Farm Carbon Toolkit

The impacts on carbon and nature associated with transitioning to regenerative dairy farming practices

Report for WWF

Dr Grace Wardell, Dr Lizzy Parker
Liz Bowles, Becky Willson

Farm Carbon Toolkit

Disclaimer

Introduction

The Farm Carbon Toolkit was approached by WWF to provide insight into the carbon and nature impacts of the transition to regenerative practices using three modelled dairy farm scenarios. Farm Carbon Toolkit constructed a set of dairy farm models to compare greenhouse gas (GHG) emissions pre- and post-transitioning and assessed the current knowledge around the selected regenerative farming practices' impacts on biodiversity and nature. Three baselines were constructed that differed in their level of grazing, including an intensively housed farm with zero grazing, a mixed housed-and-grazed farm and an extensively grazed farm. These farm pre- and post-transition scenarios were designed in tandem with accompanying financial information from collaborative partners Cumulus and Andersons. Here we present an overview of the methodology and results for the carbon emissions calculations and the findings from the literature review on nature impacts. A detailed assumptions document for the carbon calculations can be found in the appendix.

Modelling methodology

Farm scenarios for the farm carbon calculator (methodology v3.1) were designed to model three different dairy production systems matching the financial report produced by Cumulus and Andersons Centre. A short description of each system is below.

For all modelled farms, fat and protein contents of milk were 4% and 3.2% respectively. Electricity consumption was estimated at 224KwH per dairy cow (FCT, 2025) and mains water usage was estimated as 7.68 litres per litre of milk produced (Hess, Chatterton & Williams 2012). The operations involved in producing forage maize, winter wheat and silage for home use were modelled for given crop areas, to estimate fuel usage, which scaled with the size of the farm. Crop residues were assumed to be mostly removed as they were assumed to be used for bedding. Bought in feed and bedding (where necessary) alongside required agricultural materials such as silage sheets, fencing and bale wraps were included and scaled with silage production and herd size. Nitrogen fertilisers required for temporary pasture, permanent pasture and crop areas were calculated and split over two N containing products with 60% applied as Ammonium nitrate (34.5%) and 40% applied as a blend (24-6-12). Carbon sequestration potential on the farm was assumed to include areas of hedgerows, in field trees, permanent pasture and woodland scaled to the size of the farm. Modelling carbon sequestration associated with areas of permanent pasture and the inclusion of diverse swards originates from countryside stewardship data from Natural England publications (Warner et al., 2019, 2020). Detailed information for the farm production systems are below, assumptions for the farms are representative of typical UK dairy enterprises of that size and type:

Intensively Housed

A typical large UK dairy enterprise (194 ha) that houses 308 dairy cows and 172 youngstock all year round with a milk yield of 9,663 L/cow. Slurry manure produced is spread on grassland.

Housed & Grazed

A typical medium sized UK dairy enterprise (167 ha) that houses livestock for six months and grazes for six months, with 247 dairy cows, 138 youngstock and a milk yield of 8169 L/ cow. Slurry manure, when produced in stalls, is spread on grassland.

Extensively Grazed

A typical small, extensively grazed dairy enterprise (88 ha) where livestock graze outside for 100% of the year, with 114 dairy cows and 41 youngstock and a milk yield of 4,967 L/ cow. All manure is dropped in the fields.

Regenerative practices

The below practices were incorporated into the modelled transitions. A short description of practices and the associated impacts on emissions over a 5- year time period include:

Reduced application of nitrogen fertilisers

- Lower fertiliser rates applied to areas of temporary and permanent pastures.
- Replacement of forage maize with a cereals and peas mix leading to a reduced N requirement due to the inclusion of a legume.

- Replacement of winter wheat with organic winter oats in the transition which eliminates N inputs on crop area.
- These actions will reduce direct (scope 1) N_2O emissions from fertiliser application and indirect emissions (scope 3) associated with fertiliser production.

Changes to dairy herd, milk production and feed

- Reduced stocking rates (which is a consequence of both the reduction in applied N fertilisers and reduced supplementary feeding, reducing the overall efficient carrying capacity of the forage area) will reduce the total livestock enteric and manure associated GHG (scope 1) emissions on farm.
- A reduction in overall milk yield per cow lowers overall emissions, but can increase the product footprint (kg CO2e / kg FPCM), due to reduced volumes.
- A reduction in supplementary concentrate feeding per cow in all three dairy systems was modelled with increases in milk from forage (10-60% increase) associated with the greater reliance on forage (grazed and conserved) and the reduced stocking rate. This will lower scope 3 emissions associated with bought in feeds.
- Change in cow breeds and introduction of multipurpose cow breeds could not be incorporated into the models as currently there is not enough sensitivity in emissions data to be able to select by breed of cow.

Rotational and holistic grazing

- Rotational grazing on permanent pasture areas resulting in an 0.1% increase in soil organic matter (SOM) over a five year period was modelled, increasing carbon sequestration for these areas.
- Investment into fencing materials associated with these grazing systems is required, emissions associated with increased fencing materials has been incorporated into the post transition models, where applicable.

The use of diverse swards

- Planting of diverse swards in temporary pasture areas reduces the need for nitrogen fertilisation on temporary pasture areas and has the potential to sequester carbon.

Reduced cultivation depth and frequency

- A switch from ploughing and power harrow drilling of crop areas to direct drilling reduces the fuel use associated with on farm crop production.
- Due to the lack of data and large uncertainty around the impacts of reduced cultivation on UK soil organic carbon (SOC) storage and direct emissions, only fuel reductions were incorporated into the models.

Trees and Hedges

- An increase in woodland area on the farm increases the carbon sequestration potential. The increase in woodland areas was associated with a reduction in temporary pasture or cropland areas depending on the production system and thus impacting yields.
- Areas of managed hedgerows were included in pre- and post-transitions and were scaled to farm size, which contributes to carbon sequestration potential on farm.

Results

Whole Enterprise Carbon Footprint

By transitioning to more regenerative farming practices, all of the modelled farms reduced their carbon footprints over the 5 year period (see Figure 1). The intensively housed dairy farm reduced total emissions by 47%, removing 1384.19 tCO2e. The housed and grazed farm reduced emissions by 39%, removing 836.48 tCO2e and the extensively grazed farm reduced emissions by 33%, removing 308.41 tCO2e. When assessing the reductions in carbon balance, which is the total carbon emissions plus any removals by carbon sequestration, the transition reduced the carbon balance by 56% (removing 1613.39 tCO2e), 53% (removing 1070.21 tCO2e) and 50% (removing 445.87 tCO2e) for the intensively housed, housed and grazed and extensively grazed farms, respectively. The carbon emissions per hectare and carbon balance per hectare pre- and post- transition are shown in Figure 2 and Figure 3, respectively. These results highlight the combined potential for large reductions in carbon footprints when implementing multiple different regenerative practices across different production systems.

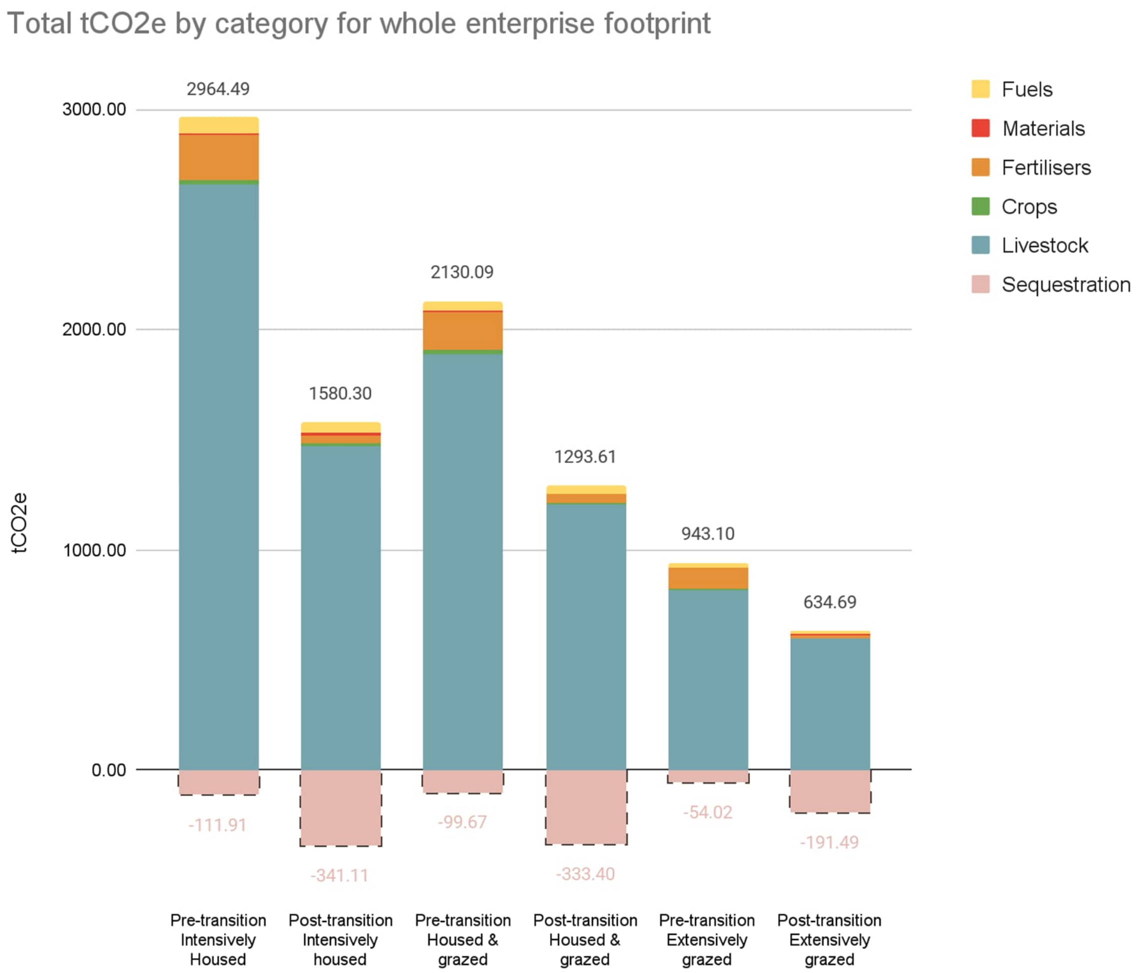

Figure 1. Total tonnes carbon dioxide equivalent (tCO2e) for pre- and post- transition whole enterprises, with emissions categories represented by colours. Total carbon emissions for each farm are listed above bars in grey. Carbon sequestration is represented in the dotted lines with the carbon removals value listed separately below in pink. The carbon balance for each enterprise = total emissions (grey value) + sequestration (pink value).

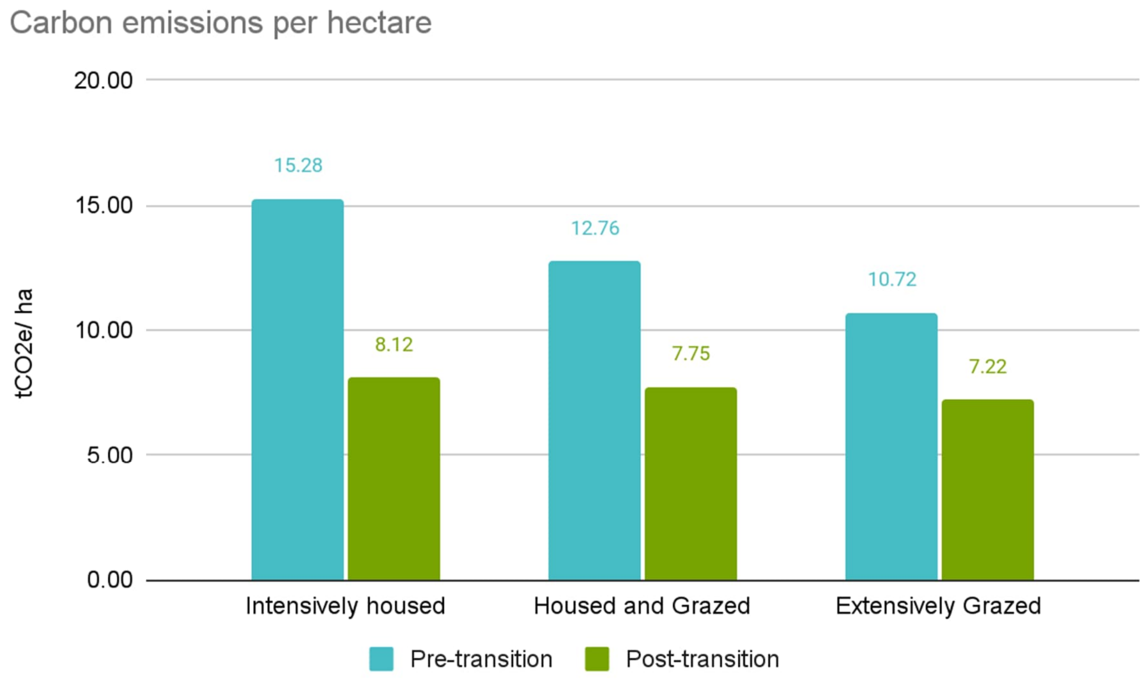

Figure 2. Carbon emissions per hectare for each farm scenario pre and post transition. Values above bars are the total tCO2e/ ha for the farm model.

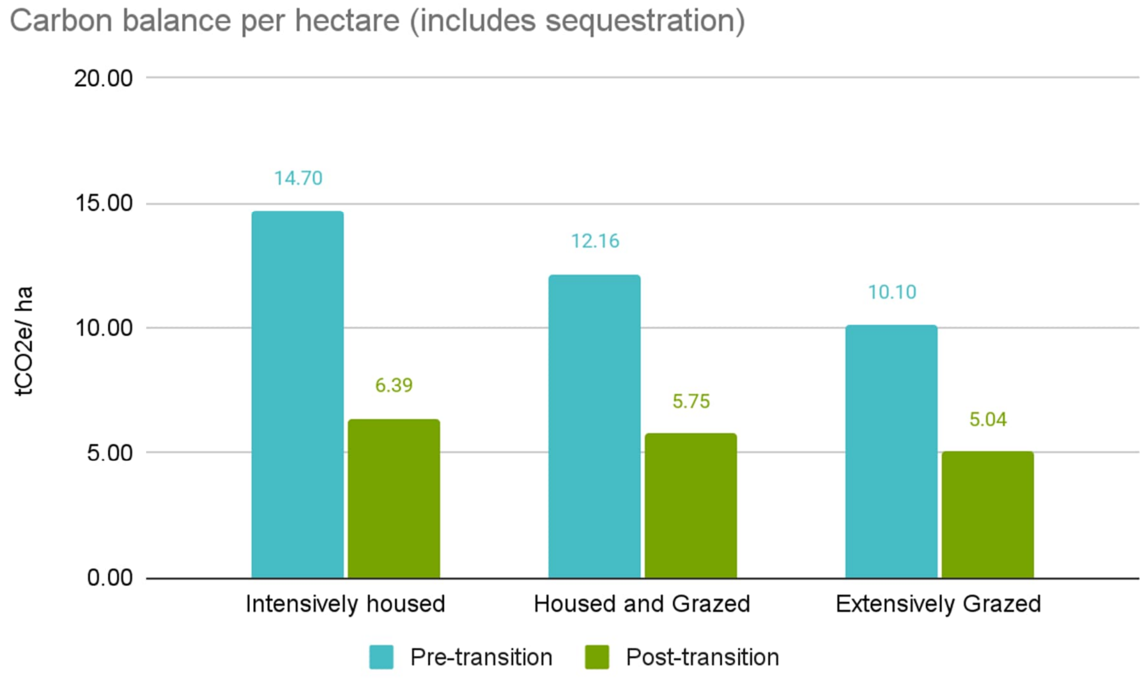

Figure 3. Carbon balance per hectare (includes sequestration) for each farm scenario pre and post transition. Values above bars are the total tCO2e/ ha for the farm model.

Breakdown of Emissions Categories

The largest portion of emissions for all three modelled farms is attributed to livestock, which accounts for enteric methane production and manure emissions associated with the different age (and size) of dairy cows (Figure 2, Figure 3, Figure 4). As a reduction in herd size and milking regimes were two of the regenerative practices modelled, livestock emissions in the post-transition scenarios are reduced by 37% for the intensively housed, 28% for housed and grazed and 21% for extensively grazed. Bought in feed and bedding is the second highest contributor to the footprint and fertilisers is third. These categories (livestock, feed and fertilisers) had the largest impacts on the carbon footprint when reduced by a combination of the regenerative practices (reduction in stocking rates, milk yield, concentrate feeding and a reduction in N fertiliser application rates) in the post-transition scenarios. Emissions from fuels, crop residues and agricultural materials represent a relatively small component of the footprints which relate to reducing tillage on crop areas, choice of crop production for home grown feed/bedding on farm and materials required for silage production, fencing and mains water usage. Sequestration was increased 3-fold in the intensively housed post-transition, 3.3-fold in the housed and grazed post-transition and 3.5-fold in the extensively grazed post-transition due to a combination of increased woodland area, planting of diverse swards and rotational grazing practices.

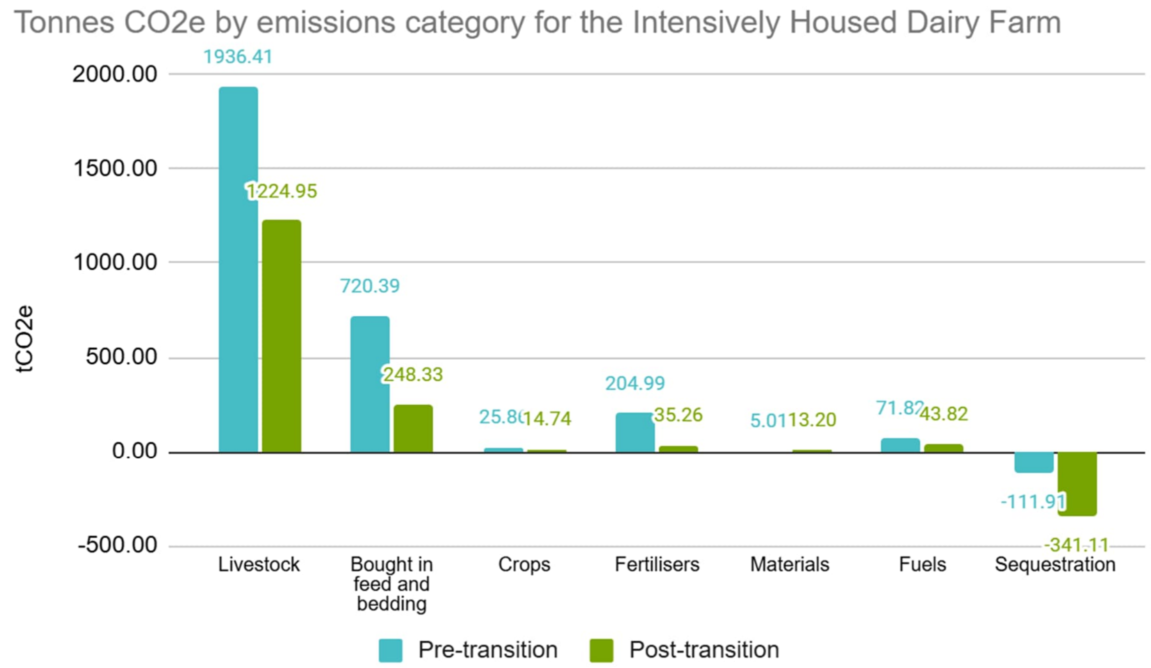

Figure 4. Total tonnes of CO2e (tCO2e) split by emissions categories for the intensively housed dairy farm. Values above bar are the total tCO2e for that category.

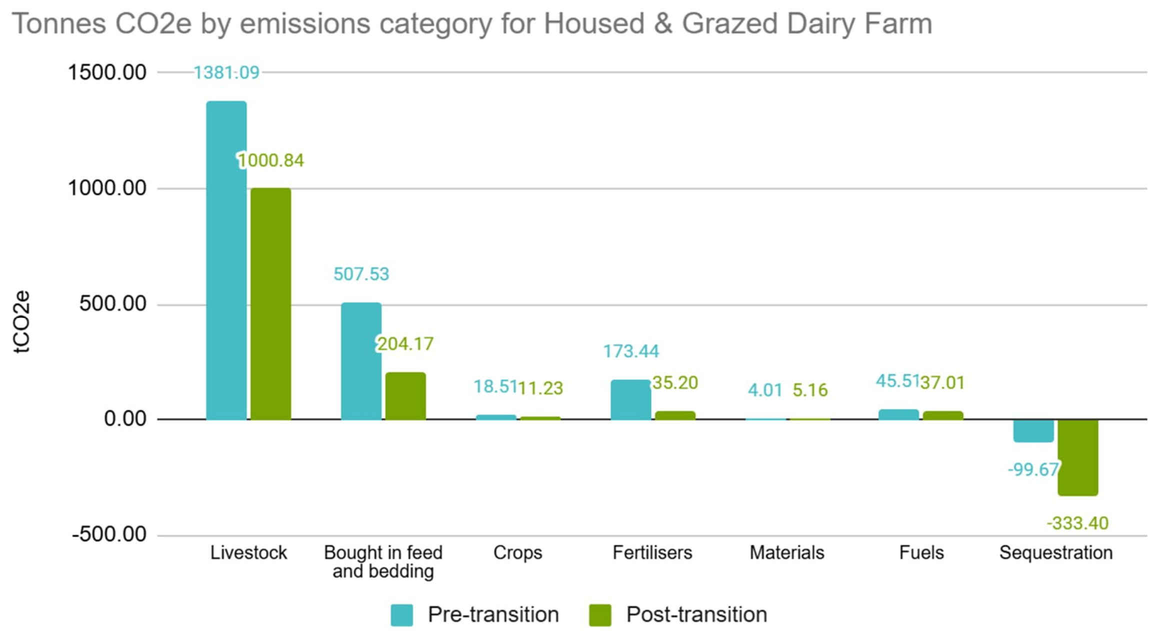

Figure 5. Total tonnes of CO2e (tCO2e) split by emissions categories for the housed & grazed dairy farm. Values above bar are the total tCO2e for that category.

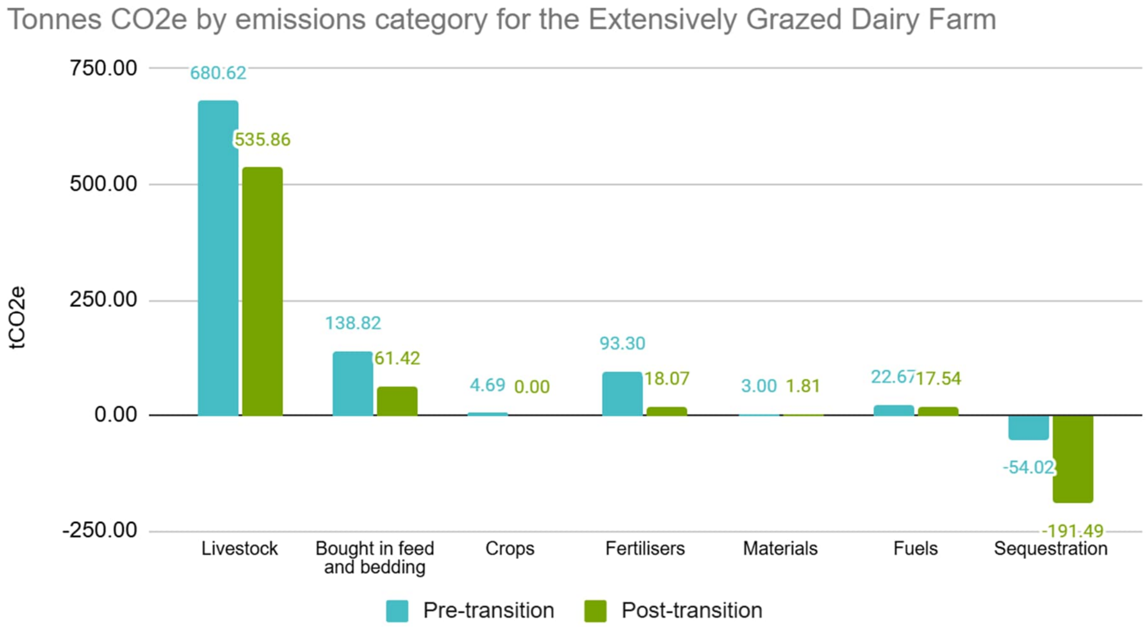

Figure 6. Total tonnes of CO2e (tCO2e) split by emissions categories for the extensively grazed dairy farm. Values above bar are the total tCO2e for that category.

Emissions reductions associated with regenerative practices

Table 1 links the calculator emissions categories (found in Figures 4, 5 and 6) to the regenerative practices that have been modelled and pulls out some specific emissions reductions. However, it is important to note that these models were created on a whole enterprise basis, incorporating multiple practices at once to model the transitions in order to align with the financial report produced by Cumulus and Andersons. Therefore, certain emissions reductions could be associated with multiple practices or a reduction in emissions in one category and an increase in emissions in another category. Hence, it is important to recognise that not all consequences of the practice changes may be reflected in the emissions values provided in column 2 of table 1 below. We have provided an additional narrative, in column 3, on the regenerative practice changes and how this can result in different impacts on the farm's production system, to highlight where areas of double counting or under counting of emissions could occur if looking at one practice change in isolation.

Table 1. Actions associated with regenerative practices that link to the emissions categories and tCO2e reductions in the models. The tCO2e reductions (and percentage reductions) for the post-transition farm models IH = intensively housed, HG = housed and grazed and EG = extensively grazed compared to their pre-transition baselines. The reduction is also expressed as a percentage of the total emissions reductions achieved for that dairy enterprise. Changes in carbon sequestration are expressed as a percentage of the post-transition total sequestration.

Regenerative practice and action in model	Emissions category and reduction in tCO2e post-transition	Additional context around practice change
Reduced application of nitrogen fertilisers • Reduced N application rates on crop areas (-45.5%) • Reduced N on temporary (-100%) and permanent pastures (-66.7%)	**Fertilisers** Savings of: IH: 169.73 tCO2e • -82.8% reduction in fertiliser associated emissions • = 12.3% of total emissions reductions HG: 138.24 tCO2e • -79.7% reduction in fertiliser associated emissions • = 16.5% of total emissions reductions EG: 75.23 tCO2e • -80.6% reduction in fertiliser associated emissions • = 24.4% of total emissions reductions	Swapping forage maize for a cereals/peas mix allowed reduced N requirements as the legume provides biologically fixed N Swapping winter wheat for winter oats reduces N inputs but a reduction in yield of around 4T/ha could be expected for models with cereals crop areas, this also reduces emissions associated with crop residues left in the field A reduction in grass production would be expected before any impact from changes to grazing management and species grown, with consequent knock on impacts on feed concentrates required and/or milk yield
Changes to dairy herd	**Livestock + Bought in feed and bedding**	These reductions are based on:

• Reduced stocking rates • Reduced milk yields • Reduced concentrate feeding (more milk produced from forage)	Savings of: IH: 1183.53 tCO2e • -44% reduction of emissions associated with animals, feed and bedding • = 85.5% of total emissions reduction HG: 683.62 tCO2e • -36% reduction of emissions associated with animals, feed and bedding • = 81.7% of total emissions reduction EG: 222.17 tCO2e • -27% reduction of emissions associated with animals, feed and bedding • = 72% of total emissions reduction	IH: 31% reduction in stocking rate and 30% reduction in milk yield HG: 30% reduction stocking rate and 17% reduction in milk yield EG: 22% reduction stocking rate and 17% reduction in milk yield These categories include the scope 1 enteric and manure emissions from animals and scope 3 emissions from bought in feed and bedding.
Reduced cultivation depth and frequency • Change from ploughing and drilling to direct drill for crop areas	**Subset of Fuels** Savings of: IH: 5.58 tCO2e • -37% reduction of emissions from fuels used on crop areas • = 0.4% of total emissions reduction HG: 3.09 tCO2e • -35% of fuels used on crop areas • = 0.4% of total emissions reduction	HG and EG had reduced crop areas associated with an increase in grassland and woodland. Only changes in fuel usage were entered into the models due to the lack of data and large uncertainty around the impacts of reduced cultivation on UK SOC storage and direct emissions.

	EG: 2.73 tCO2e - Crop areas were removed from the EG transition ● 100% reduction of fuels on crop area ● = 0.9% of total emissions reduction	
Rotational grazing/ holistic grazing ● Introduction of rotational grazing on permanent pasture areas resulting in a 0.1% increase in SOM over 5 years	**Subset of Sequestration** Additional removals of: IH: -125.5 tCO2e for 75.66 ha ● 36.8% of total post-transition sequestration HG: -134.4 tCO2e for 81 ha ● 40.3% of total post-transition sequestration EG: -89 tCO2e for 53.68 ha ● 46.5% of total post-transition sequestration	Additional associated investment in fencing materials for rotational grazing replacements and emissions associated with material production: IH: 5km fencing materials = 10.2 tCO2e HG: 1.25km fencing materials = 2.6 tCO2e EG: N/A - assumption is farm already has extensive fencing materials
The use of diverse swards ● Planting herb rich swards in temporary pasture areas using modelled data from countryside stewardship option (GS4)	**Subset of Sequestration** Additional removals of: IH: -68.6 tCO2e for 50.44 ha ● 20.1% of total post-transition sequestration HG: -72.5 tCO2e for 53.3 ha ● 21.7% of total post-transition sequestration EG: -34.7 tCO2e for 25.52 ha ● 18.1% of total post-transition sequestration	Planting legume and herb rich swards also contributes to the ability to reduce N on temporary pasture areas (reducing N fertilisers without this action would result in reduced production on temporary pasture areas with consequent higher requirement for supplementary feeds or a further reduction in stocking rate).

Trees and Hedges ● Woodland area increase in size	**Subset of Sequestration** Additional removals of: IH: -50.98 tCO2e for doubling of woodland area ● 29.9% of total post-transition sequestration HG: -43.88 tCO2e for doubling of woodland area ● 26.3% of total post-transition sequestration EG: -24.17 tCO2e for 105% increase in woodland area ● 24.7% of total post-transition sequestration	An increase in woodland areas was associated with: IH: A reduction in temporary pasture area HG: A reduction in cropland area and a slight increase in temporary pasture area EG: A reduction in cropland area and a slight increase in permanent pasture area This has knock on impacts for silage and crop production for the three dairy enterprises.

Timeframe of emissions reductions and sequestration

The timeframe to get to the total emissions reductions and sequestration for the transition to regenerative practices has been modelled over a 5 year period, however emissions reductions will be achieved in the year the practice change is implemented. For example, reducing fuel usage associated with reducing tillage and soil cultivation could be achieved the following year if the farmer decides to switch to direct drilling for cropped areas. The carbon sequestration associated with planting diverse leys is an annual value which can be attributed to the footprint from when it is established and will depend on which transition year and the total area of diverse sward to be sown. For livestock, the emissions reductions will occur in the year the animals leave the farm, as some transitions modelled a ~30% reduction in stocking rate, this practice may be implemented incrementally over a number of years and thus emissions from livestock may fluctuate year on year depending on the transition to a smaller herd size. Concurrently, any associated emissions with feed for those animals will also change when livestock levels reduce.

Emissions associated with transitioning the diets for the cattle and the amount of home grown crops will depend on what is being grown (as an example, when wheat is swapped out for organic winter oats, then the associated fertiliser is not required). Therefore, it would be expected that in the interim years (between the baseline and year 5) the emissions associated with cropping and fertilisers would reduce as more land is allocated to grassland and less to arable cropping. Implementing rotational grazing leading to carbon sequestration is currently included in the models with sequestration taking place in a linear fashion, with the total sequestered over the 5 year period presented. For the increase of woodlands areas on farms, an averaged estimate over a mixed unmanaged woodlands lifespan (of an intermediate yield class, ~6) was used, as carbon sequestration potential varies throughout woodland age and is not linear. Therefore, the sequestration associated with this practice is not for the first 5 years after planting a woodland, but gives an idea of the sequestration potential of expanding the same type of woodland and would take longer than the 5 years to occur (*e.g.* 5-15 years, when sequestration increases). To summarise, the emissions reductions and sequestration is not expected to happen in a linear fashion across the 5 year transition period but would be more led by the practice changes implemented by farmers.

Product carbon footprint

The product carbon footprint of milk, expressed as kg CO2e / kg FPCM (fat and protein corrected milk) decreased in all modelled farm scenarios when calculated using the total carbon balance (which includes sequestration - Figure 7). The intensive housed product footprint decreased by 17.2%, the housed and grazed product footprint by 26% and the extensive grazed by 26%. However, the inclusion of carbon sequestration as part of a product footprint is rare, as it can only be included if it is based on direct measurements (usually by soil sampling over a number of years to evidence sequestration) and not via modelled sequestration.

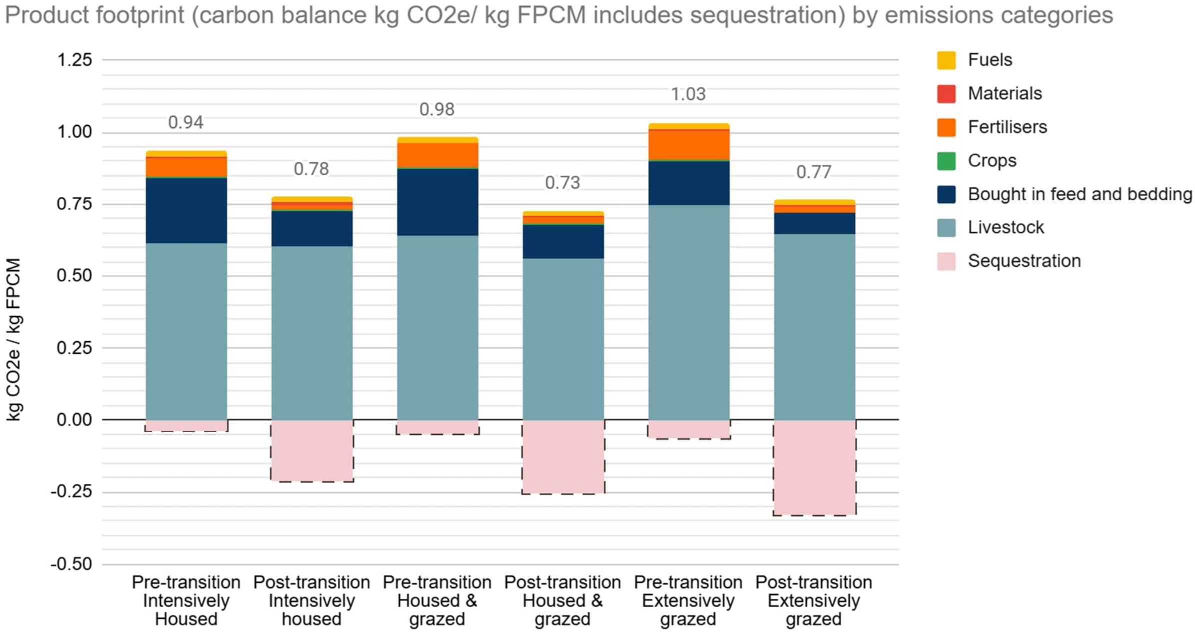

Figure 7. Product footprint (kg CO2e/kg FPCM) calculated using the total carbon balance (includes sequestration) with proportions of emissions categories represented.

Reporting of the product footprint calculated using the total carbon emissions (excludes sequestration) is more advisable and current common practice. There was very little change in the emissions product footprint (kg CO2e / kg FPCM), with a 1.6% increase in the footprint for the intensive housed farm, no change for the extensive grazed farm and a 5% reduction for the housed and grazed farm (Figure 8). The little-to-no change in emissions kg CO2e / kg FPCM is due to the reduced milk yields in the post transition scenarios, where overall whole enterprise emissions have decreased due to reduced stock on farm, concurrent with decreases in milk volumes, which increases the product footprint. The extensively grazed post- transition emissions footprint has not changed as the predicted reductions in product (milk) matches the reduction in overall emissions (-32.6%). After transitioning to more regenerative practices, the product footprints have a reduction in bought in feed and bedding and associated fertiliser use for all farms. As a result, a higher proportion of emissions in the post- transition product footprints is allocated to the direct (enteric and manure) emissions associated with livestock.

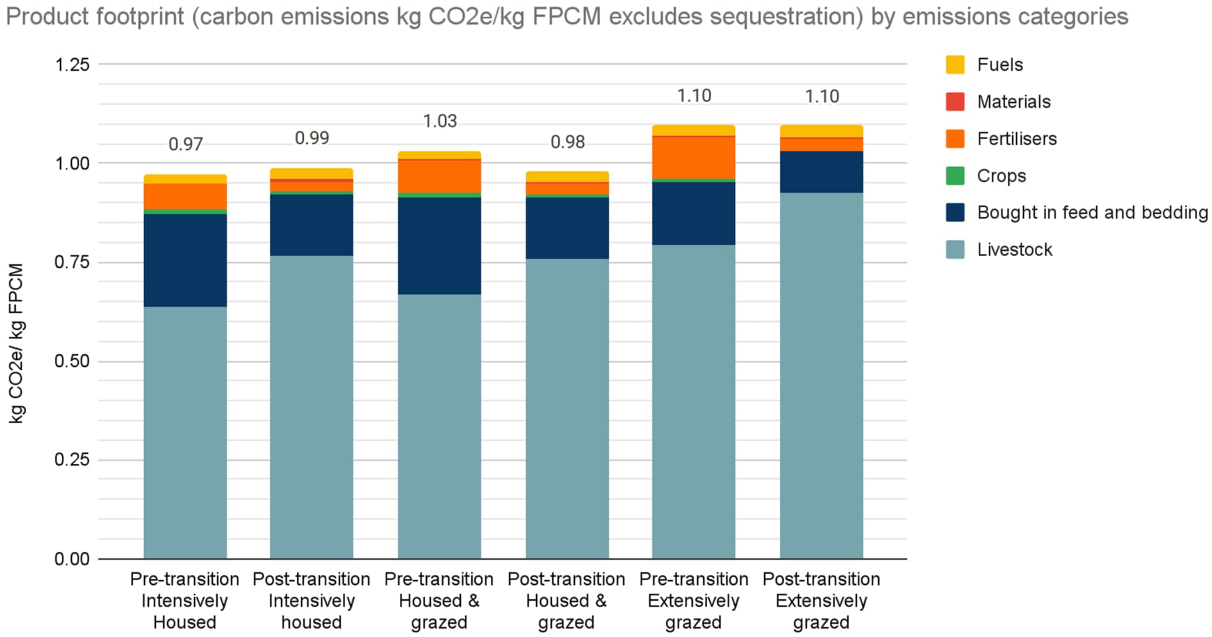

Figure 8. Product footprint (kg CO2e/kg FPCM excluding sequestration) calculated using the total carbon emissions with proportions of emissions categories represented.

Impact of regenerative practices on nature

Below is a summary of relevant literature that quantifies the impacts of the selected regenerative practices on nature. For the purposes of this assessment, nature impacts have been characterised as:

- Biodiversity
- Water quality
- Air quality
- Soil health

Rotational & holistic grazing

Rotational grazing with cattle has been shown to increase earthworm abundance on a UK farm (Hertfordshire). Earthworms act as soil 'ecosystem engineers', improving movement of water, air and nutrients through soil. Rotational grazing introduced to a three-year grass-clover ley (within an arable zero tillage system) significantly increased earthworm abundance compared to the plot without rotational grazing and compared to permanent grassland (Trickett & Warner

2022). Rotational grazing can increase the diversity of carbon sources available to earthworms, positively impacting earthworm abundance and functional group diversity within the arable rotation under evaluation.

An increase in grazing on-farm (reducing the time that cattle are housed) can positively impact dung beetle populations, as more manure is dropped in the fields as cowpats. An increase in cowpats provides habitats for dung beetle species, which play a key role in dung decomposition and can improve the efficiency of livestock production systems (through control of cattle gastrointestinal parasites). Through breaking down dung, dung beetles have been estimated to reduce GHG emissions at the dung pat and pasture ecosystem level by 7% and 12%, respectively (Study in Finland, Slade et al., 2016). Beynon et al., (2015) estimated the economic benefits associated with the ecosystem services provided by UK dung beetle species (Coleoptera: *Scarabaeidae*, *Geotrupidae*) in cattle-grazed pasture systems in the UK, these benefits include:

- reduced pest flies
- reduced gastrointestinal parasites
- reduced pasture fouling
- increased soil nutrients

Their estimates suggest that dung beetles may be currently saving the UK cattle industry c. £367 million each year: c. £354 million in conventional systems and c. £13 million in organic systems. Annual benefits per cow are greater in organic systems (£43.47) compared with conventional systems (£37.42).

Additionally, a UK research trial at Rothamsted North Wyke on rotational (cell) grazing has highlighted that cell grazing can reduce weed species within pastures, increase the cover of perennial ryegrass and maintain similar levels of white clover found within set stocking grazed areas (Rivero, Morgan & Lee, 2024). Due to the selective nature of the cattle grazers in set stocking areas, there was a clear increase in abundance of volunteer weed grass species growing within the swards (Rivero, Morgan & Lee, 2024). Additionally, nutrient leaching potential (NO_{3^-}, NH_4^+ and total P) was similar between grazing methods, despite the cell grazing method supporting, on average, a 145% higher stocking rate and grazing for 22 days longer. This suggests that the cell grazing paddocks have a lower leaching potential per kg liveweight produced. These results highlight that rotational grazing and increasing grazing time on farms can positively impact biodiversity metrics and reduce nutrient pollution.

Reduced application of nitrogen fertilisers

Excessive N fertiliser application on farms has been linked to diffuse water pollution and greenhouse gas emissions across England, prompting the design of agri-environment schemes and on farm mitigation measures aimed at reducing agricultural diffuse pollution (Zhang et al., 2017). Reducing N fertiliser rates can reduce diffuse water pollution. For example, Newell Price et al., (2011) modelled the impacts of reducing nitrogen fertiliser application on diffuse water pollution in the UK, they estimated that nitrogen leaching losses (NO_{3-}, NH_4^+ and NO_{2-}) would be reduced by up to 10%, from a 20% reduction in N fertiliser rates, which would reduce associated direct and indirect N_2O emissions, and NH_3 emissions (see table 2). Soluble phosphorus losses would be reduced by up to 10%, from a 20% reduction in P fertiliser rates, plus longer-term reductions through reduced soil P status. CO_2 emissions would be reduced as a result of lower fertiliser use and production associated emissions.

Table 2. The impact of reducing nitrogen fertiliser application on target environmental pollutants (Newell Price et al., 2011).

Direction of change for target pollutants on the area where fertiliser is applied.

Nitrogen			Phosphorus		Sediment	BOD	FIOs	Ammonia	Nitrous Oxide	Methane	Carbon Dioxide
Nitrate	Nitrite	Ammonium	Part	Sol							
↓	↓	↓	↓	↓	~	~	~	↓	↓	~	↓

Potential N fertiliser reductions would be based on the production system and farmers are recommended to follow a nutrient management guide and/or advice from a FACTs qualified advisor. For example, the nutrient management guide RB209 (AHDB, 2023) offers best practice guidance on the application of mineral fertilisers, manures and slurries to crops and grassland for target dry matters. Reductions in N fertiliser applications to the modelled different production systems (IH, HG and EG) in this project are listed in table 1 and are much larger than the 20% decrease modelled in Newall Price et al, (2011) as these estimates were provided by the financial reporting. The reduced application of N on permanent pasture and temporary grasslands would likely result in a decrease in dry matter yields. However, for the temporary pastures which were modelled as having 200kg N/ha pre-transition to 0 kg N/ha post-transition, the inclusion of clovers in these swards can supply adequate N, for example a sward with a ~40% clover cover has the potential supply 240kg N/ha (AHDB, 2023), thus allowing for the large reductions in N application rate when modelled alongside other regenerative practices (e.g. planting diverse swards). The reduction of N fertiliser applications has the potential to reduce environmental nutrient pollution, however this practice needs to be considered in tandem with other practices in order to maintain yields.

Lower Stocking Rates

Lowering stocking rates on farms can similarly reduce the amount of nutrient leaching and diffuse water pollution through a reduction of in field- deposited excreta and handled manures at the farm level (Newell Price et al., 2011). As the farm will need to produce less forage, manufactured fertiliser rates would also be reduced. Newell Price et al., (2011) suggested that nitrogen leaching losses (NO_{3-}, NH_4^+ and NO_{2-}) could be reduced by up to 20%, resulting in reduced direct and indirect N_2O emissions, and NH_3 emissions (see table 3). Particulate/soluble phosphorous and associated sediment losses would be reduced by up to 30%. Faecal indicator organisms (FIO) and biological oxygen demand (BOD; indicators of organic matter in water) would also be reduced by up to 20% in diffuse water. CH_4 and CO_2 emissions would be reduced by up to 20%. Reducing stock numbers is likely to encourage farmers to become more reliant on clover/legume based swards to reduce manufactured fertiliser N costs.

Table 3. The impact of reducing stocking rates on target environmental pollutants (Newell Price et al., 2011).

Direction of change for target pollutants at the farm scale.

Nitrogen			Phosphorus		Sediment	BOD	FIOs	Ammonia	Nitrous Oxide	Methane	Carbon Dioxide
Nitrate	Nitrite	Ammonium	Part	Sol							
↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓

Small scale farm trials in three dairy regions of New Zealand highlighted that reducing inputs of nitrogen fertiliser and purchased feed associated with a reduction in stocking rate on pastoral dairy farms, resulted in less nitrate leaching by 22% to 30%. Two out of three of these farming systems also reduced their greenhouse gas emissions, however the lower stocked systems did have an average loss of profit of approximately NZ$100/t CO_2e (Beukes et al., 2019). Lowering stocking rates on farms can reduce environmental nutrient pollution and may have knock-on impacts of reducing N fertiliser usage, however this can result in a trade off with productivity and profit of the system.

The use of diverse swards

Increasing plant diversity in grasslands can benefit multiple ecosystem functions. For example, including multispecies leys in rotations can provide benefits for improved nitrogen efficiency, nitrogen legacy effects for follow on crops, weed suppression and increased flower resources for pollinators (Malisch et al., 2024), alongside increasing the nutritive value of the forage for grazing livestock (Lüscher et al., 2014). In a study analysing biodiversity experiments in European grasslands, Hector & Bagchi (2007) found that ecosystem multi-functionality (the ability of an ecosystem to simultaneously provide multiple functions and services that benefit humans and nature) requires a great number of species, as different species influence different functions. These functions can include processes such as nutrient cycling, carbon sequestration, pollination, soil formation, water regulation, and biodiversity support. Introducing diversity into swards can contribute to increasing these associated ecosystem functions.

Integrating grass-clover-herb leys into a dairy system has been found to minimise nutrient losses, positively impact agro-biodiversity and lower the product carbon footprint of the organically managed Lindhof experimental dairy farm of Kiel University, Germany (Taube et al., 2023). The Lindhof system has demonstrated a high eco-efficiency of pasture-based milk production, with 75% of milk coming from nutritional multispecies forage mixtures. Nitrate leaching from the Lindhof system was lower compared to systems under comparable environmental conditions. A study conducted at Lindhof found pollinator abundance increased drastically within the diverse grassland leys compared to the perennial ryegrass monocultures, with 541 wild bees of 10 species in the diverse grassland leys, compared to no wild bees in the permanent grassland (Beye et al., 2022). The product carbon footprint of energy corrected milk (ECM) from the Lindhof grazing system stands at approximately 0.6 kg CO2e/ kg ECM, in contrast to >1 kg CO2e/ kg ECM attributed to conventional milk from year- round indoor systems in Germany (Taube et al., 2023).

Goh and Bruce (2005) compared perennial ryegrass- white clover mix with more diverse multi-species herbal ley mixtures for biomass yields and biological nitrogen fixation in New Zealand Pastures. Under irrigation, multi-species pastures out-yielded the ryegrass- white clover pasture in total and legume dry matter yield, which increased biological nitrogen fixation. The comprehensive multi-species pasture (containing tall fescue, cocksfoot, brome, timothy, phalaris, red clover, caucasian clover, white clover, lucerne, sulla, chicory, plantain, sheep burnet and yarrow) fixed a significantly higher amount of N_2 compared with the other less diverse lucerne or red clover based multi-species pastures and the ryegrass-white clover pasture. The results from this one- year study suggest that the multi-species pastures tend to result in higher dry matter yield, biological nitrogen fixation and legume growth compared with that of the ryegrass- white clover pasture, provided irrigation is available.

Additionally, Newell Price et al., (2011) highlighted that the use of clover in place of nitrogen fertilisers can reduce environmental pollutants with estimated reductions in NO_{3-}, NH_4^+ and NO_{2-} leaching losses by up to 20% and associated reduction in direct (up to 50%) and indirect (up to 20%) N_2O emissions, and NH_3 emissions (~50%, see table 4). Therefore, the implementation of diverse swards can provide benefits for biodiversity, ecosystem functioning and a reduction in chemical N required, whilst providing high quality feed for grazing livestock.

Table 4. The impact of using clover in grass swards to reduce N inputs on environmental pollutants (Newell Price et al., 2011).

Direction of change for target pollutants on the area of grassland.

Nitrogen			Phosphorus		Sediment	BOD	FIOs	Ammonia	Nitrous Oxide	Methane	Carbon Dioxide
Nitrate	Nitrite	Ammonium	Part	Sol							
↓	↓	↓	~	~	~	~	~	↓↓	↓↓	~	~

Reduced cultivation depth and frequency

Reduced tillage systems can improve biodiversity metrics on farms. For example, a study conducted in Denmark by Jacobsen et al., (2022) found that reducing soil disturbances improved the survival and functional diversity of ground beetles (Coleoptera: *Carabidae*) and spiders (*Araneae*), with increased activity and larger beetles consistently found under non-tilled fields compared to reduced till and conventional till. Species diversity was also higher along field edges bordering semi-natural environments such as hedgerows. These results suggest that reducing tillage can support predatory arthropod communities (invertebrates that hunt and eat other organisms), which can provide pest control at a local scale, reducing the need for chemical pesticides.

Krauss et al, (2020) utilised a 15- year field trial in Switzerland to compare tillage treatments and manure management on an organic farm. After 15 years, conversion of conventional till to reduced tillage resulted in a 25% increase in topsoil organic carbon, 32% increase in microbial biomass and 34% increase in microbial enzyme activity, with a change in microbial communities also evident. This study also found reduced tillage increased nutrients in the topsoil (0-10cm) level compared to conventional tillage (including SOC, phosphorus, potassium and fungal biomass). This practice led to increased microbial functioning in soils, improving the soil health. However, it is important to note that a DEFRA commissioned report found that tillage reduction had little effect on UK SOC stocks and was not a reliable management option to increase SOC content of UK soils (Moxley et al., 2014). Moxley et al., (2014) also suggest that the IPCC default stock change factor for tillage reduction is inappropriate to use for the UK and may overestimate SOC sequestration.

Reducing tillage/ no-till cultivations can preserve good soil structure, with the resulting soil conditions improving water infiltration rates and thereby reducing risks of particulate phosphorus and sediment loss. Newell Price et al., (2011) estimated that nitrogen leaching losses (NO_{3-}, NH_4^+ and NO_{2-}) can be reduced by up to 20%; reductions are likely to be at the higher end where manures are applied (see table 5). Indirect N_2O emissions would also be reduced, however, there is some evidence of higher direct N_2O emissions from reduced/no-till land, especially in poorly aerated soils (Rochette, 2008) and after heavy rainfall. Particulate phosphorus and associated sediment loss reductions can be up to 60% on medium/heavy soils and up to 90% on light soils, however this is highly variable by soil types. There is evidence that reducing cultivation depth and frequency can have positive impacts for biodiversity and soil health, however currently there is a lack of data around reduced tillage and SOC accumulation across different soil types in the UK.

Table 5. Impact of reducing tillage on environmental pollutants (Newell Price et al., 2011).

Effect on target pollutants where inversion (ploughed) tillage was used previously.

Nitrogen			Phosphorus		Sediment	BOD	FIOs	Ammonia	Nitrous Oxide	Methane	Carbon Dioxide
Nitrate	Nitrite	Ammonium	Part	Sol							
↓	↓	↓	↓↓	(↓)	↓↓	~	~	~	(↑)	~	↓*

( ) Uncertain.
* Plus enhanced soil carbon storage.

Trees and hedges

In addition to the carbon storage benefits that trees and hedgerows can provide, they can also offer an important habitat for other wildlife on the farm, including both functionally important and threatened species. Staley et al., (2023) suggests an increase in hedgerow extent from the current average area of 4.2 km/km^2 to around 10 km/km^2 in UK landscapes where hedges are a frequent feature, could maximise the support for farmland wildlife, increase habitat connectivity and carbon storage.

Additionally, managing hedgerows, for example, reducing cutting intensity to once every 3 years to allow for incremental growth, has strong benefits for resource provision for wildlife in the UK (Staley et al., 2018). A UK study observed that the number of hawthorn and blackthorn flowers increased under reduced cutting which resulted in larger numbers of pollinators utilising resources (Staley et al., 2018). Berry provision for overwintering wildlife was also increased for hawthorn, blackthorn and bramble. Cutting once in three years also increased the abundance and diversity of the Lepidoptera (butterflies and moths) community (Staley et al., 2018).

Image, Gardner and Breeze (2023) modelled the impact of different farmland tree-planting scenarios in the UK on bumblebee populations. They found that extending existing hedgerow networks would be the most effective way to support bumblebee populations and to ensure widespread crop pollination services for mass-flowering arable crops. Additionally, to enhance crop pollination, woodland creation plots should be more evenly distributed across the landscape rather than concentrated in a few areas. Smaller woodland plots or a mix of tree-planting methods on farms can improve pollination services and support a wider variety of bee species, not just tree-nesting specialists (Image, Gardner & Breeze 2023).

Increasing the number of hedgerows can also help to reduce sediment and associated nutrient losses by 'trapping' and lowering surface runoff volumes. Hedges can also help to protect soils from wind erosion. Newell Price et al., (2011) estimated that planting new hedges can reduce nitrogen (NO_{3-}, NH_4^+ and NO_{2-}) leaching losses and direct and indirect N_2O emissions by a small (<1%) amount; as a result of the land area (c.1%) being taken out of production (see table 6). Particulate/soluble phosphorus and associated sediment losses would be reduced by up to 20%. Faecal indicator organisms (FIO) and biological oxygen demand (BOD) losses would be reduced by a small amount (<1%) from grazed grassland fields. Initial CO_2 emissions would be increased by a small amount through hedge planting activities from soil disruption, however once established hedges will start to sequester carbon from 3 years of age (Biffi et al., 2022). To summarise, trees and hedges can provide invaluable habitats for farmland wildlife and reduce nutrient leaching alongside their potential to sequester carbon on farm.

Table 6. The impact of planting new hedges on target environmental pollutants (Newell Price et al., 2011).

Direction of change for target pollutants at the farm scale.

Nitrogen			Phosphorus		Sediment	BOD	FIOs	Ammonia	Nitrous Oxide	Methane	Carbon Dioxide
Nitrate	Nitrite	Ammonium	Part	Sol							
↓	↓	↓	↓↓	↓	↓↓	↓*	↓*	~	↓	~	↑

* Farms with livestock/manures.

Less Intensive milking regimes

No research/ data found

Change in cow breeds

No research/ data found

Introduction of multipurpose cow breeds

No research/ data found

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Appendix

- WWF Modelling Assumptions Document - the provided document outlines the data entered into the farm carbon calculator.

WWF Regenerative Dairy Modelling Assumptions Document

This document outlines the assumptions behind the data for emissions estimates in the farm carbon calculator for three dairy farm transitions. Values/ assumptions that have stayed the same in the modelled scenarios have been greyed out to help identify what's changed. Values that will be entered into the carbon reports are highlighted in bold.

Baseline: Intensively Housed

- Total area: 194 ha
  - Permanent pasture = 75.66 ha
  - Temporary pasture = 60.14 ha
  - Cropland = 48.50 ha
  - Woodland = 9.70 ha
  - Forage Area total = 160.05 ha
    - Total of PP + TP + 24.24 ha Forage Maize
  - Areas for Edit farm details page in calculator
    - Cultivated (Temp pasture + cropland)= **108.64 ha**
    - Grass (Perm pasture) = **75.66 ha**
    - Non-cropping (Woodland) = **9.70 ha**
- *Livestock*
  - Days spent housed = 365
  - Dairy Cows
    - Head = **308**
    - Milk Yield = **9663** L/cow
    - Manure - Slurry
      - 100% spread on grassland
  - Dairy heifers (>12 months)
    - Head = **86**

        - Manure - Slurry
            - 100% spread on grassland
    - Calves (<12 months)
        - Head = **86**
        - Manure - Slurry
            - 100% spread on grassland
    - Feed
        - 3115kg 18% CP Dairy blend per dairy cow *(308)
        - 960kg 18% CP Dairy blend per heifer *(86)
            - Total 18% CP Dairy blend = **1041.98 tonnes**
    - Bedding
        - 0.9 kg sawdust /cow/days housed
        - 0.9*480*365= **157.68 tonnes**
- *Fuels*
    - Total Red Diesel = 12425.20 Litres
        - Red Diesel for Winter Wheat Cultivation
            - Operations for 24.25 ha
                - 1 x Mouldboard Ploughing
                - 1 x Rolling
                - 1 x Power Harrow drilling
                - 1 x Combining
                - 4 x Spraying
                - 1 x Silage trailer/ Carting
                - 1 x Solid fertiliser spreading
                    - **2064.89** = **Litres**
        - Red Diesel for Forage Maize Cultivation
            - Operations for 24.24 ha
                - 1 x Mouldboard Ploughing
                - 1 x Rolling
                - 1 x Power Harrow drilling
                - 1 x Forage Harvester
                - 0 x Spraying
                - 1 x Silage trailer/ Carting

            - 1 x Solid fertiliser spreading
                - **2388.85** = **Litres**
        - Red diesel for Grassland
            - Operations for 339.5 ha total
                - (Temp + perm pasture area = 135.8 ha x 2.5) includes 2.5 cuts for forage conservation
                    - 2.5 x Mowing
                    - 2.5 x Tedding
                    - 2.5 x Silage carting
                - Operations for 135.8 ha (temp and perm pasture)
                    - 1 x Solid fertiliser spreading
                    - **= 7971.46 Litres**
    - Electricity - 224 KwH per cow
        - 308 Dairy cows * 224 KwH = **68992 KwH**
- *Materials*
    - Complete fencing: Stock fencing + 1 strand HT wire (half round posts)
        - **0m**
    - LDPE bale wrap (750mm x 1500m approx 33 bales per roles)
        - **10 roles**
    - LDPE film silage sheet
        - Assumption: need 2 x 11m by 42m sheets
        - 44.1 kg x 2
            - **= 88.2 kg**
    - Mains water usage
        - Assumption of [7.6 litres of blue water needed per kgFPCM]() (zero grazing production system)
            - 1 kg FPCM = 1.01 litre milk (7.6 * 1.01 = 7.68 Litres of water needed per litre of milk)
        - Total Milk yield = Milk yield per cow (9663 L) * number of dairy cows (308) = 2,976,204 L of milk
            - (Total Milk yield * 7.68 L water) / 1000 = **22857.25 m^3**

- *Inputs*
    - Permanent Pasture N required = 150 kgN/ha
        - 60% of N applied as Ammonium Nitrate (34.5%)
            - (150*0.60 = 90kgN)*75.66 ha = 6,809.4 kgN
            - (6,809.4 kgN / 34.5%)/ 1000 = 19.74 tonnes AN
        - 40% of N applied as Custom blend (24N-6P-12K)
            - (150*0.40 = 60kgN)*75.66 ha = 4539.6 kgN
            - (4539.60kgN / 24%)/1000 = 18.92 tonnes Blend
    - Temporary Pasture N required = 200 kgN/ha
        - 60% of N applied as Ammonium Nitrate (34.5%)
            - (200*0.60 = 120kgN)*60.14 ha = 7216.8 kgN
            - (7216.8 kgN / 34.5%)/1000 = 20.92 tonnes AN
        - 40% of N applied as Custom blend (24N-6P-12K)
            - (200*0.40 = 80kgN)*60.14 ha = 4811.2 kgN
            - (4811.2 kgN / 24%)/1000 = 20.05 tonnes Blend
    - Forage Maize N required = 110 kgN/ha
        - 60% of N applied as Ammonium Nitrate (34.5%)
            - (110*0.60 = 66kgN)*24.24 ha = 1599.84 kgN
            - (1599.84 kgN/ 34.5%)/1000 = 4.64 tonnes AN
        - 40% of N applied as Custom blend (24N-6P-12K)
            - (110*0.40 = 44kgN)* 24.24 ha = 1066.56 kgN
            - (1066.56 kgN/ 24%)/1000 = 4.44 tonnes Blend
    - Cereals for livestock feed
        - Winter Wheat N required = 185 kgN
            - 100% applied as Ammonium Nitrate
                - 185 kgN * 24.25 ha = 4486.25 kgN
                - (4486.25 kgN / 34.5%)/1000 = 13 tonnes AN
    - Ammonium Nitrate (34.5%) Total = **58.3 tonnes**
    - Custom blend 24-6-12 = **43.41 tonnes**
- *Crops*
    - Cereals: Winter Wheat for Livestock feed
        - **24.25 ha** * 9t/ha = **218.25 tonnes**
    - Forage: Forage Maize for livestock feed

        - **24.24 ha * 43t/ha =1042.32 tonnes**
- *Sequestration*
    - Managed hedgerows (>15 years old)
        - 10km length x 2km width per 100 ha = **19,400m length**
    - In field trees
        - 35 x 35m2 per 100 ha = **67.90 x 35m^2**
    - Woodland area
        - Average options - Mixed woodland
            - **9.70 ha**
    - Countryside stewardship
        - GS2 - Permanent grassland with very low inputs - Baseline = cattle
            - Permanent pasture area = **75.66**

Post Transition Scenario: Intensively Housed

- Total area: 194 ha
    - Permanent pasture = 75.66 ha
    - Temporary pasture = 50.44 ha
    - Cropland = 48.50 ha
    - Woodland = 19.40 ha
    - Forage Area total = 150.34 ha
        - Total of PP + TP + 24.24 ha Cereals/Peas mix
    - Areas for Edit farm details page in calculator
        - Cultivated (Temp pasture + cropland)= **98.94 ha**
        - Grass (Perm pasture) = **75.66 ha**
        - Non-cropping (Woodland) = **19.40 ha**
- *Livestock*
    - Days spent housed = 182.5
    - Dairy Cows
        - Head = **230**
        - Milk Yield = **6790** L/cow
        - Manure

                - **50% Slurry** - 100% spread on grassland
                - **50% in field manure**
    - Dairy heifers (>12 months)
        - Head = **41**
        - Manure
            - **50% Slurry** - 100% spread on grassland
            - **50% in field manure**
    - Calves (<12 months)
        - Head = **41**
        - Manure
            - **50% Slurry** - 100% spread on grassland
            - **50% in field manure**
    - Feed
        - 1396 kg 18% CP Dairy blend per dairy cow *(230)
        - 960 kg 18% CP Dairy blend per heifer *(41)
            - Total 18% CP Dairy blend = **360.44 tonnes**
    - Bedding
        - 0.9 kg sawdust/cow/days housed
        - 0.9*312*182.5= **51.25 tonnes**
- *Fuels*
    - Total Red Diesel = 6376.21 Litres
        - Red Diesel for Winter Oats (organic) Cultivation
            - Operations for 24.25 ha
                - 0 x Mouldboard Ploughing
                - 1 x Rolling
                - 0 x Power Harrow drilling
                - 1 x Direct drilling
                - 1 x Combining
                - 0 x Spraying
                - 1 x Silage trailer/ Carting
                - 0 x Solid fertiliser spreading
                    - = **1187.04 Litres**
        - Red Diesel for Cereals/Peas mix Cultivation

- Operations for 24.24 ha
    - 0 x Mouldboard Ploughing
    - 1 x Rolling
    - 0 x Power Harrow drilling
    - 1 x Direct drilling
    - 1 x Forage Harvester
    - 0 x Spraying
    - 1 x Silage trailer/ Carting
    - 1 x Solid fertiliser spreading
        - **1618.02 = Litres**
- Red diesel for Grassland forage area (151.32 ha) multiple passes
    - Operations for 152.32 ha (The temp + perm pasture area with the assumption of 60% grass forage area for 1st cut, 40% for 2nd cut and 20% for 3rd cut summed together.)
        - 1 x Mowing
        - 1 x Tedding
        - 1 x Silage carting
    - Operations for 75.66 ha (perm pasture area only)
        - 1 x Solid fertiliser spreading
            - =**3571.15 Litres**
- Electricity - 224 KwH per cow
    - 230 Dairy cows * 224 KwH = **51520 KwH**

- *Materials*
    - Complete fencing: Stock fencing + 1 strand HT wire (half round posts) - fencing materials for increased grazing and rotational grazing
        - 5000m
    - LDPE bale wrap (750mm x 1500m approx 33 bales per roles
        - 10 roles
    - LDPE film silage sheet

        - Assumption: 1 x 11m by 42m (need roughly half if outside for majority of year)
        - 44.1 kg
    - Mains water usage
        - Assumption of 7.6 litres of blue water needed per kgFPCM (zero grazing production system)
            - 1 kg FPCM = 1.01 litre milk (7.6 * 1.01 = 7.68 Litres of water needed per litre of milk)
        - Total Milk yield = Milk yield per cow (6790 L) * number of dairy cows (230) = 1,561,700 L of milk
            - (Total Milk yield * 7.68 L water) / 1000 = **11,993.86 m^3**
- *Inputs*
    - Permanent Pasture N required = 50 kgN/ha
        - 60% of N applied as Ammonium Nitrate (34.5%)
            - (50*0.60 = 30kgN)*75.66 ha = 2269.8 kgN
            - (2269.8 kgN / 34.5%)/ 1000 = 6.58 tonnes AN
        - 40% of N applied as Custom blend (24N-6P-12K)
            - (50*0.40 = 20kgN)*75.66 ha = 1513.2 kgN
            - (1513.2 kgN / 24%)/1000 = 6.31 tonnes Blend
    - Temporary Pasture N required = 0 kgN/ha
    - Forage Cereals/Peas mix N required = 60 kgN/ha
        - 60% of N applied as Ammonium Nitrate (34.5%)
            - (60*0.60 = 36kgN)*24.24 ha = 872.64 kgN
            - (872.64 kgN/ 34.5%)/1000 = 2.53 tonnes AN
        - 40% of N applied as Custom blend (24N-6P-12K)
            - (60*0.40 = 24kgN)* 24.24 ha = 581.76 kgN
            - (581.76 kgN/ 24%)/1000 = 2.42 tonnes Blend
    - Cereals for livestock feed
        - Winter Oats N required = 0 kgN
    - Ammonium Nitrate (34.5%) Total = **9.11 tonnes**
    - Custom blend 24-6-12 Total = **8.73 tonnes**
- *Crops*
    - Cereals: **Winter Oats for Livestock feed**

        - **24.25 ha** * 2.50t/ha = **60.63 tonnes**
    - Forage: Cereals/Peas mix for livestock feed
        - 24.24 ha * 25t/ha = 606 tonnes
            - Splitting 50:50
                - 303 tonnes - field beans and dry peas
                - 303 tonnes - wheat
- *Sequestration*
    - Managed hedgerows (>15 years old)
        - 10km length x 2km width per 100 ha = **19,400m length**
    - In field trees
        - 35 x 35km2 per 100 ha = **67.90 x 35m^2**
    - Woodland area
        - Average options - Mixed woodland
            - **19.40 ha**
    - Countryside stewardship (for inclusion of N fixing swards)
        - GS4 - Legume and herb-rich swards
            - Temporary pasture area = **50.44 ha**
    - SOM 0.1% increase over 5 years (for rotational grazing)
        - Depth 0.3
        - Bulk density 1.3
        - 2020 SOM = 5, 2025 SOM = 5.1%
        - Area = perm pasture **75.66 ha**

Baseline: Housed and Grazed

- Total area: 167 ha
    - Permanent pasture = 81 ha
    - Temporary pasture = 50 ha
    - Cropland = 27.65 ha
    - Woodland = 8.35 ha
    - Forage Area total = 150.65 ha

        - Total of PP + TP + 19.65 Forage Maize
    - Areas for Edit farm details page in calculator
        - Cultivated (Temp pasture + cropland)= **77.65 ha**
        - Grass (Perm pasture) = **81 ha**
        - Non-cropping (Woodland) = **8.35 ha**
- *Livestock*
    - Days spent housed = 165
    - Dairy Cows
        - Head = **247**
        - Milk Yield = **8169** L/cow
        - Manure
            - **45.21% Slurry** - 100% spread on grassland
            - **54.79% in field manure**
    - Dairy heifers (>12 months)
        - Head = **69**
        - Manure
            - **45.21% Slurry** - 100% spread on grassland
            - **54.79% in field manure**
    - Calves (<12 months)
        - Head = **69**
        - Manure
            - **45.21% Slurry** - 100% spread on grassland
            - **54.79% in field manure**
    - Feed
        - 2792 kg 18% CP Dairy blend per dairy cow *(247)
        - 960 kg 18% CP Dairy blend per heifer *(69)
            - Total 18% CP Dairy blend = **755.86 tonnes**
    - Bedding
        - 0.9 kg sawdust/cow/days housed
        - 0.9*385*165= **57.17 tonnes**
- *Fuels*
    - Total Red Diesel = 6390.51 Litres
        - Red Diesel for Winter Wheat Cultivation

            - Operations for 8 ha
                - 1 x Mouldboard Ploughing
                - 1 x Rolling
                - 1 x Power Harrow drilling
                - 1 x Combining
                - 4 x Spraying
                - 1 x Silage trailer/ Carting
                - 2 x Solid fertiliser spreading
                    - = **681.20 Litres**
        - Red Diesel for Forage Maize Cultivation
            - Operations for 19.65 ha
                - 1 x Mouldboard Ploughing
                - 1 x Rolling
                - 1 x Power Harrow drilling
                - 1 x Forage Harvester
                - 0 x Spraying
                - 1 x Silage trailer/ Carting
                - 1 x Solid fertiliser spreading
                    - = **1936.51 Litres**
        - Red diesel for Grassland total of 157.2 ha (multiple cutting)
            - Operations for 157.2 ha (The temp + perm pasture area with the assumption of 60% grass forage area for 1st cut, 40% for 2nd cut and 20% for 3rd cut summed together.)
                    - 1 x Mowing
                    - 1 x Tedder
                    - 1 x Silage trailer / carting
            - Operations for 131 ha (temp and perm pasture)
                - 1 x Solid fertiliser spreading
                    - = **3772.80 Litres**
    - Electricity - 224 KwH per cow
        - 247 Dairy cows * 224 KwH = **55328 KwH**

- *Materials*
    - Complete fencing: Stock fencing + 1 strand HT wire (half round posts)
        - **200m**
    - LDPE bale wrap (750mm x 1500m approx 33 bales per roles
        - **10 roles**
    - LDPE film silage sheet
        - Assumption: need 1 x 11m by 42m sheet
        - **44.1 kg**
    - Mains water usage
        - Assumption of 7.6 litres of blue water needed per kgFPCM (zero grazing production system)
            - 1 kg FPCM = 1.01 litre milk (7.6 * 1.01 = 7.68 Litres of water needed per litre of milk)
        - Total Milk yield = Milk yield per cow (**8169 L**) * number of dairy cows (**247**) = 2,017,743 L of milk
            - (Total Milk yield * 7.68 L water) / 1000 = **15496.27 m^3**
- *Inputs*
    - Permanent Pasture N required = 150 kgN/ha
        - 60% of N applied as Ammonium Nitrate (34.5%)
            - (150*0.60 = 90kgN)*81 ha = 7290 kgN
            - (7290 kgN / 34.5%)/ 1000 = 21.13 tonnes AN
        - 40% of N applied as Custom blend (24N-6P-12K)
            - (150*0.40 = 60kgN)*81 ha = 4860 kgN
            - (4860 kgN / 24%)/1000 = 20.25 tonnes Blend
    - Temporary Pasture N required = 200 kgN/ha
        - 60% of N applied as Ammonium Nitrate (34.5%)
            - (200*0.60 = 120kgN)*50 ha = 6000 kgN
            - (6000 kgN / 34.5%)/1000 = 17.39 tonnes AN
        - 40% of N applied as Custom blend (24N-6P-12K)
            - (200*0.40 = 80kgN)*50 ha = 4000 kgN
            - (4000 kgN / 24%)/1000 = 16.67 tonnes Blend
    - Forage Maize N required = 110 kgN/ha

        - 60% of N applied as Ammonium Nitrate (34.5%)
            - (110*0.60 = 66kgN)*19.65 ha = 1286.9 kgN
            - (1286.9 kgN/ 34.5%)/1000 = 3.76 tonnes AN
        - 40% of N applied as Custom blend (24N-6P-12K)
            - (110*0.40 = 44kgN)* 19.65 ha = 864.6 kgN
            - (864.6 kgN/ 24%)/1000 = 3.60 tonnes Blend
    - Cereals for livestock feed
        - Winter Wheat N required = 185 kgN
            - 100% applied as Ammonium Nitrate
                - 185 kgN * 8 ha =1480 kgN
                - (1480 kgN / 34.5%)/1000 = 4.29 tonnes AN
    - Ammonium Nitrate (34.5%) Total = **46.57 tonnes**
    - Custom blend 24-6-12 Total = **40.52 tonnes**
- *Crops*
    - Cereals: Winter Wheat for Livestock feed
        - 8 ha * 9t/ha = **72 tonnes**
    - Forage: Forage Maize for livestock feed
        - 19.65 ha * 43t/ha = **844.95 tonnes**
- *Sequestration*
    - Managed hedgerows (>15 years old)
        - 10km length x 2km width per 100 ha = **16,700m length**
    - In field trees
        - 35 x 35km2 per 100 ha = **58.45 x 35m^2**
    - Woodland area
        - Average options - Mixed woodland
            - **8.35 ha**
    - Countryside stewardship
        - GS2 - Permanent grassland with very low inputs - Baseline = cattle
            - Permanent pasture area = **81 ha**

Post Transition Scenario: Housed and Grazed

- Total area: 167 ha

- Permanent pasture = 81 ha
- Temporary pasture = 53.3 ha
- Cropland = 16 ha
- Woodland = 16.70 ha
- Forage Area total = 153.95 ha
  - Total of PP + TP + 19.65 Cereals/Peas mix
- Areas for Edit farm details page in calculator
  - Cultivated (Temp pasture + cropland)= **69.30ha**
  - Grass (Perm pasture) = **81 ha**
  - Non-cropping (Woodland) = **16.70 ha**

- *Livestock*
  - Days spent housed = 165
  - Dairy Cows
    - Head = **190**
    - Milk Yield = **6790** L/cow
    - Manure
      - 45.21% Slurry - 100% spread on grassland
      - 54.79% in field manure
  - Dairy heifers (>12 months)
    - Head = **34**
    - Manure
      - 45.21% Slurry - 100% spread on grassland
      - 54.79% in field manure
  - Calves (<12 months)
    - Head = **34**
    - Manure
      - 45.21% Slurry - 100% spread on grassland
      - 54.79% in field manure
  - Feed
    - 1390 kg 18% CP Dairy blend per dairy cow *(190)
    - 960 kg 18% CP Dairy blend per heifer *(34)
      - Total 18% CP Dairy blend = **297.88 tonnes**
  - Bedding

            - 0.9 kg sawdust/cow/days housed
            - 0.9*258*165= **38.31 tonnes**
- *Fuels*
    - Total Red Diesel = 5507.12 Litres
        - Red Diesel for Winter Oats Cultivation
            - Operations for 8 ha
                - 0 x Mouldboard Ploughing
                - 1 x Rolling
                - 0 x Power Harrow drilling
                - 1 x Direct drilling
                - 1 x Combining
                - 4 x Spraying
                - 1 x Silage trailer/ Carting
                - 0 x Solid fertiliser spreading
                    - =**391.60 Litres**
        - Red Diesel for Cereals/ Peas mix Cultivation
            - Operations for 19.65 ha
                - 0 x Mouldboard Ploughing
                - 1 x Rolling
                - 0 x Power Harrow drilling
                - 1 x Direct drilling
                - 1 x Forage Harvester
                - 0 x Spraying
                - 1 x Silage trailer/ Carting
                - 2 x Solid fertiliser spreading
                    - = **1311.64 Litres**
        - Red diesel for Grassland
            - Operations for **161.16** ha (The temp + perm pasture area with the assumption of 60% grass forage area for 1st cut, 40% for 2nd cut and 20% for 3rd cut summed together.)
                - 1 x Mowing
                - 1 x Tedder

        - 1 x Silage trailer / carting
      - Operations for 81 ha (perm pasture area)
        - 1 x Solid fertiliser spreading
          - = **3803.88 Litres**
  - Electricity - 224 KwH per cow
    - 190 Dairy cows * 224 KwH = **42560 KwH**
- *Materials*
  - Complete fencing: Stock fencing + 1 strand HT wire (half round posts) increase in fencing for rotational grazing
    - **1250m**
  - LDPE bale wrap (750mm x 1500m approx 33 bales per roles
    - **10 roles**
  - LDPE film silage sheet
    - Assumption: need 1 x 11m by 42m (same number of days spent grazing)
    - **44.1 kg**
  - Mains water usage
    - Assumption of 7.6 litres of blue water needed per kgFPCM (zero grazing production system)
      - 1 kg FPCM = 1.01 litre milk (7.6 * 1.01 = 7.68 Litres of water needed per litre of milk)
    - Total Milk yield = Milk yield per cow (6790 L) * number of dairy cows (190) = 1,290,100 L of milk
      - (Total Milk yield * 7.68 L water) / 1000 = **9907.97 m^3**
- *Inputs*
  - Permanent Pasture N required = 50 kgN/ha
    - 60% of N applied as Ammonium Nitrate (34.5%)
      - (50*0.60 = 30kgN)*81 ha = 2430 kgN
      - (2430 kgN / 34.5%)/ 1000 = 7.04 tonnes AN
    - 40% of N applied as Custom blend (24N-6P-12K)
      - (50*0.40 = 20kgN)*81 ha = 1620 kgN
      - (1620 kgN / 24%)/1000 = 6.75 tonnes Blend
  - Temporary Pasture N required = 0 kgN/ha

- Forage Cereals/Peas mix N required = 60 kgN/ha
  - 60% of N applied as Ammonium Nitrate (34.5%)
    - (60*0.60 = 36kgN)*19.65 ha = 707.4 kgN
    - (707.4 kgN/ 34.5%)/1000 = 2.05 tonnes AN
  - 40% of N applied as Custom blend (24N-6P-12K)
    - (60*0.40 = 24kgN)*19.65 ha = 471.6 kgN
    - (471.6 kgN/ 24%)/1000 = 1.97 tonnes Blend
- Cereals for livestock feed
  - Winter Oats N required = 0 kgN
- Ammonium Nitrate (34.5%) Total = **9.09 tonnes**
- Custom blend 24-6-12 Total = **8.72 tonnes**

- *Crops*
  - Cereals: Winter Oats for Livestock feed
    - **8 ha** * 2.5t/ha = **20 tonnes**
  - Forage: Cereals/peas mix for livestock feed
    - **19.65 ha** * 25t/ha = **491.25 tonnes**
      - Splitting 50:50
        - **245.62 tonnes wheat**
        - **245.62 tonnes field beans and peas**
- *Sequestration*
  - Managed hedgerows (>15 years old)
    - 10km length x 2km width per 100 ha = **16,700m length**
  - In field trees
    - 35 x 35km2 per 100 ha = **58.45 x 35m^2**
  - Woodland area
    - Average options - Mixed woodland
      - **16.70 ha**
  - Countryside stewardship (for inclusion of red clover in grasslands and N fixing swards)
    - GS4 - Legume and herb-rich swards
      - Temporary pasture area = **53.3 ha**
  - SOM 0.1% increase over 5 years (assumption of SOM increase for rotational grazing)

        - Depth 0.3
        - Bulk density 1.3
        - 2020 SOM = 5, 2025 SOM = 5.1%
        - Area = perm pasture **81 ha**

Baseline: Extensively Grazed

- Total area: 88 ha
    - Permanent pasture = 49.82 ha
    - Temporary pasture = 25.52 ha
    - Cropland = 8.8 ha
    - Woodland = 4.4 ha
    - Forage Area total = 79.2 ha
        - Total of TP + PP + 4.4 Forage Maize
    - Areas for Edit farm details page in calculator
        - Cultivated (Temp pasture + cropland)= **34.32 ha**
        - Grass (Perm pasture) = **49.82 ha**
        - Non-cropping (Woodland) = **4.4 ha**
- *Livestock*
    - Days spent housed = 0
    - Dairy Cows
        - Head = **141**
        - Milk Yield = **5959** L/cow
        - Manure
            - **100% in field manure**
    - Dairy heifers (>12 months)
        - Head = **31**
        - Manure
            - **100% in field manure**
    - Calves (<12 months)
        - Head = **31**

        - Manure
            - **100% in field manure**
    - Feed
        - 1300 kg 18% CP Dairy blend per dairy cow *(141)
        - 960 kg 18% CP Dairy blend per heifer *(31)
            - Total 18% CP Dairy blend = **213.06 tonnes**
    - Bedding
        - 0.9 kg sawdust/cow/days housed
        - 0.9*203*0= **0 tonnes**
- *Fuels*
    - Total Red Diesel = 2669.18 Litres
        - Red Diesel for Winter Wheat Cultivation
            - Operations for 4.4 ha
                - 1 x Mouldboard Ploughing
                - 1 x Rolling
                - 1 x Power Harrow drilling
                - 1 x Combining
                - 4 x Spraying
                - 1 x Silage trailer/ Carting
                - 1 x Solid fertiliser spreading
                    - = **374.66 Litres**
        - Red Diesel for Forage Maize Cultivation
            - Operations for 4.4 ha
                - 1 x Mouldboard Ploughing
                - 1 x Rolling
                - 1 x Power Harrow drilling
                - 1 x Forage Harvester
                - 0 x Spraying
                - 1 x Silage trailer/ Carting
                - 1 x Solid fertiliser spreading
                    - = **433.62 Litres**
        - Red diesel for Grassland
            - Operations for 75.34 ha (temp + perm pasture)

            - Assumption is one cut
                - 1 x Solid fertiliser spreading
                - 1 x Mowing
                - 1 x Tedder
                - 1 x Baler
                - 1 x Bale wrapper
                - = **1860.90 Litres**
    - Electricity - 224 KwH per cow
        - 141 Dairy cows * 224 KwH = **31584 KwH**
- *Materials*
    - Complete fencing: Stock fencing + 1 strand HT wire (half round posts)
        - **200m**
    - LDPE bale wrap (750mm x 1500m approx 33 bales per roles)
        - **14 roles (enough for 440 bales)**
    - LDPE film silage sheet
        - Assumption: grass baled and wrapped no silage pit
        - **0 kg**
    - Mains water usage
        - Assumption of <u>7.6 litres of blue water needed per kgFPCM</u> (zero grazing production system)
            - 1 kg FPCM = 1.01 litre milk (7.6 * 1.01 = 7.68 Litres of water needed per litre of milk)
        - Total Milk yield = Milk yield per cow (5959 L) * number of dairy cows (141) = 840,219 L of milk
            - (Total Milk yield * 7.68 L water) / 1000 = **6452.88 m^3**
- *Inputs*
    - Permanent Pasture N required = 150 kgN/ha
        - 60% of N applied as Ammonium Nitrate (34.5%)
            - (150*0.60 = 90kgN)*49.82 ha = 4483.8 kgN
            - (4483.8 kgN / 34.5%)/ 1000 = 13 tonnes AN
        - 40% of N applied as Custom blend (24N-6P-12K)
            - (150*0.40 = 60kgN)*49.82 ha =2989.2 kgN

            - (2989.2 kgN / 24%)/1000 = 12.46 tonnes Blend
    - Temporary Pasture N required = 200 kgN/ha
        - 60% of N applied as Ammonium Nitrate (34.5%)
            - (200*0.60 = 120kgN)*25.52 ha =3062.4 kgN
            - (3062.4 kgN / 34.5%)/1000 = 8.88 tonnes AN
        - 40% of N applied as Custom blend (24N-6P-12K)
            - (200*0.40 = 80kgN)*25.52 ha = 2041.6 kgN
            - (2041.6 kgN / 24%)/1000 = 8.51 tonnes Blend
    - Forage Maize N required = 110 kgN/ha
        - 60% of N applied as Ammonium Nitrate (34.5%)
            - (110*0.60 = 66kgN)*4.4 ha = 290.4 kgN
            - (290.4 kgN/ 34.5%)/1000 = 0.84 tonnes AN
        - 40% of N applied as Custom blend (24N-6P-12K)
            - (110*0.40 = 44kgN)*4.4 ha = 193.6 kgN
            - (193.6 kgN/ 24%)/1000 = 0.81 tonnes Blend
    - Cereals for livestock feed
        - Winter Wheat N required = 185 kgN
            - 100% applied as Ammonium Nitrate
                - 185 kgN * 4.4 ha =814 kgN
                - (814 kgN / 34.5%)/1000 = 2.36 tonnes AN
    - Ammonium Nitrate (34.5%) Total = **25.07 tonnes**
    - Custom blend 24-6-12 Total = **21.77 tonnes**
- *Crops*
    - Cereals: Winter Wheat for Livestock feed
        - **4.4 ha** * 9t/ha = **39.6 tonnes**
    - Forage: Forage Maize for livestock feed
        - **4.4 ha** * 43t/ha = **189.20 tonnes**
- *Sequestration*
    - Managed hedgerows (>15 years old)
        - 10km length x 2km width per 100 ha = **8,800m length**
    - In field trees
        - 35 x 35km2 per 100 ha = **30.80 x 35m^2**
    - Woodland area

        - Average options - Mixed woodland
            - **4.4 ha**
    - Countryside stewardship
        - GS2 - Permanent grassland with very low inputs - Baseline = cattle
            - Permanent pasture area = **= 49.82 ha**

Post Transition Scenario: Extensively Grazed

- Total area: 88 ha
    - Permanent pasture = 53.68 ha
    - Temporary pasture = 25.52 ha
    - Cropland = 0 ha
    - Woodland = 9 ha
    - Forage Area total = 79.2 ha
        - Total of TP + PP
    - Areas for Edit farm details page in calculator
        - Cultivated (Temp pasture + cropland)= **25.25 ha**
        - Grass (Perm pasture) = **53.68 ha**
        - Non-cropping (Woodland) = **9 ha**
- *Livestock*
    - Days spent housed = 0
    - Dairy Cows
        - Head = **114**
        - Milk Yield = **4967** L/cow
        - Manure
            - **100% in field manure**
    - Dairy heifers (>12 months)
        - Head = **20.5**
        - Manure
            - **100% in field manure**
    - Calves (<12 months)
        - Head = **20.5**

        - Manure
            - **100% in field manure**
    - Feed
        - 650 kg 18% CP Dairy blend per dairy cow *(114)
        - 960 kg 18% CP Dairy blend per heifer *(20.5)
            - Total 18% CP Dairy blend = **93.78 tonnes**
    - Bedding
        - 0.9 kg sawdust/cow/days housed
        - 0.9*155*0= **0 tonnes**
- *Fuels*
    - Total Red Diesel = **1925.62 Litres**
        - Red diesel for Grassland
            - Operations for 79.20 ha (temp + perm pasture) Assumption is one cut
                - 1 x Mowing
                - 1 x Tedder
                - 1 x Baler
                - 1 x Bale wrapper
            - Operations for 53.68 ha (perm pasture area)
                - 1 x Solid fertiliser spreading pass
                    - = **1925.62 Litres**
    - Electricity - 224 KwH per cow
        - 114 Dairy cows * 224 KwH = **25536 KwH**
- *Materials*
    - Complete fencing: Stock fencing + 1 strand HT wire (half round posts)
        - 200m
    - LDPE bale wrap (750mm x 1500m approx 33 bales per roles
        - 14 roles (enough for 440 bales)
    - LDPE film silage sheet
        - Assumption = no sheet required as no forage conservation
            - 0 kg

- Mains water usage
    - Assumption of 7.6 litres of blue water needed per kgFPCM (zero grazing production system)
        - 1 kg FPCM = 1.01 litre milk (7.6 * 1.01 = 7.68 Litres of water needed per litre of milk)
    - Total Milk yield = Milk yield per cow (4967.00 L) * number of dairy cows (114) = 566,238 L of milk
        - (Total Milk yield * 7.68 L water) / 1000 = **4348.71 m^3**
- *Inputs*
    - Permanent Pasture N required = 50 kgN/ha
        - 60% of N applied as Ammonium Nitrate (34.5%)
            - (50*0.60 = 30kgN)*53.68 ha = 1610.4 kgN
            - (1610.4 kgN / 34.5%)/ 1000 = 4.67 tonnes AN
        - 40% of N applied as Custom blend (24N-6P-12K)
            - (50*0.40 = 20kgN)*53.68 ha =1073.6 kgN
            - (1073.6 kgN / 24%)/1000 = 4.47 tonnes Blend
    - Temporary Pasture N required = 0 kgN/ha
    - Ammonium Nitrate (34.5%) Total = **4.67 tonnes**
    - Custom blend 24-6-12 Total = **4.47 tonnes**
- *Crops - No cropland*
- *Sequestration*
    - Managed hedgerows (>15 years old)
        - 10km length x 2km width per 100 ha = **8,800m length**
    - In field trees
        - 35 x 35km2 per 100 ha = **30.80 x 35m^2**
    - Woodland area
        - Average options - Mixed woodland
            - **9 ha**
    - Countryside stewardship (for inclusion of red clover in grasslands and N fixing swards)
        - GS4 - Legume and herb-rich swards
            - Temporary pasture area = **25.52ha**

- SOM 0.1% increase over 5 years (assumption of SOM increase for rotational grazing)
  - Depth 0.3
  - Bulk density 1.3
  - 2020 SOM = 5, 2025 SOM = 5.1%
  - Area = perm pasture **53.68 ha**
