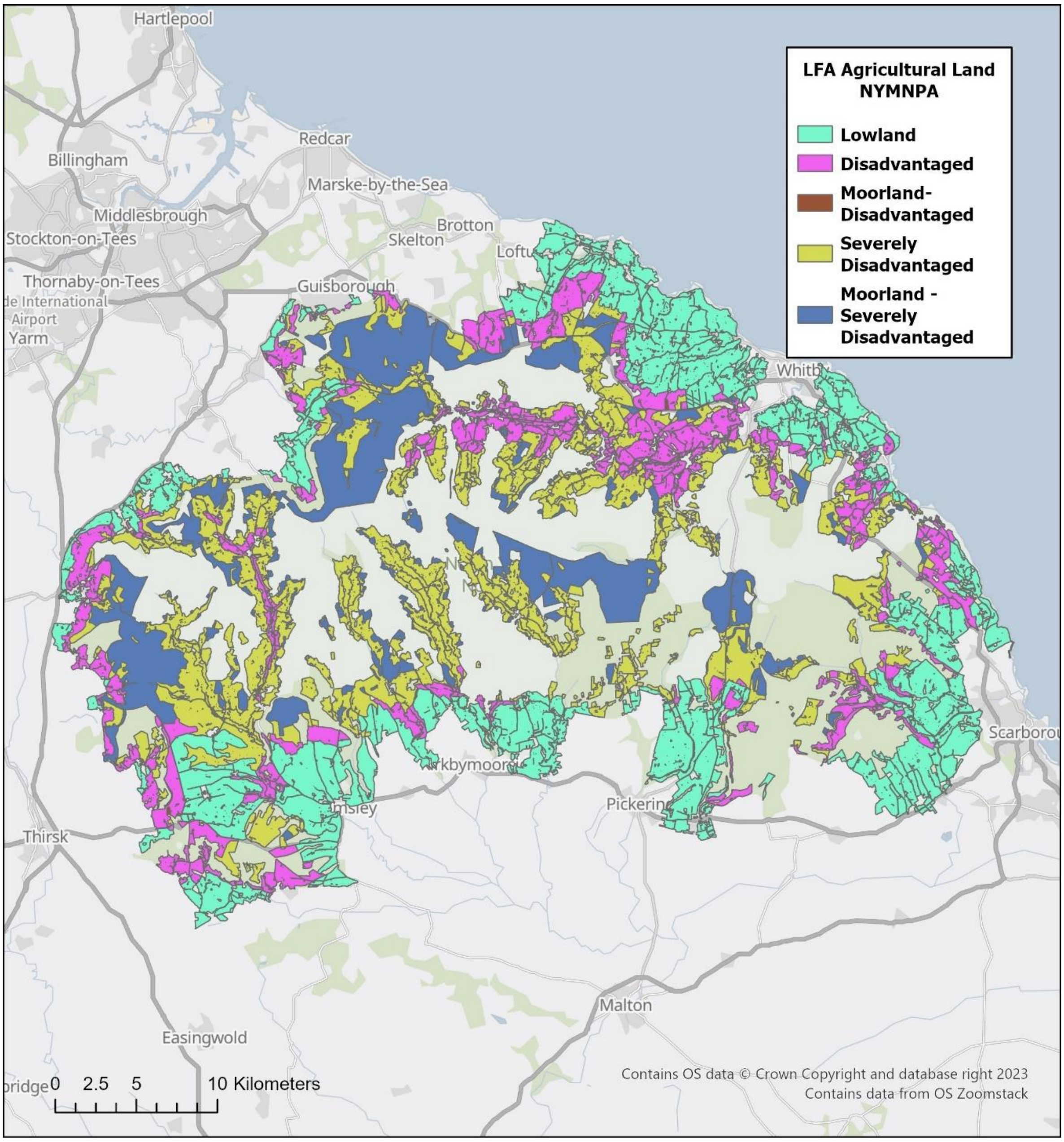
	Disadvantaged	Severely Disadvantaged	Moorland - Disadvantaged	Moorland - Severely Disadvantaged	Lowland	Total
Agricultural area (sq. km)	0.56	0	0	0	187.26	187.82
% of agricultural area	0.3	0	0	0	99.7	100.0
% of Protected Landscape	0.3	0	0	0	91.7	92.0

Figure A1-3: Map of agricultural land in the Nidderdale NL registered with the RPA showing classification by LFA status



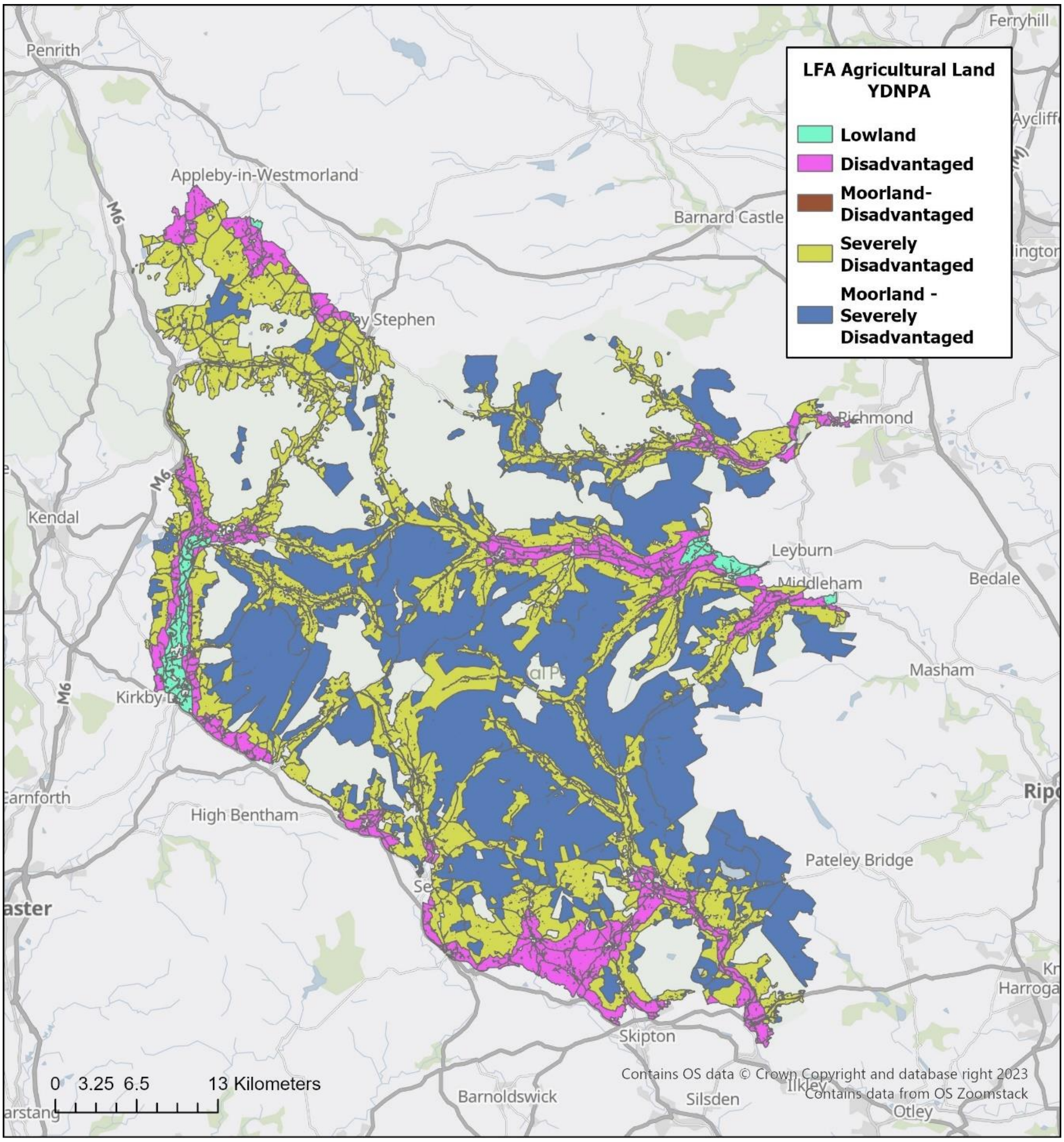
	Disadvantaged	Severely Disadvantaged	Moorland - Disadvantaged	Moorland - Severely Disadvantaged	Lowland	Total
Agricultural area (sq. km)	109.71	129.92	0.15	170.06	79.95	489.79
% of agricultural area	22.4	26.5	0	34.7	16.3	100.0
% of Protected Landscape	18.2	21.6	0	28.3	13.3	81.5

Figure A1-4: Map of agricultural land in the North York Moors NP registered with the RPA showing classification by LFA status



	Disadvantaged	Severely Disadvantaged	Moorland - Disadvantaged	Moorland - Severely Disadvantaged	Lowland	Total
Agricultural area (sq. km)	150.89	255.66	0.47	162.70	291.08	860.81
% of agricultural area	17.5	29.7	0.1	18.9	33.8	100.0
% of Protected Landscape	10.5	17.7	0	11.3	20.2	59.7

Figure A1-5: Map of agricultural land in the Yorkshire Dales NP registered with the RPA showing classification by LFA status.



	Disadvantaged	Severely Disadvantaged	Moorland - Disadvantaged	Moorland - Severely Disadvantaged	Lowland	Total
Agricultural area (sq. km)	181.28	629.32	0.02	736.59	24.33	1571.54
% of agricultural area	11.5	40.0	0	46.9	1.5	100.0
% of Protected Landscape	8.3	28.8	0	33.7	1.1	71.9

Figure A1-6: Number of holdings in PLs by farm type (% of total), from Defra June Survey 2021

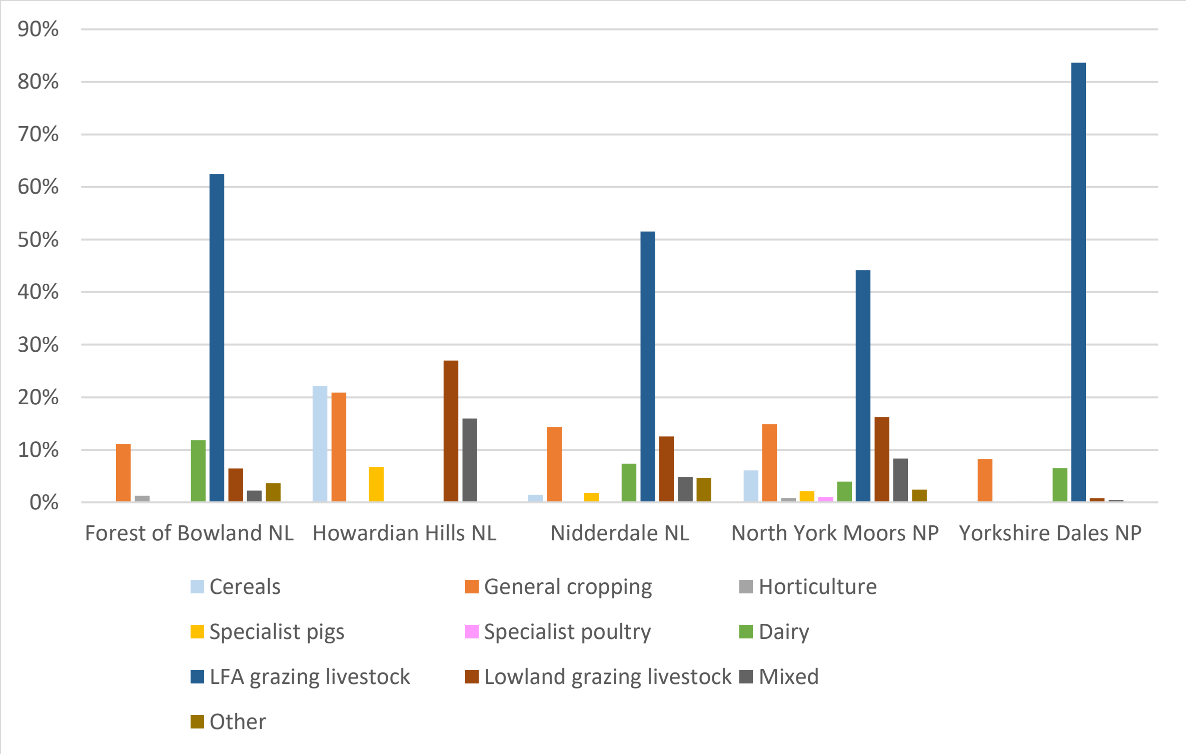


Figure A1-7: Area of holdings in PLs by farm type (% of total), from Defra June Survey 2021

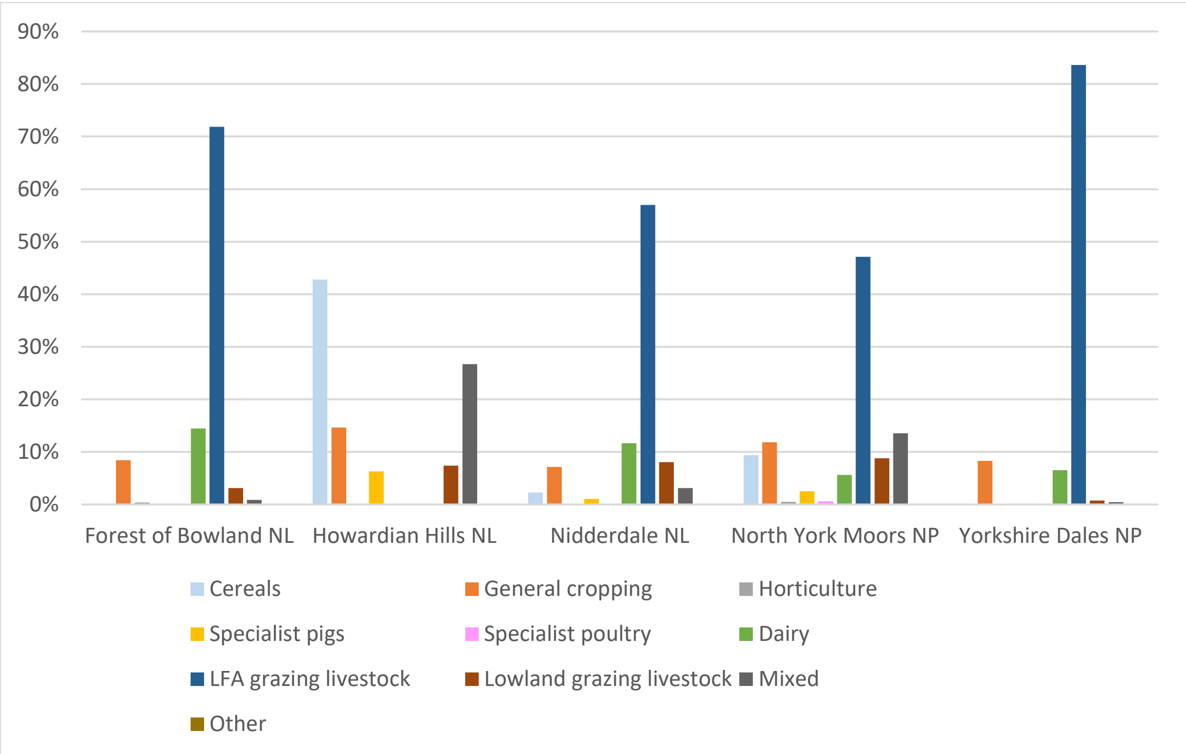


Figure A1-8: Average farm (holding) size in PLs by farm type (ha), from Defra June Survey 2021

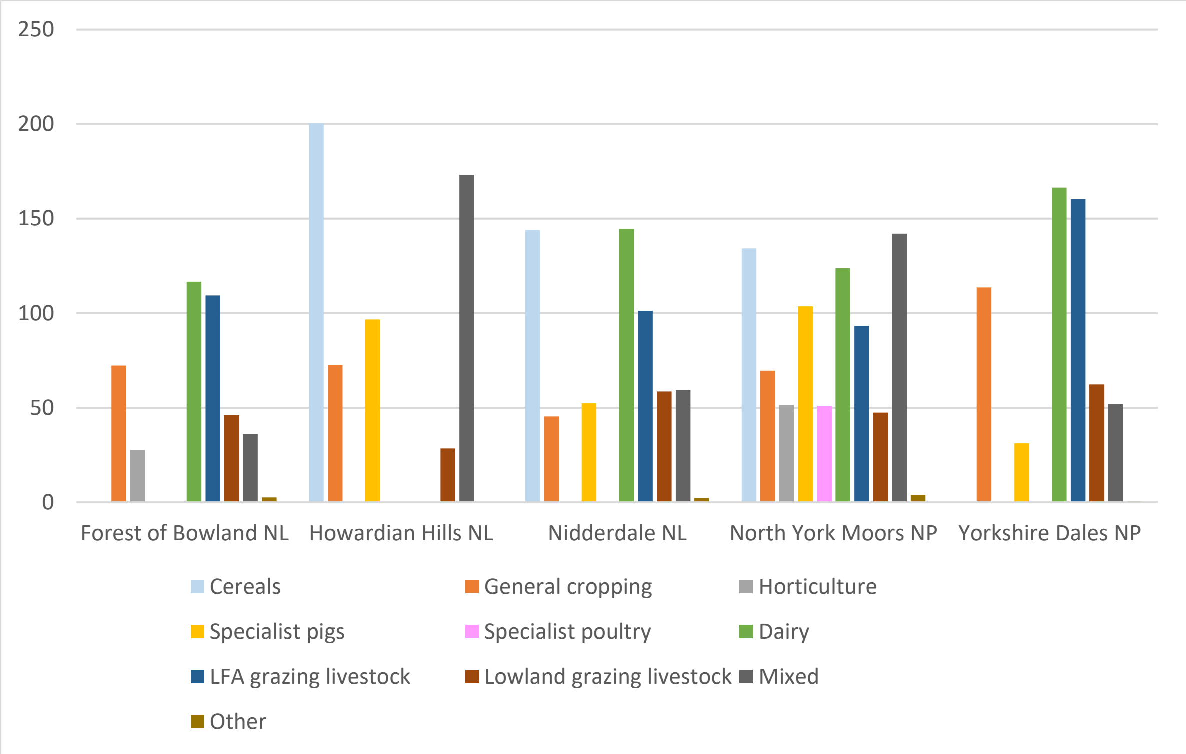


Figure A1-9: Total livestock numbers in PLs, from Defra June Survey 2021

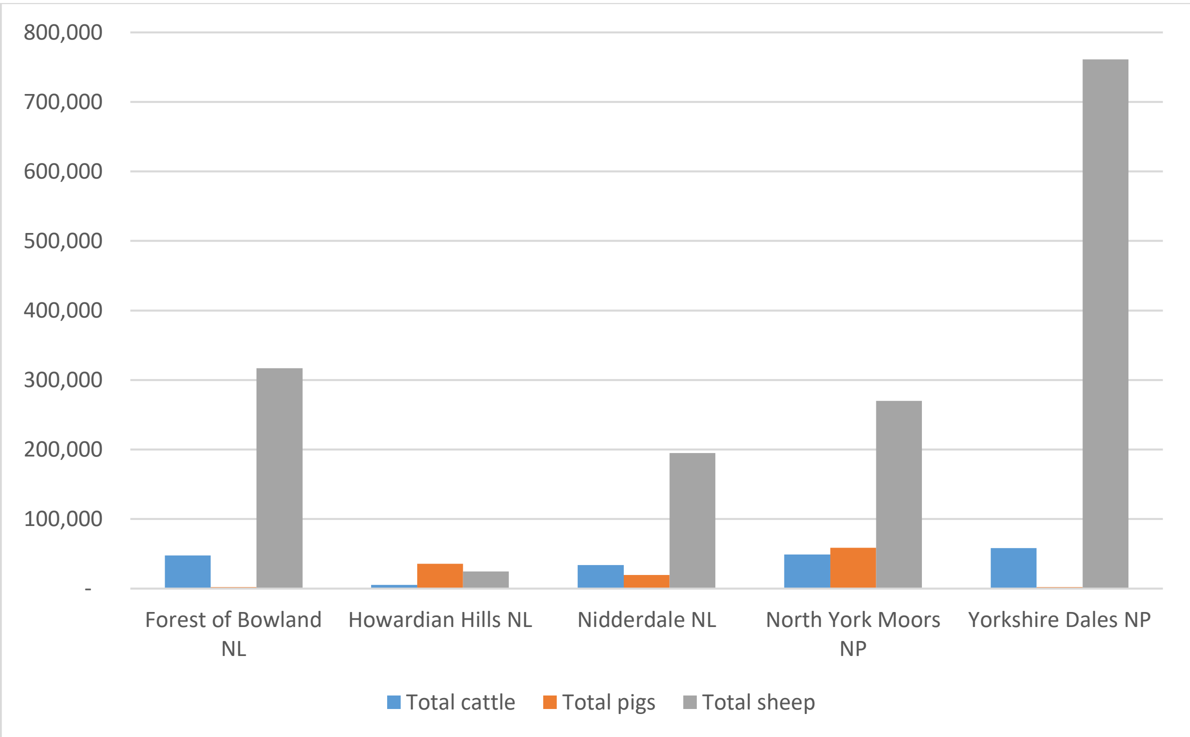


Figure A1-10: Land Use by Farm Type – LFA Grazing Livestock Farms in PLs, from Defra June Survey 2021

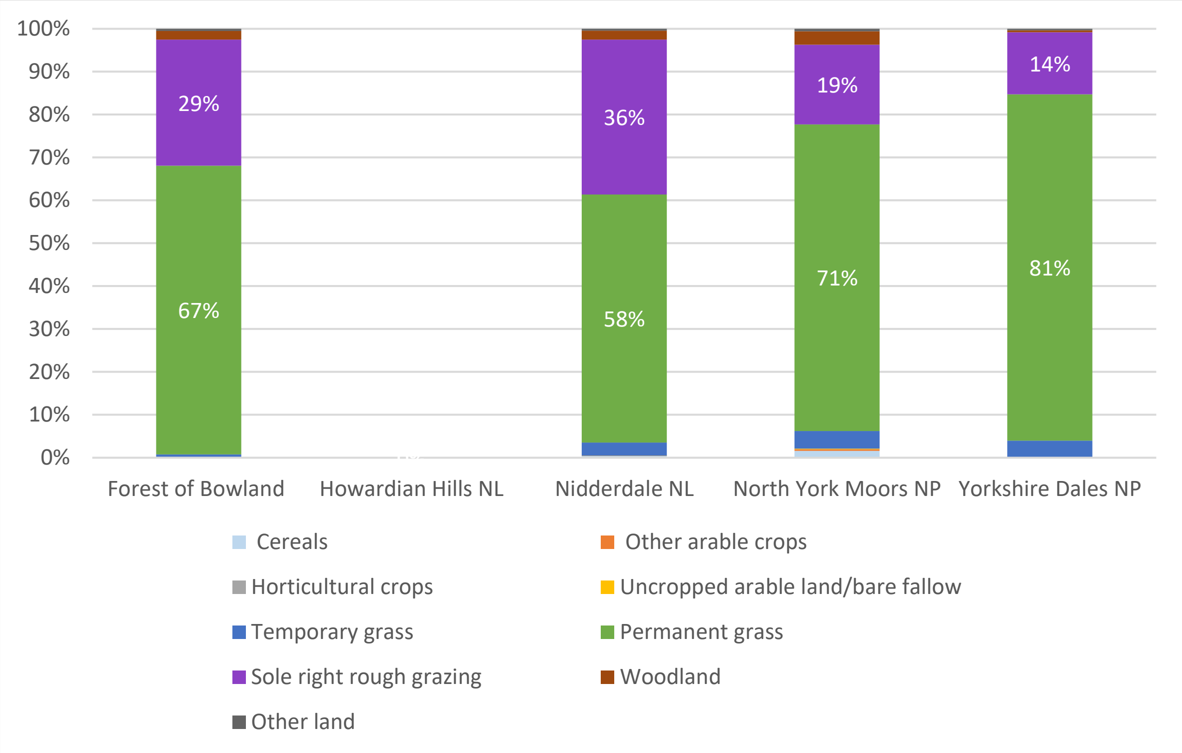


Table A1-1: Summary table of number of holdings, area (ha), number of livestock, from Defra June Survey 2021

	Forest of Bowland NL	Howardian Hills NL	Nidderdale NL	North York Moors NP	Yorkshire Dales NP	**Total**
Holdings	711	163	557	983	1,150	**3,564**
Area (ha)	67,606	16,874	50,951	85,899	165,794	**387,124**
Livestock:						
Total sheep	316,833	24,487	194,963	270,258	761,105	**1,567,646**
Total cattle	47,758	5,475	33,869	48,862	58,375	**194,339**
of which Dairy herd	12,284	357	7,028	5,546	11,658	**36,873**
Total pigs	2,302	35,778	19,620	58,636	2,133	**118,470**

Appendix 2: Case studies

As part of this work, nine farm case studies were developed, based on face-to-face interviews with farmers and land managers in all five PLs. These are enclosed separately.

Appendix 3: Scenario analysis

Forest of Bowland NL	Baseline	Scenario	Total Change	% Change
Emissions ktCO2e/yr				
Scenario	Baseline	Scenario	Total Change	% Change
25% Uptake	220.93	198.99	-21.94	-9.93
50% Uptake	220.93	177.05	-43.88	-19.86
100% Uptake	220.93	133.17	-87.77	-39.73
Official Estimate	254.21			
Woodland Sequestration ktCO2e/yr				
Scenario	Baseline	Scenario	Total Change	% Change
25% Uptake	-9.01	-10.50	-1.49	16.59
50% Uptake	-9.01	-12.00	-2.99	33.18
100% Uptake	-9.01	-14.99	-5.98	66.37
Soil Carbon Sequestration (20% Uplift) ktCO2e/yr				
Scenario	Baseline	Scenario	Total Change	% Change
25% Uptake	-4.44	-10.41	-5.97	134.33
50% Uptake	-4.44	-16.38	-11.94	268.66
100% Uptake	-4.44	-28.32	-23.87	537.33

Howardian Hills NL	Baseline	Scenario	Total Change	% Change
Emissions ktCO2e/yr				
Scenario	Baseline	Scenario	Total Change	% Change
25% Uptake	39.54	38.82	-0.72	-1.83
50% Uptake	39.54	38.10	-1.44	-3.65
100% Uptake	39.54	36.65	-2.89	-7.31
Official Estimate	42.03			
Woodland Sequestration ktCO2e/yr				
Scenario	Baseline	Scenario	Total Change	% Change
25% Uptake	-6.7	-6.7	0	0
50% Uptake	-6.7	-6.7	0	0
100% Uptake	-6.7	-6.7	0	0
Soil Carbon Sequestration (20% Uplift) ktCO2e/yr				
Scenario	Baseline	Scenario	Total Change	% Change
25% Uptake	-1.55	-3.32	-1.77	113.76
50% Uptake	-1.55	-5.09	-3.53	227.53
100% Uptake	-1.55	-8.62	-7.07	455.05

Nidderdale NL	Baseline	Scenario	Total Change	% Change
Emissions ktCO2e/yr				
Scenario	Baseline	Scenario	Total Change	% Change
25% Uptake	144.03	129.68	-14.35	-9.96
50% Uptake	144.03	115.33	-28.69	-19.92
100% Uptake	144.03	86.64	-57.39	-39.84
Official Estimate	150.82			
Woodland Sequestration ktCO2e/yr				
Scenario	Baseline	Scenario	Total Change	% Change
25% Uptake	-6.28	-7.09	-0.82	13.01
50% Uptake	-6.28	-7.91	-1.63	26.01
100% Uptake	-6.28	-9.54	-3.26	52.02
Soil Carbon Sequestration (20% Uplift) ktCO2e/yr				
Scenario	Baseline	Scenario	Total Change	% Change
25% Uptake	-2.83	-6.79	-3.96	139.95
50% Uptake	-2.83	-10.75	-7.92	279.9
100% Uptake	-2.83	-18.67	-15.84	559.8

North York Moors NP	Baseline	Scenario	Total Change	% Change
Emissions ktCO2e/yr				
Scenario	Baseline	Scenario	Total Change	% Change
25% Uptake	244.15	233.36	-10.80	-4.42
50% Uptake	244.15	222.56	-21.59	-8.84
100% Uptake	244.15	200.97	-43.18	-17.69
Official Estimate	261.77			
Woodland Sequestration ktCO2e/yr				
Scenario	Baseline	Scenario	Total Change	% Change
25% Uptake	-23.6	-24.97	-1.37	5.81
50% Uptake	-23.6	-26.34	-2.74	11.62
100% Uptake	-23.6	-29.09	-5.49	23.24
Soil Carbon Sequestration (20% Uplift) ktCO2e/yr				
Scenario	Baseline	Scenario	Total Change	% Change
25% Uptake	-4.87	-11.43	-6.56	134.61
50% Uptake	-4.87	-17.99	-13.12	269.23
100% Uptake	-4.87	-31.11	-26.24	538.45

Yorkshire Dales NP	Baseline	Scenario	Total Change	% Change
Emissions ktCO2e/yr				
Scenario	Baseline	Scenario	Total Change	% Change
25% Uptake	364.79	349.93	-14.86	-4.07
50% Uptake	364.79	335.07	-29.72	-8.15
100% Uptake	364.79	305.34	-59.45	-16.30
Official Estimate	376.50			
Woodland Sequestration ktCO2e/yr				
Scenario	Baseline	Scenario	Total Change	% Change
25% Uptake	-16.91	-18.75	-1.84	10.90
50% Uptake	-16.91	-20.60	-3.69	21.80
100% Uptake	-16.91	-24.28	-7.37	43.61
Soil Carbon Sequestration (20% Uplift) ktCO2e/yr				
Scenario	Baseline	Scenario	Total Change	% Change
25% Uptake	-8.05	-23.93	-15.88	197.39
50% Uptake	-8.05	-39.82	-31.77	394.79
100% Uptake	-8.05	-71.6	-63.54	789.58

Appendix 4: References

[1]https://www.nethergillassociates.co.uk/Sustainable-Farming-Insights/Podcasts-and-Reports
[2] Harmonisation of farm carbon accounting tools report published | ADAS
[3] Martin MP, Dimassi B, Román Dobarco M, Guenet B, Arrouays D, Angers DA, Blache F, Huard F, Soussana JF, Pellerin S. Feasibility of the 4 per 1000 aspirational target for soil carbon: A case study for France. Glob Chang Biol. 2021 Jun;27(11):2458-2477
[4] IPCC 2019. 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Chapter 10: Emissions from Livestock and Manure Management.
[5] Cumulus (2022) The Economics of a Transition to Agroecological Farm. Report for the Soil Association
[6] Agro Business Consultants Ltd (ABC). 2024. The Agricultural Budgeting & Costing Book No.99 – November 2024
[7] Redman, G. (2023) John Nix Pocketbook for Farm Management. Agro Business Consultants Ltd.
[8] Newton P, Civita N, Frankel-Goldwater L, Bartel K, Johns C (2020) What Is Regenerative Agriculture? A Review of Scholar and Practitioner Definitions Based on Processes and Outcomes. Frontiers in Sustainable Food Systems 4 (194)
[9] IPCC, 2019: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. In press.
[10]https://www.climaterealityproject.org/2020-annual-report#:~:text=OUR%20MISSION,mission%20challenged%20like%20never%20before. Accessed 07/08/24
[11] Principles of Regenerative Agriculture - Groundswell Groundswell (groundswellag.com)
[12] Giller, K. E., Hijbeek, R., Andersson, J. A., & Sumberg, J. (2021). Regenerative Agriculture: An agronomic perspective. Outlook on Agriculture.
[13] Magistrali, M., Cooper, J., Franks, J.,George, D., and Standen, J. (2022) Identifying and implementing regenerative agriculture practices in challenging environments: experiences of farmers in the north of England. Project Report No. PR640-09 for AHDB/BBSRC.
[14] L. Schreefel, R.P.O. Schulte, I.J.M. de Boer, A. Pas Schrijver, H.H.E. van Zanten (2020) Regenerative agriculture – the soil is the base. Global Food Security, Volume 26, 2020.
[15] https://farmbusinesssurvey.co.uk/DataBuilder/UK_Farm_Classification_2014_Final.pdf Accessed 12/08/24
[16] Teague, R., & Barnes, M. (2017). Grazing management that regenerates ecosystem function and grazingland livelihoods. African Journal of Range & Forage Science, 34(2), 77–86.
[17] Mitchell, J. P., Reicosky, D. C., Kueneman, E. A., Fisher, J., and Beck, D. (2019) Conservation agriculture systems. CABI Reviews. Volume 2019.
[18] https://publications.naturalengland.org.uk/publication/50034 Accessed 12/08/24
[19] https://www.fas.scot/downloads/tn686-conservation-grazing-semi-natural-habitats/ Accessed 12/08/24
[20] https://www.grazeonline.com/why-you-should-avoid-grazing-coarse-stems Accessed 12/08/24
[21] Tolhurst, S.A. and Oates, M. (eds.) 2001. The breed profiles handbook: a guide to the selection of livestock breeds for grazing wildlife sites. Grazing Animals Project. English Nature, Peterborough, UK
[22] SAC Consulting (2022) Outwintering Strategies for Livestock. 1st edition, Scotlands Rural College (SRUC).
[23] H. Gosnell, N. Gill, M. Voyer (2019) Transformational adaptation on the farm: processes of change and persistence in transitions to 'climate-smart' regenerative agriculture. Global Environ. Change, 59.
[24]https://sheepevent.org.uk/assets/documents/nsa-and-woodland-trust-sheep-and-trees-compressed-v1707756675.pdf Accessed 12/08/24
[25] Cumulus (2021) Woodland & trees in the farmed landscape: agroforestry & farm woodland economy. Report for Soil Association.

[26] Beckert, M. R., Smith, P., Lilly, A., & Chapman, S. J. (2016). Soil and tree biomass carbon sequestration potential of silvopastoral and woodland-pasture systems in North East Scotland. *Agroforestry Systems*, *90*(3), 371–383. https://doi.org/10.1007/s10457-015-9860-4
[27]https://ahdb.org.uk/knowledge-library/rotational-grazing-systems-for-cattle#:~:text=Rotational%20grazing%20works%20on%20the,in%20a%20rotational%20grazing%20system.
Accessed 12/08/24
[28]https://www.wildlifetrusts.org/sites/default/files/2019-11/Hill%20farm%20profitability%20report%20-%20FINAL%20agreed%2015%20Nov%2019.pdf
Accessed 12/08/24
[29] Zaralis, K., & Padel, S. (2019). Effects of High Stocking Grazing Density of Diverse Swards on Forage Production, Animal Performance and Soil Organic Matter: A Case Study. In Immunological Tolerance (pp. 131–146).
[30] Norton LR, Maskell LC, Wagner M, Wood CM, Pinder AP, Brentegani M: 'Can pasture fed livestock farming practices improve the ecological condition of grassland in the UK? Ecol Solut Evid 2022
[31] https://www.pastureforlife.org/media/2018/10/PFL-Health-Benefits-at-14-Sept-FINAL.pdf
Accessed 12/08/24
[32] https://www.sciencedirect.com/science/article/pii/S1751731107000134
[33] Bhogal, A., Chambers, B.J., Whitmore, A.P. & Powlson, D.S. (2007) Effects of reduced tillage practices and organic material additions on the carbon content of arable soils. Final report to Defra for project SP0561.
[34] Baldock, D., Bartley, J., Farmer, M., Hart, K., Lucchesi, V., Silcock, P., Zobbe, H., and Pointereau, P. (2007) Evaluation of the environmental impacts of CAP (Common Agricultural Policy) measures related to the beef and veal sector and the milk sector. Report prepared for DG Agriculture
[35] https://www.theccc.org.uk/wp-content/uploads/2020/12/Sector-summary-Agriculture-land-use-land-use-change-forestry.pdf Accessed 12/08/24
[36] Mason, R. et al (2021) Farm-level interventions to reduce agricultural Greenhouse Gas emissions. Report for the Sustainable Agriculture Workstream of the WWF-UK and Tesco Partnership. Prepared by Eunomia Research Consulting in association with Innovation for Agriculture, RAU and Reading University.
[37] Teague, W.R. (2018) Forages and Pastures Symposium – Cover crops in livestock production: Whole system approach: Managing grazing to restore soil health and farm livelihoods. Journal of Animal Science. Vol 96, issue 4, pages 1519- 1530
[38] Jordon, M. W., K. J. Willis, P. C. Bürkner, and G. Petrokofsky. 2022. Rotational grazing and multispecies herbal leys increase productivity in temperate pastoral systems – A meta-analysis. Agriculture, Ecosystems & Environment 337:108075.
[39] Lemaire, G., F. Gastal, A. Franzluebbers, and A. Chabbi. 2015. Grassland-cropping rotations: An avenue for agricultural diversification to reconcile high production with environmental quality. Environmental Management 56 (5):1065–77.
[40] https://www.theccc.org.uk/wp-content/uploads/2020/12/Sector-summary-Agriculture-land-use-land-use-change-forestry.pdf Accessed 12/08/24
[41] https://www.genusplc.com/media/2060/genus_sustainabilitydatareport_2022_1310.pdf Accessed 12/08/24
[42] https://cielivestock.co.uk/climate-smart-food-systems/breed-for-ch4nge/#:~:text=Further%20gains%20are%20possible%20through,%E2%80%93%2020%25%20after%2010%20years. Accessed 12/08/24
[43] https://huveta.hu/bitstream/handle/10832/1273/O%27ReganThesis.pdf?sequence=1&isAllowed=y
Accessed 12/08/24
[44] Mason, R. et al (2021) Farm-level interventions to reduce agricultural Greenhouse Gas emissions. Report for the Sustainable Agriculture Workstream of the WWF-UK and Tesco Partnership. Prepared by Eunomia Research Consulting in association with Innovation for Agriculture, RAU and Reading University.
[45] ADAS (2016) Impacts of bioenergy maize cultivation on agricultural land rental prices and the environment

[46] Wheeler, L. (2019). Development of a low-cost outdoor dairy-bred beef system. https://projectblue.blob.core.windows.net/media/Default/Research%20Papers/Beef%20&%20Lamb/61110047-Outdoor-Dairy-Beef-Final-Report-Aug19.pdf
[47] McCarthy, K. M., C. G. McAloon, M. B. Lynch, K. M. Pierce, and F. J. Mulligan. 2020. Herb species inclusion in grazing swards for dairy cows-A systematic review and meta-analysis. Journal of Dairy Science 103 (2):1416–30.
[48] Martin, G., J.-L. Durand, M. Duru, F. Gastal, B. Julier, I. Litrico, G. Louarn, S. Médiène, D. Moreau, M. Valentin-Morison, et al. 2020. Role of ley pastures in tomorrow's cropping systems. A review. Agronomy for Sustainable Development 40 (4).
[49] Teague, W. R., Apfelbaum, S., Lal, R., Kreuter, U. P., Rowntree, J., Davies, C. A., Byck, P. (2016). The role of ruminants in reducing agriculture's carbon footprint in North America. Journal of Soil and Water Conservation, 71(2), 156-164.
[50] https://cielivestock.co.uk/climate-smart-food-systems/breed-for-ch4nge/#:~:text=Further%20gains%20are%20possible%20through,%E2%80%93%2020%25%20after%2010%20years. Accessed 12/08/24
[51] https://assets.publishing.service.gov.uk/media/641073c8e90e076cd09acda9/fbs-uk-farmclassification-2014-14mar23.pdf Accessed 12/08/24
[52] https://www.farmhealthonline.com/health-welfare/cattle/breeds-and-breeding/ Accessed 12/08/24
[53] Cumulus (2024) Fallow years analysis for regenerative dairy farms. Report for WWF-UK & Private Client
[54] https://www.farmhealthonline.com/health-welfare/cattle/breeds-and-breeding/ Accessed 12/08/24
[55] Van Diepen, P, Mclean, B and Frost, D (2007) Livestock breeds and Organic farming systems. ADAS Pwllpeiran 1–39. Available at http://orgprints.org/10822/1/breeds07.pdf.
[56] https://ahdb.org.uk/knowledge-library/increasing-milk-from-forage-to-drive-profitability Accessed 24/10/24
[57]https://www.soilassociation.org/causes-campaigns/agroforestry/agroforestry-what-are-the-benefits/
[58] England, J. R., O'Grady, A. P., Fleming, A., Marais, Z., & Mendham, D. (2020). Trees on farms to support natural capital: An evidence-based review for grazed dairy systems. Science of The Total Environment, 704, 135345. https://doi.org/10.1016/j.scitotenv.2019.135345
[59] Arnott, G., Ferris, C.P. & O'Connell, N.E. (2017) Review: welfare of dairy cows in continuously housed and pasture-based production systems. Animal 11:2, 261–273
[60] Tikofsky, L, Cornell University. Presentation on Pasture and Animal Health. http://www.nodpa.com/symposium_presentations/LindaTikofskyPresentation.pdf cited in Pasture for Life (2018) *The animal welfare and environmental benefits of Pasture for Life farming – interim findings*
[61] Charlton, G., Rutter, M. (2017) The behaviour of housed dairy cattle with and without access to dairy pasture: A Review. Applied Animal Behaviour Science. Volume 192, Pages 2-9
[62] https://defrafarming.blog.gov.uk/sustainable-farming-incentive-pilot-guidance-use-controlled-traffic-farming/ Accessed 12/08/24
[63] https://ahdb.org.uk/cover-crops Accessed 12/08/24
[64]https://projectblue.blob.core.windows.net/media/Default/Imported%20Publication%20Docs/AHDB%20Cereals%20&%20Oilseeds/General/GS100%20Livestock%20and%20the%20arable%20rotation%20V2.pdf Accessed 12/08/24
[65] https://www.csuchico.edu/regenerativeagriculture/_assets/documents/fact-sheets/compost-inoculants-fact-sheet.pdf Accessed 12/08/24
[66] Cumulus (2021) Woodland & trees in the farmed landscape: agroforestry & farm woodland economy. Report for Soil Association.
[67] https://defrafarming.blog.gov.uk/sustainable-farming-incentive-pilot-guidance-use-controlled-traffic-farming/ Accessed 12/08/24
[68] https://www.fwi.co.uk/arable/crop-management/nutrition-and-fertiliser/foliar-feed-can-help-cut-nitrogen-use-and-emissions Accessed 05/09/24

[69] Mason, R. et al (2021) Farm-level interventions to reduce agricultural Greenhouse Gas emissions. Report for the Sustainable Agriculture Workstream of the WWF-UK and Tesco Partnership. Prepared by Eunomia Research Consulting in association with Innovation for Agriculture, RAU and Reading University.
[70] Clark C, Scanlon B and Hart K, 2019, Less is More: Improving profitability and the natural environment in hill and other marginal farming systems Hill farm profitability report - FINAL agreed 15 Nov 19.pdf
[71] https://www.fas.scot/downloads/tn686-conservation-grazing-semi-natural-habitats/#:~:text=Grasslands%20tend%20to%20be%20more,and%20the%20underlying%20fertility%20of Accessed 12/08/24
[72] https://www.gov.uk/guidance/using-nitrogen-fertilisers-in-nitrate-vulnerable-zones Accessed 12/08/24
[73]https://projectblue.blob.core.windows.net/media/Default/Imported%20Publication%20Thumbs/RB209/2023/NutManGuideRB209S2_230526_WEB.pdf Accessed 14/08/24
[74] https://www.soilassociation.org/media/1884/factsheet-arable-rotations.pdf Accessed 14/08/24
[75] https://assets.publishing.service.gov.uk/media/667ad606aec8650b1008ffc9/2005-22-uk-protected-landscapes-ghg-emissions.xlsx
[76] https://ahdb.org.uk/knowledge-library/greenhouse-gas-emissions-agriculture
[77] Department for Energy Security and Net Zero (2024) UK local authority and regional greenhouse gas emissions statistics: 2005-2022.
[78] Farming Statistics, Department for Environment, Food and Rural Affairs, June 2021