Qualitative Impact Assessment of Land Management Interventions on Ecosystem Services (“QEIA”)

Report-3 Theme-2: Greenhouse Gases

30- June-2023

Qualitative impact assessment of land management interventions on Ecosystem Services

Report-3 Theme-2: Greenhouse Gases (GHG)

30-June-2023

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This report is one of a set of reviews by theme:

Braban, C.F., Nemitz, E., Drewer, J. (2023). *Qualitative impact assessment of land management interventions on Ecosystem Services ("QEIA").* Report-3 Theme-1: Air Quality (Defra ECM_62324/UKCEH 08044)

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Williams, J.R., Newell Price, J.P., Williams, A.P., Bowes, M.J., Hutchins, M.G. & Qu, Y. et al. (2023). *Qualitative impact assessment of land management interventions on Ecosystem Services ("QEIA")*. Report-3, Theme-4: Water (Defra ECM_62324/UKCEH 08044)

Staley, J.T., Botham, M.S., Broughton, R.K., Carvell, C., Pywell, R.F., Wagner, M. & Woodcock, B.A. (2023). *Qualitative impact assessment of land management interventions on Ecosystem Services ("QEIA")*. Report-3 Theme-5A: Biodiversity - Cropland (Defra ECM_62324/UKCEH 08044)

Keenleyside, C.B. & Costa Domingo, G. (2023). *Qualitative impact assessment of land management interventions on Ecosystem Services ("QEIA")*. Report-3 Theme-5B: Biodiversity - Grassland (Defra ECM_62324/UKCEH 08044)

Maskell, L. & Norton, L. (2023). *Qualitative impact assessment of land management interventions on Ecosystem Services ("QEIA")*. Report-3 Theme-5C: Biodiversity - Semi-Natural Habitats (Defra ECM_62324/UKCEH 08044)

Siriwardena, G.M. (2023). *Qualitative impact assessment of land management interventions on Ecosystem Services ("QEIA")*. Report-3 Theme-5D: Biodiversity - Integrated System-Based Actions (Defra ECM_62324/UKCEH 08044)

Bentley, L., Feeney, C., Matthews, R., Evans, C.D., Garbutt, R.A., Thomson, A. & Emmett, B.A. (2023). *Qualitative impact assessment of land management interventions on Ecosystem Services ("QEIA")*. Report-3 Theme-6: Carbon Sequestration (Defra ECM_62324/UKCEH 08044)

Short, C., Dwyer, J., Fletcher, D., Gaskell P., Goodenough, A., Urquhart, J., McGowan, A.J., Jones, L. & Emmett, B.A. (2023). *Qualitative impact assessment of land management interventions on Ecosystem Services ("QEIA")*. Report-3.7: Cultural Services (Defra ECM_62324/UKCEH 08044)

A list of all references used in the reports is also available as a separate database.

Foreword

The focus of this project was to provide a rapid qualitative assessment of land management interventions on Ecosystem Services (ES) proposed for inclusion in Environmental Land Management (ELM) schemes. This involved a review of the current evidence base by ten expert teams drawn from the independent research community in a consistent series of ten Evidence Reviews. These reviews were undertaken rapidly at Defra's request and together captured more than 2000 individual sources of evidence. These reviews were then used to inform an Integrated Assessment (IA) to provide a more accessible summary of these evidence reviews with a focus on capturing the actions with the greatest potential magnitude of change for the intended ES and their potential co-benefits and trade-offs across the Ecosystem Services and Ecosystem Services Indicators.

The final IA table captured scores for 741 actions across 8 Themes, 33 ES and 53 ES-indicators. This produced a total possible matrix of 39,273 scores. It should be noted that this piece of work is just one element of the wider underpinning work Defra has commissioned to support the development of the ELM schemes. The project was carried out in two phases with the environmental and provisioning services commissioned in Phase 1 and cultural and regulatory services in a follow-on Phase 2.

Due to the urgency of the need for these evidence reviews, there was insufficient time for systematic reviews and therefore the reviews relied on the knowledge of the team of the peer reviewed and grey literature with some rapid additional checking of recent reports and papers. This limitation of the review process was clearly explained and understood by Defra. The review presented here is one of the ten evidence reviews which informed the IA.

Acknowledgments

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INDEX OF ACTION CODES IN THIS REPORT

1. INTRODUCTION

Within each Action section.

2. OUTCOMES

Service	Indicators for services flow
Global, regional & local climate regulation	Above ground carbon sequestration
	Below ground Carbon sequestration
	Recapturing carbon on farms
	Reduction in greenhouse gasses (agriculture)

The intended outcomes of this section are an understanding of:

- the effect of low-intensity grazing systems on GHG mitigation
- identification of the existing knowledge gaps that require further investigation
- the increased capacity of farm slurry and manure stores to improve timing of slurry applications
- measures which reduce the release of GHG from slurries and manure into the atmosphere.
- the effects of diluting slurry to improve soil infiltration, coupled with irrigation measures to reduce the release of GHG into the atmosphere and nutrient losses to water systems.
- replacement of nitrogen fertiliser with clover in pasture or arable cropping systems.
- methods of creating and managing coastal habitats to create environmental benefits.
- active diet and feeding management planning on GHG Mitigation and identification of the existing knowledge gaps that require further investigation.
- The main outcomes of this section are focused around the capture and reuse of Carbon Dioxide within plant production environments and the overall impact on reduction of total CO2 production.
- The intended outcome of this section is to explore the GHG effect of the use of more high starch diets and the use of reduced crude protein in diets.
- The intended outcomes include a switch to efficient / precision fertiliser application machinery resulting in reduced application of artificial fertiliser, reduced run-off and improved air quality.
- The intended outcomes from this section include the identification of measures which reduce the release of GHG from slurry and digestate into the atmosphere through separate storage of different fractions.
- The intended outcomes from this section include measures which reduce the release of GHG from the export of manure and slurry.
- The intended outcome of this component is the understanding of the use of ad lib feeding systems to reduce emissions.
- The intended outcomes of this section are to Optimise livestock feeding strategy to match animal requirements and to understand the effect this will have on GHG emissions.
- The intended outcome of this report is an understanding of the impact of phase feeding on GHG emissions of livestock.
- The intended outcomes from this section are an evaluation of the use of very low input permanent grassland on overall GHG emissions.
- The intended outcomes from this section include the understanding of the effect of no use fertiliser as a measure to reduce GHG emissions.
- The intended outcome of this section is the building of evidence to support arguments for maintaining genetic diversity by rearing rare breed livestock.
- The intended outcome of this section is the understanding of the effect of replacing sheep grazing with cattle grazing on overall GHG output.
- This study seeks to summarise current knowledge around the impact of farm animal genetic improvement on GHG Mitigation.

- This report seeks to indicate the currently understood effect of productivity improvement on GHG mitigation.
- The intended outcome from this review is an understanding of the impact of improved Animal Health on GHG Mitigation.

3. MANAGEMENT BUNDLES

3.1. RESTORATION, MANAGEMENT AND ENHANCEMENT/GRAZING TO REDUCE GREENHOUSE GASES

This Bundle is focused on grazing management strategies and their effects on greenhouse gas production at macro and micro level. There are known effects on biodiversity, but less evidence around GHG production.

The sub-section is primarily focused on the delivery of Global, regional & local climate regulation ecosystem services. The main outcome will be changed practice at a farm level which Improves the GHG balance and reduces environmental impact.

3.1.1. ECCM-014: Use low-intensity grazing systems using biodiverse sward mixtures

This section is focused on changes which can be mitigated through alteration of grass species and animal type and number. The main outcome will be changed practice at a farm level which reduces GHG emissions through:

1) increased absorption/sequestering due to altered grass species
2) Reduced emissions through altering the type and number of animals feeding on the grass mix

Climate Change is recognised as the most significant challenge of our time. Multiple human activities impact on climate change. Ruminant animal production is one of these challenges, and research activity is being undertaken across the globe to determine methods of reducing its impact. GHG emissions from ruminants are affected by:

1) The number of animals
2) The type of animals
3) The diet on which the animals are fed
4) The productiveness of each animal (output vs input)

Multiple methods of mitigating the environmental impact of ruminants are being investigated globally, and grazing management is potentially one of the most important.

3.1.1.1. Causality

A summary of the literature shows that the use of low intensity grazing systems does reduce overall GHG emissions and that there is a strong level of understanding of methods and mechanisms by which this is achieved. Multiple factors affect the ongoing impact at a practical level and consequently this section is rated Amber for the purpose of this report.

The improved GHG balance is mainly a result of reduced animal numbers, potential reductions in the use of artificial fertiliser and the ability of the grassland to sequester GHG. The link is established. However, what is less clear from the literature is the extent of the effect. Below is a summary of the identified evidence.

The EIP-Agri Focus Group published a “Grazing for carbon” report (Van den Pol *et al.,* 2018). This paper brought together much of the evidence around grazing practices which contribute to carbon capture, and also to GHG mitigation. They state that *"The potential of grasslands as a carbon (C) sink in Europe is large. However, it is unclear to what extent different grazing systems can contribute to C sequestration"*

Understanding is lacking at a macro level across the UK around the Carbon content of soils, the grass species which are present on each soil type and how both factors change over time. It is acknowledged at a practical level that species dominance in MSS changes over time, changing the ability of the grassland to sequester or trap carbon. The changing species mix also alters animal performance and hence overall GHG emissions per unit of output. In addition, the changing species mix also alters the carrying capacity of the land, meaning that careful management is needed to avoid overgrazing and sub-optimal animal nutrition. This means that the actual impact of MSS at a practical (as opposed to research) level is not completely clear.

Van den Pol *et al.*, 2018, states *"The extent to which grazing livestock contribute to global greenhouse gas emissions or to their reduction remains a question that is still debated (e.g. Garnett et al., 2017; Koncz et al., 2017). However, it is clear that grazed grasslands contribute significantly to the rural economies of many European countries, are part of their cultural heritage and provide a range of valuable ecosystem services. For example, provision of feed for herbivores, combatting soil erosion, regulation of water regimes, supporting biodiversity (Gaujour et al., 2012)."*

The above statement is accurate for England and the rest of the UK. Grasslands are valuable and confer a range of economic, environmental and social benefits. However, as the following statement highlights, the level of these benefits is substantially impacted by the activity which takes place on each parcel of land.

Van den Pol *et al.*, 2018, also states "Grasslands can potentially contribute either positively or negatively, depending mostly on the intensity of management activities, to all groups of ecosystem services. Grazed grasslands will most likely remain a major element in the European landscapes in the future. This means that it is relevant to consider how they can be managed so that they maintain or increase the sequestration of C in their soils." (EU report on grazing for Carbon)

A key component which impacts the GHG output resulting from the management and use of land is the amount of artificial fertiliser which is applied. In general, it is accepted that Multispecies swards are usually less dependent on the application of chemical fertiliser. The following section is directly lifted from a review of the impact of multispecies swards in beef and sheep grazing species by Lowe *et al.,* (2021).

"There is evidence of many positives aspects of incorporating MSS in beef and sheep systems. MSS provide an opportunity to increase sward diversity whilst producing similar herbage yields to PRG swards, but with 45% less nitrogen fertiliser/ha/year (Grace et al., 2018), thus increasing nitrogen use efficiency." Lowe et al (2021)

The reduction in use of Nitrogen fertiliser is associated with a very significant reduction in the production of NO_2 and CO_2. This can be viewed as one of the significant benefits of utilising multi-species grass.

With regard to a reduction in grazing density, this is clearly associated with a reduction in overall GHG emissions as a direct result of reduced livestock numbers. However, the impact on GHG per unit of production is less clear. If the individual livestock continue to grow at the same rate as previously, GHG per unit of output will remain very similar, if growth rates drop as a result of the management changes, GHG emissions per unit of output will rise. Aklilu et al (2017), found that a reduction in stocking density was associated with increases in intensity (output per kg) of greenhouse gases, suggesting that the overall impact of low intensity grazing needs to be very clearly thought through prior to implementation as it may not have the intended effect.

3.1.1.2. Co-Benefits and Trade-offs

There are a number of co-benefits associated with multi-species grass including air quality benefits, soil compositional benefits (over an extended period of time), water quality benefits (mainly through reduced run-off and leeching) and reduced chemical fertiliser use. Multi-species are also likely to enable additional sequestering of Carbon.

[TOCB Report-3-3 Soils]: Grazing at lower stocking rates and increasing the plant species diversity of grass swards could potentially have limited positive benefits for soil erosion and soil structure, although the evidence for this is limited. The timing and location of grazing can often be more important for poaching risk than the stocking rate (Newell Price *et al.,* 2013).

[TOCB Report-3-2 GHG **ECCM-014**] Where stocking rates and intensity are reduced as a result of matching grazing to the requirements of the habitat there may be a reduced burden on fresh waters from nutrient run-off. Decreased grazing by livestock can sometimes lead to increased grazing by wild animals such as deer that can lead to unexpected biodiversity outcomes at the landscape level (DeGabriel et al, 2011). Increased soil erosion by grazing can lead to off-site impacts on fresh-water habitats by increased surface run-off risk. There may also be trade-offs between different biodiversity objectives for the grassland e.g. between floristic diversity and habitats for breeding waders.

3.1.1.3. Magnitude

Impact on GHG reduction

The evidence around the magnitude of the effect of MSS is not conclusive. A range of literature exists but the bulk of this work has been carried out under non-commercial conditions and not at field-scale. Vogeler *et al.,* (2017) modelled the potential effect of replacing 50% of the area of a beef and sheep farm with diverse swards. The model suggested that farm profit would increase by 16% but this needs to be tested by field scale projects across a range of scenarios and land types (Lowe at al. 2021).

Literature surrounding the impact of MSS on CH_4 emissions for sheep and beef cattle is scarce and the majority is conducted in vitro. However, most of the work which has been published indicates that there is some effect (at least at a laboratory level). MSS have been shown to reduce CH_4 (g/kg DMI) in grazing dairy cows (Carmona-Flores *et al.,* 2020) and Niderkorn *et al.,* (2019) observed similar CH_4 emissions from lambs grazing PRG or MSS but reported a 22% reduction in CH_4 (g/kg DMI) in lambs grazing pure chicory compared to PRG. Angus X Holstein and Holstein steers grazed on PRG produced significantly higher CH_4 emissions of 190 g/day, yielding 25.9 g/kg DMI, compared to cows grazed on three different MSS mixtures (~120 g/day, yielding ~18 g/kg DMI; Humphries et al, 2021b). Conversely, another study reported that grazing Jersey cows on six species MSS, compared to a PRG and white clover mix increased CH_4 emissions by 18% (Loza et al, 2021). Similar, conflicting research is reported in sheep, with some studies reporting positive effects of chicory in mitigating CH_4 emissions, but no effect when diverse multi-species sward are grazed (Niderkorn et al, 2019).

This suggests that it is the individual plant species within the swards which influence the CH_4 emissions released from rumination. There is limited evidence available about the ideal species mix to best mitigate GHG emissions. Additional research is needed to establish the ideal sward mixtures and ingredient proportions which are most applicable to a range of land types, management systems and grazing species. This should be delivered through a combination of on-farm trials, in vitro or through modelling work.

Impact on Animal Performance

There are indications that MSS enable raised performance in sheep. Grace *et al.,* (2019) studied four pasture types for sheep grazing including (i) PRG sward, (ii) PRG and white clover sward (iii) six species MSS (PRG, timothy, white clover, red clover, plantain and chicory), (iv) nine species MSS (the previous six species with the addition of cocksfoot, greater birdsfoot trefoil and yarrow).

There is evidence that the use of multispecies swards can be associated with a reduction in parasite burden, which will be linked to performance improvement and a potential reduction in anthelmintic use (Grace *et al.,* 2019).

The following information is predominantly taken from a review paper authored in 2021 by Drs. Denise Lowe, Lynda Perkins, Naomi Rutherford and Francis Lively from the Agri-Food and Biosciences Institute.

Sheep Performance

Female sheep grazing the two MSS swards displayed increased liveweight and body condition scores during early lactation when compared to ewes grazing the PRG and PRG/white clover swards. The six species MSS resulted in the greatest 6 week weight and weaning weight of lambs and the nine species MSS was similar to lambs grazed on PRG/White clover. The Lowe (2021) paper suggests that the improved lamb performance to six weeks was due to improved quantity and quality of milk resulting from improved ewe condition (based on evidence from Grace et al., 2019 and Danso et al., 2016). Hutton et al., (2011) reported that ewes grazing herb-legume swards produced 17-25% more milk than the ewes grazing predominately PRG swards, although in this particular study, milk composition (measured on days 7, 14 and 21 of lactation) did not differ between grazing treatments.

In addition, lamb survival to 75 days of age has been reported to be greater for those grazing a herb sward than those on a PRG / white clover pasture (Kenyon et al., 2010). Grace et al., (2019) also reported that of the four pasture types, lambs grazing PRG had the greatest days to slaughter. The literature on pastures containing three functional groups is limited, however, numerous studies have reported improved post-weaning growth rates of lambs grazing herb-legume (two functional group) swards (Golding et al., 2011, Fraser et al., 2004, Moorhead et al., 2002, Speijers et al., 2004, Kenyon et al., 2017). These improvements in lamb performance are thought to be due to the higher nutrient value and/or herbage intakes of herb-legume swards than PRG swards (Fraser et al., 2004, Golding et al., 2011). Over a three-year period, Kenyon et al., (2017) reported that a chicory-plantain-clover pasture and plantain-clover pasture produced 12.4 and 14.5% more kg live weight per hectare, respectively than a grass-clover pasture; indicating that increased levels of production could be obtained over more than just one grazing season.

Cattle Performance Inconclusive

The following are direct excerpts from the Lowe *et al.,* (2021) paper as they outline existing knowledge very effectively:

The effect of multi-species sward pastures on daily live weight gains (DLWG) have been shown to be inconsistent within cattle studies. An individual study documented an increased DLWG of 0.33 kgd-1 for individual grazing seasons and no effect other years for cows and calves (Tracy and Faulkner, 2006). Inconsistent effects of MSS on DLWG has also been reported by Giebelhausen et al., (2007). More recently increases in DLWG and animal performance were reported in calves grazed on diverse swards composed of grasses, herbs and legumes, however, results were, again, inconsistent and varied depending on year and season (Jerrentrup et al., 2020).

Similarly, no differences were found when Angus-Holstein steers were grazed on either herbal (17 species), 'Biomix' (12 species) or 'Smartgrass' (6 species) multi-species sward combination compared to PRG (Humphries et al., 2021a). A study evaluating the effect of a chicory and PRG sward mix compared to PRG reported that the chicory and PRG mixture effect on live weight gain was consistent with that of the PRG control treatment (Marley et al., 2014). This is in accordance with a similar study evaluating the effect of chicory and PRG on beef steers (Parish et al., 2012). These studies are also consistent with research investigating MSS pastures and dairy cow milk yield performance (Totty et al., 2013). Despite this, finishing steers on alfalfa and chicory during the summer months has also been documented to increase DLWG compared to steers fed burmudagrass, cowpea and pearl millet swards (Schmidt et al., 2013).

This inconsistency would suggest that seasonality (and in turn nutritive value) is a stronger influence than sward diversity in increasing DLWG of cattle. Despite this, a potential for DLWG and live weights to be increased as a result of diverse sward mixtures has been highlighted, particularly in very dry summer months, if the supply or nutritive value of PRG or white clover becomes limited (Elgersma et al., 2000). The potential *is directly reflected by improvements in feeding values of leys over the last 15 years (Kemp et al., 2010; Grace et al., 2018). Similarly, large ruminants such as beef cattle graze less selectively, but equally have a reduced bite depth when swards are shorter, compared to small ruminants (Martin et al., 2020), highlighting the importance of sward length when considering a multi-species sward mixture. Research suggests, the link between beef cattle and lamb nutrition and MSS could be bridged by carefully combining swards species such as cocksfoot, lucerne and chicory, which are rich in minerals (due to being deep rooting) while also being appropriate for soil type and rainfall levels in NI (Connolly et al., 2009; Pirhofer-Walzl et al., 2011). For example; chicory and plantain are high yielding herb species which are particularly productive in the summer months (Cranston et al., 2015). However, grazing on chicory and plantain in the winter is less successful where the nutritive value and persistence is reduced (Sanderson et al., 2003).*

The use of herbage in multi-species sward combinations contain higher levels of crude protein and acid detergent fibre (Jerrentrup et al., 2020). This has the potential to improve animal production, while maintaining or acting favourably to rumen health by ensuring optimal digestion by rumen bacteria (O'Callaghan et al., 2018; Smith et al., 2020). Other studies, however, have disputed this. For example; when PRG was studied alongside a mix of Leptostigma setulosum and Centella spp., crude protein levels were higher in the PRG group (White et al., 2004). This could have detrimental effects on forage digestibility and may also result in urea being recycled to cover the shortfall (Mutsvangwa et al., 2016). Low crude protein is also associated with reduced nutrient digestibility and reduced DM intake, ultimately resulting in a reduced DLWG and impacting in overall animal production.

3.1.1.4. Timescale

The effect of the multi-species sward is likely to be seen from about 8 weeks after establishment and the effects will persist for a number of years. Effective maintenance of the sward is required to ensure that benefits continue. The different species within the sward can have different lifespans which are often affected by different grazing systems, weather conditions, soil conditions etc. Consequently the GHG benefits of the sward will change as it ages.

The impact of reduced stocking density is immediate at a local level, although there will be no significant national effect unless the size of the national herd reduces.

3.1.1.5. Spatial Issues

Multi-species swards can be established almost anywhere and are broadscale. The system can be applied to a range of enterprises including beef, sheep and dairy. Multi-species can be applied on a wide range of land types, although slightly different grass mixes may be required to suit land conditions. There will be limitations on reseeding in upland areas of permanent grassland e.g. moorland, common land, mountain areas. Reseeding is most likely to be done on temporary grassland and enclosed permanent grassland. Farmers will reseed by either ploughing or cultivation which can release soil carbon. Alternatively, farmers reseed by direct drilling after application of herbicide to reduce competition from existing grasses such as PRG. The impacts of reseeding on soil carbon if established by tilling, and herbicide use for no-till methods need to be considered in establishing the MSS

3.1.1.6. Displacement

Displacement is a possibility with mixed species swards. As has already been highlighted, there is a potentially negative economic impact and this can result in less economically sustainable farms, a reduction in livestock numbers and, ultimately, increased imports of food products to compensate for the reduced UK product.

In addition, there is the potential for meat or milk from animals to have a higher GHG cost per unit of production if they have been fed at a level which is below performance potential. Animals which do not achieve their performance potential use a higher proportion of their intake to support basal maintenance.

3.1.1.7. Maintenance and Longevity

Literature (and practical experience) shows that multi-species swards are harder to manage than Perennial Ryegrass swards and that there are often problems with persistency in the sward (Lowe *et al.,* 2021). Changing the species in a grass mix changes the performance of the grass, with the different species growing at different points in the year. As a result, increased management time is required to ensure that the swards meet the needs of the animal and that the swards remain persistent, with an appropriate species mix.

Early management of the sward is really important after establishment, and will impact the persistence and overall success of implementation. The EIP Wales MSS project has provided evidence that rotational grazing is the most appropriate management method (as opposed to set-stocking which is often used on-farm). AHDB (2020) state that rotational grazing (as opposed to set stocking) results in better sward quality and persistence and also tends to encourage more equal grazing by the animals.

Cranston et al, (2015) found that PRG and white clover had comparable DM production, but growth patterns were variable.

The Lowe paper states that *"balancing swards with seasonality, financial implications and grazing animal species will be complex and needs a consensus from many research partners".*

They note that, despite their comprehensive review, there is still a significant lack of evidence. As a result, they recommend the need for a further comprehensive analysis of the impact of multi-species sward grazing on animal performance, health, disease control, in addition to environmental impacts, soil quality, financial viability and overall suitability to farm management is essential. It is likely that the reason for the variation in findings about the performance of multispecies swards is a result of the multiplicity of factors which influences overall performance. These factors include, but are not limited to: land type, weather conditions, soil conditions, species mix and their interaction with one another, grazing type and intensity, type of stock which are being grazed etc, Study of the impact of MSS may therefore benefit from standardisation of species mixes and other influencing factors to allow the scientific community to more effectively determine effects.

According to Provenza 1996 and Tracy and Faulkner 2006 the benefits of cattle and sheep grazing on diverse swards may include reduced toxin consumption, increased rumination and maintenance of ruminal microflora. There is considerable literature surrounding the impact of MSS on ewe, lamb and dairy cow performance, but the literature surrounding beef is considerably more limited.

3.1.1.8. Climate Adaptation or Mitigation

The use of multi-species grass is affected by climatic conditions. As climate changes, different species mix may be necessary. Multispecies likely to increase tolerance to drought and wet soils.

3.1.1.9. Climate Factors / Constraints

There are no major soil constraints around the establishment of MSS, provided that appropriate species are chosen for each soil type and environment. However, there is a clear economic constraint around the cost of reseeding and establishment. Potential constraints around the establishment and use of multi-species grass can be summarised as follows:

1) The cost of establishment of the new sward
2) The increased management time to properly manage the sward
3) The potential performance impact of the multi species sward
4) The economic impact of reduced stocking density of animals

3.1.1.10. Benefits and Trade-offs to Farmer/Land manager

Several benefits result from the use of multi-species grass:

According to Lowe at al. 2021,*"Herb species such as plantain and cocksfoot are characterised by their deep root system, which assists in drought resistance and resource utilisation from deeper soil layers (Jing et al., 2017). In addition, herb and legume swards to have a higher feeding value for ruminants than PRG swards (Kemp et al., 2010). These swards can contribute to rumen health, provide a higher feeding value for ruminant species, while improving biodiversity and mitigating environmental concerns by reducing the need for fertiliser and nitrogen leaching risks (Vogeler et al., 2015; Vibart et al., 2016)."*

The Lowe paper also states that *"research on the effect of grazing MSS on animal performance is often conflicting and a focus on beef cattle in particular is limited. Much of the research that has been carried out is conflicting especially in regards to animal performance, endo-parasite control and environmental impacts. This is likely as a consequence of different methodologies and different combinations of swards (which have different nutritional properties)."*

After MSS establishment, early management post establishment is important and will impact the persistence and the overall success of implementing them. Pastures are usually ready for grazing from around 6-8 weeks after establishment, although they have to be carefully managed at this stage. (Beaumont, 2020). Research and practical evidence indicates that rotational grazing is a superior to a set stocking regime as it gives plants time to recover. This is backed up by findings from the EIP Wales MSS project in which rotational grazing was compared to continuous grazing. Results showed that this prevented herbs from being grazed out. Rotational grazing results in raised sward quality, more equal grazing of plant species and increased sward persistence (AHDB, 2020). However, in a 3-4 week rotational grazing study, Cranston et al, (2015) found that PRG and white clover had comparable DM production, but growth patterns were variable. This finding is expected and a result of plants responding differently to local weather conditions, soil types and grazing practice.

Meat Quality

There are a range of papers which indicate some kind of an impact of MSS on meat quality De Brito *et al*., (2016), (Hopkins *et al.,* 1995). Evidence shows that finishing lambs on brassicas can lower meat sensory quality (predicated through a change in the fatty acid balance). MSS containing plantain and chicory have been reported to have a higher proportion of polyunsaturated fatty acids (PUFA) than a ryegrass clover sward, while also containing secondary compounds such as phenols (Elgersma *et al.,* 2013).

Improved PUFA concentration was indicated by Kliem et al (2018) in lamb muscle offered a MSS when compared with PRG sward. In beef cattle, a mix of chicory and ryegrass diet had no effect on fat grade, kill out and carcass weight of steers, compared with a grazing diet PRG (Marley et al, 2014).

Mineral Content

There may be human health benefits of meat from animals fed on MSS. The mineral content of MSS is known to be higher and have a greater range that for PRG, with herbs in the forage contributing significantly to this. For example, Plantain contains higher concentrations of selenium, magnesium, iron and calcium (amongst other minerals) than PRG (Raeside *et al.,* , 2017) and similarly Darch et al (2020) showed herbs had higher concentrations of iodine and selenium, grasses in manganese and legumes in copper, cobalt, zinc and iron. In particular, chicory and plantain, with their deep roots, are able to access soil nutrient resources which most grasses are unable to.

3.1.1.11. Uptake

There are several barriers to overcome if the practice is to be adapted.

1) Cost of Reseeding
2) The potentially lower persistence of the multi-species swards
3) The ongoing time cost of the additional management required for MSS

4) The economic cost of reduced stocking densities if this is required
5) The need for farmers to be educated about the different management practices required to effective use the new sward.
    - Grazing times and patterns
    - Fertiliser
    - Manure

3.1.1.12. Other Notes

None

3.2. SOIL MANAGEMENT AND PROTECTION/SOIL INPUT MANAGEMENT TO REDUCE GREENHOUSE GASES

This overall soil management bundle considers the effectiveness of optimised soil management and protection as a tool for reducing GHG emissions. The specific grouping of input management to reduce GHG considers GHG mitigation approaches within soil management and protection provoking farmers to modify production processes to deliver GHG reduction.

3.2.1. ECAR-004: Increase the capacity of farm slurry and manure stores to improve timing of slurry applications

This action is focused on increasing the capacity of farm slurry and manure stores to improve timing of slurry applications. The intention is to facilitate a more accurate nutrient management plan to optimise timing of slurry application.

De Klein and Eckard (2008) highlighted the potential to limit N_2O emissions resulting from fertilisation through appropriate timing of application in relation to soil wetness. N_2O emissions have been shown to be higher when the slurry is applied to wet soil compared with drier soil (Saggar *et al.,* 2004).

When fertilisers are applied to agricultural fields, less than half of the N is taken up by the crops and converted to plant biomass (Bindraban *et al.,* 2015), while the rest is susceptible to loss in the form of pollutant compounds. The most important N losses occur through;

- Nitrate leaching to waterways
    - Nitrogen leaching causes algal blooms and fish kills (Glibert, 2020);
- Ammonia volatilisation to the air
    - Volatilisation contributes to water eutrophication, soil acidification, and biodiversity loss (Fangueiro *et al.,* 2015);
- Nitrous oxide emissions
    - Nitrous Oxide is a powerful greenhouse gas and a ozone-depleting substance.

When mismanaged, application of slurry can generate large nitrous oxide emissions, ammonia volatilisation, and nitrate leaching (Svoboda *et al.,* 2013) or infiltration into the groundwater, resulting in pollution of nearby watercourses. Mitigating these losses is essential to improving sustainability of livestock farming. In terms of application timing, it is essential to optimise application timing and subsequent utilisation. Spring application has been recommended as a means to reduce nitrate leaching and nitrous oxide emissions because the nitrogen is supplied to a fast-growing crop, thereby reducing soil nitrogen availability for nitrifiers, denitrifiers and infiltration into the groundwater (VanderZaag *et al.,* 2011; Abalos *et al.,* 2016a, 2018).

However, it is important to consider that site-specific climatic properties may determine the overall effect of slurry application timing on nitrogen losses. Nitrogen losses differs largely between seasons due to contrasting precipitation and temperature patterns (Bowles *et al.,* 2018).

3.2.1.1. Causality

The relationships between timing of slurry applications and the reduction in GHG emissions is established and is rated green. Research demonstrates that autumn application poses the most significant risks in terms of nutrient losses and pollutants, primarily due to increased rainfall and precipitation (Kerebel *et al.,* 2013).

Timing of slurry application is critical for maximising N availability to herbage. Applications in autumn and winter can lead to high leaching losses, whereas summer applications are more prone to gaseous ammonia losses because of warmer and drier air and soil conditions (Smith and Chambers, 1993; Schröder, 2005).

Application in spring appears to be optimal as it allows nutrients to be applied at a period when uptake by herbage is high, and when ammonia and leaching losses are relatively low (Carton and Magette, 1999). While application in spring is desirable to maximise N use efficiency, soils are often too wet for slurry application.

This requires the ability to hold additional volumes of slurry for application at the appropriate points when nutrients can be most effectively be utilised by plant growth.
It should be noted that a typical farm will need to use the whole grazing season to spread slurry, and an increase in slurry capacity alone is not necessarily a solution if weather conditions are not suitable for long periods of time at important points in farming calendar. Increasing capacity would be most effective when used in conjunction with, for instance, Anaerobic Digestion or slurry separation and export.

3.2.1.2. Co-Benefits and Trade-offs

Benefits of increased capacity for slurry and manure to improve timing of application include the reduction of loss of methane and ammonia into the air, reduction of Nitrous Oxide under cold conditions and the retention of additional nitrogen within manures which increases the value of slurry. Trade-offs centre around the cost of additional storage, and the long-term nature of payback.

Overall, this strategy has the potential to result in much more efficient nutrient management with benefit for air and water quality.

[TOCB Report-3-4 Water **ECAR-004** and others] Reductions in nitrate losses to water following application will increase nitrogen use efficiency of the manures and reduce the need for manufactured fertiliser N applications to meet optimal crop demand. Ensuring that manure applications are made when soil conditions are suitable to withstand the weight of application machinery will reduce the risk of soil compaction.

[TOCB Grassland **ECAR-004**] Assuming this action leads to timing of slurry applications to avoid run-off into surfaces waters there is potential for indirect benefits to aquatic habitats and species of reducing the risk of pollution, but the extent of this benefit is likely to depend on the proportion of livestock farms in the sub-catchment that take up this action.

[TOCB Report-3-1 AQ **ECAR-004** and others] Actions have trade-offs with greenhouse gas emissions, especially nitrous oxide and methane (Kupper *et al.,* 2020).

[TOCB Report-3-5B Croplands **ECAR-004**] Assuming this action leads to timing of slurry applications to avoid run-off into surfaces waters there is potential for indirect benefits to aquatic habitats and species of reducing the risk of pollution, but the extent of this benefit is likely to depend on the proportion of livestock farms in the sub-catchment that take up this action.

3.2.1.3. Magnitude

The magnitude of impact is estimated accurately and based on current scientific data, these estimates are as accurate as can be at present.

- Autumn application increased nitrate leaching by 65 % compared with winter and spring due to high rainfall following application, resulting in lower herbage yield and nitrogen uptake (Maris *et al.,* 2021).
- F. Bourdin et al (2014) found that switching slurry application from summer to spring resulted in increased mitigation of both NH_3 and GHG emissions due to favourable soil and climatic factors which enhanced crop growth. They found that NH_3 volatilisation is 43% lower when applying slurry in April compared to July.

3.2.1.4. Timescale

These interventions represent significant changes within current farm practices, but are very achievable with the correct incentive for a farmer to implement each mitigation. The table below shows the expected timescales for response:

Component	Expected timescale	Reason	Size of benefit
Improve timing of slurry applications	Year 1	Improving the timing of slurry application will improve nitrogen use efficiency and reduce the environmental losses dramatically	Medium

3.2.1.5. Spatial Issues

Timing of slurry application and optimising the benefit is very dependent on geographical location, soil type and meteorological factors. Nutrient management plans should be tailored to suit the local conditions. However, in general, spring application appears to be the most beneficial in terms of nitrogen use efficiency.

Additionally, correct application is dependent on there being enough suitable days available to spread all the slurry, and this can be highly geographically dependent.

3.2.1.6. Displacement

In general, the practices implemented will not result in displacement and will enhance the environment sustainability and land productivity.

3.2.1.7. Maintenance and Longevity

The important aspect to consider is the requirement for increased storage of livestock slurry and manure. This storage must minimise GHG emission and losses to the environment. The creation of additional slurry storage is a significant structural change and is associated with a high financial cost. There are relatively low maintenance costs associated with below ground tanks and slightly higher costs associated with above ground storage.

3.2.1.8. Climate Adaptation or Mitigation

The proposed strategies contribute to both adaptation and mitigation. These strategies are not affected by climate change, but have a positive impact on reducing emissions from agriculture systems.

3.2.1.9. Climate Factors / Constraints

There are a number of potential constraints including the initial cost of increased storage and the implementation of a nutrient management plan. The farmers' willingness to adopt best practice is key to optimising application timing which lead to improved yield, reduced artificial fertiliser use, and improve nutrient use efficiency.

Weather factors are always a challenge for the application of manures or slurries and the farmer is regularly balancing limited storage (and the need to spread slurry) against weather conditions.

3.2.1.10. Benefits and Trade-offs to Farmer/Land manager

The most obvious benefit is reducing the use of artificial N fertiliser and improving nutrient use efficiency. Furthermore, there is a reduction in GHG emissions and improved environmental footprint. Overall, these strategies have the potential to result in much more efficient production systems.

3.2.1.11. Uptake

The one key factor likely to limit uptake is the initial cost of increased storage capacity and the farmers' willingness to implement an effective nutrient management plan. A second factor is the lack of understanding of the actual impact of inadequate storage facilities on the GHG emission of the manure. Without a true understanding of the value of an activity, the incentive to make appropriate changes is greatly reduced.

In reality, the financial savings associated with changing the timing of slurry application will not offset the cost of additional storage and farms are unlikely to invest in this unless required to do so.

3.2.1.12. Other Notes

Farm assurance could be used as a tool to verify that farm interventions are occurring. To some extent this already happens, but the specific details are not always verified. There is definite potential for farm assurance to be used to encourage good practice and to verify that key actions have been implemented and delivered.

3.2.2. ECAR-001 Cover slurry, sludge, and digestate stores where business is not regulated under IED

This management bundle considers the effectiveness of optimised soil management and protection as a tool for reducing GHG emissions and includes: *Soil Management and Protection and Soil Input Management to Reduce Greenhouse Gases*

This management bundle will consider GHG mitigation approaches within soil management and protection provoking farmers to modify production processes to deliver GHG reduction.

The covering of slurry, sludge and digestate stores can reduce the release of GHG and pollutants into the atmosphere. Ammonia emissions from manure storage account for 9% of the UK's agricultural ammonia emissions (AHDB: Benefits of covering slurry stores, 2022[1]). Ammonia and odorous gases are created by microbial activity within the slurry and are released in proportion to the wind speed over the surface. Covering slurry and manure stores will reduce the air movement and therefore the release of these gases.

Manure stores are the second largest source of methane emissions (after enteric fermentation) in European dairy farming (Sneath *et al.,* 2006). As well as CH_4 emissions, which mainly arise from slurry stores, there is a significant contribution of N_2O from farmyard manure stores (Chadwick *et al.,* 1999). As liquid and solid manures decompose, they produce ammonia, a proportion of which is subsequently converted to N_2O.

Several factors affect the rate of NH_3 CH_4 and N_2O emissions, including manure composition and physical variables, including temperature, rainfall, airflow etc. (Monteny *et al.,* 2006, Sommer *et al.,* 2004, Kupper et

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[1] Benefits of covering slurry stores | AHDB

al 2020). Furthermore, slurry and farmyard manure stored outside are also significant sources of NH_3, but they show great variations according to the temperature, the surface area, the duration of storage, and the occurrence of mechanical aeration (Bussink and Oenema, 1998).

The choice of a mitigation option will mainly depend on the nature of the effluent (liquid or solid manure), and there are various technologies that exist to meet wide-ranging requirements (VanderZaag *et al.,* 2015). These include floating covers, natural crust (if manure properties allow and the slurry is not agitated) (Chadwick *et al.,* 2011), rigid covers, and suspended impermeable plastic covers (tent-like structures). Covering slurry stores (including the use of slurry bags) reduces the area exposed to air and surface area air velocity, thereby reducing the rate of ammonia production (Hou *et al.,* 2014). If an additional 50% of slurry stores were covered, the reduction in nitrous oxide arising from ammonia volatilisation during slurry storage would be significant. For example, a review by Hou *et al.,* (2014) found that artificial film cover reduces the net GHG emissions (including indirect N_2O emissions) by 25%, while reducing NH_3 emissions from storage by over 90%.

3.2.2.1. Causality

Cover slurry, sludge, and digestate stores where business is not regulated under the Industrial Emissions Directive (IED)

- Amber
    - Covering of manures and slurries is known to reduce the release of odorous gases, reducing air pollution (and nitrogen loss from the slurry). A cover on slurry stores is an effective technique to reduce CH_4 and NH_3 emissions (Amon *et al.,* 2006; Clemens *et al.,* 2006), and N_2O emissions under cold conditions.
    - Covers may also shelter the natural surface crust from rain and help to keep it dry during winter. The addition of a cover reduces CH_4 and NH_3 emissions from slurry more than a natural surface crust alone. Also, the performance of natural surface crusts is variable.
    - It should be noted, however, that covers stop release from stored manures but do not decrease the overall emissions as the gases are released later when spreading.

3.2.2.2. Co-Benefits and Trade-offs

Benefits of covering slurry stores include the reduction of loss of methane and ammonia into the air, reduction of Nitrous Oxide under cold conditions and the retention of additional nitrogen within manures which increases the value of slurry. Trade-offs centre around the cost of the roofs or covers, and the long term nature of payback.

[TOCB Report-3-1 AQ **ECAR-001** and others] All actions have trade-offs with greenhouse gas emissions, especially nitrous oxide and methane (Kupper *et al.,* 2020).

3.2.2.3. Magnitude

Store covers are a well-established method of reducing ammonia which are reported both in the UNECE guidance document on NH_3 abatement (attached) and the UK national NH_3 inventory. These apply a 40% reduction in NH_3 for a floating cover and an 80% reduction in NH_3 for a fixed cover, relative to the emissions from an uncovered and un-crusted store.

The magnitude of impact shown below is based on current scientific data. MacLeod *et al.,* (2015) have measured the average abatement potential of covering stores to be 5-7ktCO_2e. However, there are differences in the literature between impermeable and permeable covers. The effects are shown below:

Impermeable Cover

- CH_4 emissions
    - -47% (Rodhe *et al.,* 2012)

- Direct N_2O emissions
  - -100% (Rodhe *et al.,* 2012)
- NH_3 emissions
  - -80% (VanderZaag *et al.,* 2015)

Permeable Cover

- CH_4 emissions
  - +2% (VanderZaag *et al.,* 2010)
- Direct N_2O emissions
  - -68% (VanderZaag *et al.,* 2010)
- NH_3 emissions
  - -60% (VanderZaag *et al.,* 2010)

It is clear from the literature that the use of covers reduces GHG emissions. However permeable covers have a larger effect than impermeable ones and are effective for Methane, Nitrous Oxide and Ammonia, whereas impermeable covers do not appear to reduce Methane emissions.

It is important to note that that most NH_3 emissions from a livestock enterprise are derived from the house (flooring surfaces and under-slat tanks) and at manure land-spreading. So applying a fixed cover to a store, without other ammonia reduction strategies, may only result in a c.10% reduction in total farm ammonia (from interrogating the farm-scale NH_3 reduction scenarios AFBI modelled).

Crusting of cattle stores also impacts the rate of the loss of GHG gases. For example, a cattle slurry store which crusts over has a natural barrier to emission (a crusted store is applied a 40% reduction in NH_3 relative to a crust-free store in the inventory, this is applied to 50% of cattle stores in the UK). In practice the crusting is unpredictable as a mitigation measure – depending on rainfall, temperature, rates of filling the store, straw content and agitation of the slurry. High rainfall is likely to make crusting difficult.

The additional ammonia abatement of applying a cover to a crusted store is minimal (i.e. 40% of 60% if applying a floating cover) and the law of diminishing returns applies. As a result, the cost-effectiveness of a store cover is reduced in this case. Store covers probably have greater application for digestate and pig slurry stores, as these will not naturally crust, and in addition they have higher TAN contents (digestate also has a higher pH) making these more predisposed to ammonia emission. For these, the cost-effectiveness of covering a store would be more favourable.

Work carried out by ABFI on NH_3 abatement suggested that there are more effective NH_3 reduction options available, in particular LESS and lower CP diets. Overall, however, slurry store covers should still be considered a viable option for reducing NH_3 particularly in some applications (digestate and pig slurry).

In terms of N_2O emissions following store covering, a small increase is observed in many studies and may be linked to the drying out of a thin layer on the surface of the store beneath the cover. It is important, however, to note that approximately 90% of agricultural N_2O emissions are from the soil, not from manure management (which is the overwhelming source of NH_3 emissions).

A similar picture emerges for CH_4, where there isn’t a strong consensus in the literature around the impact of slurry covers. However, plastic covers seem to increase emissions slightly, while carbon-type floating covers, such as straw and sawdust, have been shown to reduce CH_4 slightly (but perversely, increase CH_4 if mixed with the bulk of the slurry).

Overall, the effect of store covering on GHG emissions appears in practical terms to be close to negligible, given that the major sources of N_2O and CH_4 are soil and the rumen respectively. It is worth noting that the inventory does not consider a covered store as a form of mitigation because the methane and nitrous oxide is still present.

3.2.2.4. Timescale

These interventions require investment and infrastructure changes to current farm practice, but these are relatively easy to achieve. Incentives can encourage farmer to implement the mitigation. The impact of the cover is realised immediately upon installation.

Component	**Expected timescale**	**Reason**	**Size of benefit**
Slurry Cover	Year 1	Technology freely available	5-7ktCO_2e

3.2.2.5. Spatial Issues

There are limited spatial issues as these technologies are well established and can be applied to almost any overground slurry store. The technology will be most applicable to intensive livestock systems where slurry/manure management is a significant aspect of the business. Application to loose-housed livestock systems producing solid manure using straw bedding will be limited, since manure is often not removed until the end of wintering. Where removal does occur, solid manure is often stored in yards prior to spreading at the appropriate time.

3.2.2.6. Displacement

The implementation of slurry covers will not result in displacement, and will enhance the environment and land productivity.

3.2.2.7. Maintenance and Longevity

The mitigation requires infrastructure change which will require ongoing maintenance and regular replacement.

3.2.2.8. Climate Adaptation or Mitigation

The proposed strategies contribute to both adaptation and mitigation. These strategies are not affected by climate change, but have a positive impact on reducing emissions from agriculture systems.

3.2.2.9. Climate Factors / Constraints

Application of improved nutrient management through the use of slurry covers is relevant to all farming systems. A possible constraint is the initial investment required to acquire and maintain cover.

3.2.2.10. Benefits and Trade-offs to Farmer/Land manager

The most obvious benefit of minimising GHG emissions from slurry is that the nutrient content is maintained, enabling a reduction in use of artificial fertiliser. Overall, the use of slurry covers has the potential to result in more efficient production systems with reduced wastage and improved productivity. However, the economic benefits are relatively minimal in this regard in relation to the cost of covering the manures.

Mitigation measures (i.e. slurry covers) that reduce ammonia and methane emissions will provide further benefits, primarily in terms of improved air quality.

3.2.2.11. Uptake

The limited potential for overall emission abatement will impact uptake at farm level. Secondly, the potential cost of the cover will be a severe disincentive, meaning that widespread uptake is unlikely without financial support. In additional it is not always possible to retrofit slurry covers to all facilities.

3.2.2.12. Other Notes

Farm assurance could be used as a tool to verify that the covers have been installed and are being used.

3.2.3. **ECAR-006 Dilute slurry to improve soil infiltration, coupled with irrigation**

Dilution of slurry with water not only decreases the ammonium-N concentration, but also increases the rate of infiltration into the soil following spreading on land.

Ammonia emissions from Agriculture will continue to increase if no mitigation actions are taken. Improving nitrogen use efficiency is a key focus for improving farm efficiency and sustainability, as well as reducing the ammonia, nitrate, and greenhouse gas (GHG) footprint of agriculture.

Increases in animal stocking and the price of chemical fertilisers encourage farmers to use animal manure and slurry as an option to reduce the use of commercial fertilisers. However, the handling and spreading of these organic fertilisers may pose an agronomic and environmental risk, not only because of leakage of nitrate to ground waters but also because of gaseous losses of NH_3 and NO_2 (Asman, 1992). Ammonia can form secondary particulate matter in the atmosphere that may have adverse effects on human health (Moldanová *et al.,* 2011).

Dilution of slurry with water not only decreases the ammonium-N concentration, but also increases the rate of infiltration into the soil following spreading on land. Ammonia emissions from dilute slurries with low DM content are generally lower than for whole (undiluted) slurries because of faster infiltration into the soil (Misselbrook *et al.,* 2004). However, increasing rate of infiltration into the soil will only happen when soil type and conditions allow. For undiluted slurry (i.e., 8%–10% DM), dilution must be at least 1:1 (one part slurry to one part water) to reduce emissions by at least 30% (Kupper *et al.,* 2020). It is vitally important that soil conditions allow for rapid soaking of dilute slurries and that there are no physical impediments to infiltration, such as high soil water content, poor soil structure, fine texture. or other soil attributes that reduce infiltration rates of liquids into soil, and there is no decrease in infiltration rate due to high application volumes.

A major disadvantage of the technique is that extra storage capacity may be needed, and a larger volume of slurry must be applied to land. In some slurry management systems, slurry may be already diluted (e.g., where milking parlour or floor washings, rainfall, etc., are mixed with the slurry) and there may be only a small advantage in actively diluting further. Extra cost for storage capacity and, mainly, for transport in land application, should discourage use of this technique. Also, there may be a greater risk of aquifer pollution, more water wastage. and a greater carbon footprint because of the additional transport.

Slurry dilution for use in irrigation systems has advantages. Doses of slurry, calculated to match the nutrient requirement of crops, can therefore be added to irrigation water to be applied onto grassland or growing crops on arable land. Slurry is pumped from the stores, injected into the irrigation water pipeline and brought to a low-pressure sprinkler or travelling irrigator, which sprays the mix onto land.

3.2.3.1. Causality

There is established causality in the scientific literature around the effect of dilution of slurry on GHG emissions. The general effect of the technique is known, but the range of practical applications varies.

- Amber
    - Dilution of slurry with water not only decreases the ammonium-N concentration, but also increases the rate of infiltration into the soil following spreading on land. Ammonia emissions from dilute slurries with low DM content are generally lower than for whole (undiluted) slurries because of faster infiltration into the soil (Misselbrook *et al.,* 2004; Amon *et al.,* 2006)

- This system is very well suited to irrigation systems where emission reduction is proportional to the extent of dilution. Ammonia emissions from dilute slurries with low DM content are generally lower than for whole (undiluted) slurries because of faster infiltration into the soil (Stevens and Laughlin, 1997). In practice irrigation systems will be installed in low rainfall areas.

- Mitigation of GHG emissions can be achieved by a reduction in slurry dry matter and easily degradable organic matter content (Amon *et al.,* 2006)

3.2.3.2. Co-Benefits and Trade-offs

Benefits of diluting slurry include the reduction of GHG emissions to the atmosphere and reduced run-off to water systems. Trade-offs centre around the cost of infrastructure and capacity to facilitate dilution.

Overall, this strategy has the potential to result in much more efficient nutrient management with benefit for air and water quality.

[TOCB Report-3-1 AQ **ECAR-006** and others] Actions have trade-offs with greenhouse gas emissions, especially nitrous oxide and methane (Kupper *et al.,* 2020).

3.2.3.3. Magnitude

The magnitude of impact has been measured and it has been shown that the dilution of slurry to improve soil infiltration, coupled with irrigation at a rate of at least 1:1 (one part slurry to one part water) will reduce emissions by at least 30% (Bittman *et al.,* 2014).

3.2.3.4. Timescale

These interventions represent significant changes within current farm practices, but are very achievable with the correct incentive for a farmer to implement each mitigation. The table below shows the expected timescales for response:

Component	Expected timescale	Reason	Size of benefit
Dilute slurry to improve soil infiltration, coupled with irrigation	Year 1	Methodology well established and relatively easy to implement	Small

3.2.3.5. Spatial Issues

There are spatial issues as this mitigation is well established in lowland, flat farming systems. This will be most applicable to intensive livestock systems where irrigation is required for either crop production or grassland. The mitigation option will not be practicable for farms using solid manure management, not for high rainfall areas.

3.2.3.6. Displacement

In general, the practices implemented will not result in displacement and will enhance land productivity and reduce emissions if managed correctly.

3.2.3.7. Maintenance and Longevity

The improvement of resource use efficiency through reduced ammonia losses will improve environmental sustainability and soil performance. This has multiple secondary benefits including reduced cost associated with artificial fertilisers and better soil health.

3.2.3.8. Climate Adaptation or Mitigation

The proposed strategies contribute to both adaptation and mitigation. These strategies are not affected by climate change, but have a positive impact on reducing emissions from agriculture systems.

3.2.3.9. Climate Factors / Constraints

Application of precision nutrient management through the use of slurry dilution will be specific to farm systems with low precipitation and soils that are suitable for rapid infiltration.

3.2.3.10. Benefits and Trade-offs to Farmer/Land manager

The most obvious benefit of optimising nutrient application is improved resource use efficiency, improved environmental footprint, and improved profit margins. Overall, these strategies have the potential to result in much more efficient production systems.

Trade-offs include the costs around the extra storage and equipment which is necessary to enable the dilution of slurry, as well as the potentially increased risks of spillage when diluting slurry. In addition, care is required in spreading or injecting diluted slurry to soils with low permeability or high saturation since this will increase the risks of run-off and water pollution. Subsoiling may be necessary to increase soil permeability.

3.2.3.11. Uptake

The main factors likely to limit uptake and reduce the effectiveness of implementation which is the suitable landscape for implementation and the cost of infrastructure. There can be a cost implication of slurry dilution, and ideally, dilution should come from rainwater sources rather than abstraction or mains water supply.

3.2.3.12. Other Notes

None

3.2.4. **ECAR-015 Replace nitrogen fertiliser application by using clover in pasture or arable cropping systems**

This management bundle will consider GHG mitigation approaches within soil management and protection provoking farmers to modify production processes to deliver GHG reduction.

This report investigates the effect of replacing nitrogen fertiliser by using clover in pasture. The reduction in fertiliser use should reduce the overall GHG impact of farming operations by reduced GHG associated with the manufacture of chemical fertiliser.

Cardenas *et al.,* (2019) wrote a paper on Nitrogen use efficiency and Nitrous Oxide emissions in the UK. They stated the following:

"During recent decades, the demand for global food has increased rapidly as a consequence of population growth and changes in patterns of food consumption. One of the most relevant changes in the global agro-food system has been the intensification of production systems and the increase of nitrogen (N) use and trades (Lassaletta et al., 2016). Cultivated grasslands are an example of this intensification process and constitute a significant share of the agricultural area in some temperate countries (FAOSTAT, 2018). It is expected that further intensification will occur to fulfil increasing global demand for livestock products, putting pressure on farming activities that will likely result in increased N use.
N fertilisation of grasslands has relevant productive and environmental effects. It has major effects on the nutritive value *of fresh herbage, as well as on animal nutrition and N balance (Lee, 2018).*

However, fertiliser *rates exceeding crop requirements lead to an N surplus, reduced N use efficiency (NUE) and losses to the environment (Van Eerd et al., 2018). In terms of* gaseous *pollutants, N* fertiliser *applications are associated with emissions of* nitrous oxide *(N2O) (Reay et al., 2012), a powerful greenhouse gas (GHG) with a large* global warming potential *(Forster et al., 2007), and a gas that contributes to ozone (O3) depletion in the* stratosphere *(Ravishankara et al., 2009). In the case of urea-based fertiliser applications, ammonia (NH3) is also emitted (*Pan *et al., 2016), with NH3 emissions directly implicated in detrimental environmental quality (Krupa, 2003). An improved NUE is required in intensively managed grasslands to reduce the negative effects of an N surplus while preserving productivity and soil fertility.”*

Their paper gave a very strong outline of the challenges around the use of fertiliser, much of it driven globally by the intensification of agriculture. Overuse of fertiliser is a significant challenge and much of the surplus N is liable to be lost to the aqueous and atmospheric environments where it can become a serious pollutant and a conservation concern.

The main nutrient-related negative environmental impacts of pasture systems are eutrophication of fresh waters, estuaries, coastal water and nutrient-poor land habitats; emissions of ‘greenhouse’ gases to the atmosphere; and a decrease in biodiversity within and outside the pastures (Jarvis, 1993, D Scholefield 2003, Firbank, L.G., 2005). It is now a necessity to reduce the level of pollutants from agriculture and to promote biodiversity.

The challenge, especially for the intensive livestock sector, is to reduce the use of inorganic fertilisers and associated pollutants whilst maintaining economic viability. Currently, the quantity of Nitrogen (N) applied to land is high and with the rising cost of artificial fertiliser, there is much merit in establishing alternatives such as clover swards. White clover is highly digestible and unlike perennial ryegrass, performs well with low fertiliser N inputs. White Clover, an N_2-fixing legume grown in association with the grass, is the main legume used, especially in long-term pasture (Hodgson & White, 2000). This approach is effectively utilised within organic systems and has the potential to become established as a priority mitigation for GHG emissions.

On-farm research has shown that where grassland has been converted over to clover-based swards on intensively stocked dairy farms, fertiliser N inputs have been halved while maintaining or increasing milk output (Johansen *et al.,* 2017). Furthermore, greenhouse gas emissions resulting from N fertiliser production would be greatly reduced with the perennial ryegrass/white clover pasture systems.

Increasing the abundance of legume species in some grass swards can also improve sequestration and forage quality. In combination with legumes, a more diverse vegetation cover (>4 species) can make grasslands more resilient in terms of climate change and may provide both a better forage quality and organic matter input.

3.2.4.1. Causality

- Inclusion of clover in pasture swards is green rated for association with GHG emission reduction.
    - Increasing the abundance of legume species in some grass swards can improve sequestration, forage quality, and reduce inorganic N inputs. This in turn will reduce losses to the environment, including GHG emissions. In combination with legumes, a more diverse vegetation cover (>4 species) can make grasslands more resilient in terms of climate change, and may provide both a better forage quality and organic matter input. (Arlete *et al.,* 2019)
    - Forage legumes might also be capable or reducing enteric CH_4 emissions, partly through their condensed tannin content (Jayanegara *et al.,* 2012), though the evidence is not conclusive yet (Lüscher *et al.,* 2014).
    - “Average emissions from the application of AN fertiliser are 5.1 kg CO_2-eqv per kg applied N. This is due to N_2O losses caused by denitrification and volatilisation in the soil. Since N_2O has a strong impact on the environment, N_2O losses are an important consideration.” Yara. Carbon Footprint | Reduce your farm’s impact on climate change | Grow the Future | Yara UK

3.2.4.2. Co-Benefits and Trade-offs

Benefits of reducing fertiliser use include the reduction of loss of N_2O into the atmosphere and reduced run-off, improving water quality. Trade-offs centre around the cost of establishing and maintaining clover / legumes in swards.

[TOCB Report-3-6 Carbon **ECAR-015**] Bai *et al.,* (2019) found that SOC sequestration was greater under leguminous crops (including clover) than non-leguminous crops.

[TOCB Report-3-5B Grasslands **ECAR-015** and others] Through decreasing the need for exogenous nitrogen inputs, incorporating legumes into grazed pastures can reduce the risk of nitrogen leaching into water leading to biodiversity benefits downstream (Harris and Ratnieks, 2021).

[TOCB Report-3-1 AQ **ECAR-015** and others] White clover living mulch plots have been shown to also have higher greenhouse gas fluxes.

3.2.4.3. Magnitude

The magnitude of impact is estimated accurately and based on current scientific data, these estimates are as accurate as can be at present: Inclusion of clover in pasture swards

- Clover will fix, on average, 80 kg N/ha/yr (Burchill *et al.,* 2015).
    - Average artificial Nitrogen input per Ha in the UK is approximately 120kg.
    - England has approximately 14.75 million Ha of grassland/rough grazing/forest.
    - The effective implementation of clover on 1/3 of this land could potentially reduce the total artificial N use by around 390,000 tonnes annually.
- Lanigan & Donnellan (2019) estimate that greenhouse gas emission reductions of 69 kt CO_2e can be achieved from avoided fertiliser emissions (direct and indirect N_2O)

3.2.4.4. Timescale

These interventions represent significant changes within current farm practices, but are very achievable with the correct incentive for a farmer to implement each mitigation. The table below shows the expected timescales for response:

Component	**Expected timescale**	**Reason**	**Size of benefit**
Inclusion of clover in pasture swards	Year 3	Including legumes in pasture swards will facilitate N_2-fixation and reduce the requirement for artificial fertilisers	Large

3.2.4.5. Spatial Issues

Clover is affected by soil temperatures and viability will depend on geographical location as higher soil temperature are required for growth compared to ryegrasses.

Furthermore, clover does not establish well in wet, peaty and acidic soils so once again geographical location will be a consideration for implementation.

3.2.4.6. Displacement

In general, the practices implemented will not result in displacement and will enhance the environment and land productivity and sustainability.

3.2.4.7. Maintenance and Longevity

Clover is a relatively vulnerable sward and requires a degree of management. It requires to be sown at the correct time of the year and maintained at a shallow depth. The use of artificial fertiliser N must be greatly decreased and allow the clover to supply N via biological fixation.

Mixed swards containing multiple species of grass and legumes show higher yield than average monocultures (Cardinale *et al.,* 2007, Cong *et al.,* 2018), and draught tolerance, an important aspect in adapting to the changing climate, particularly in south England (Finn *et al.,* 2018)

3.2.4.8. Climate Adaptation or Mitigation

The proposed strategies contribute to both adaptation and mitigation. These strategies are not affected by climate change, but have a positive impact on reducing emissions from agriculture systems.

3.2.4.9. Climate Factors / Constraints

Clover is affected by soil temperatures and viability will depend on geographical location as higher soil temperature are required for growth compared to ryegrasses. Furthermore, clover does not establish well in wet, peaty and acidic soils so once again geographical location will be a consideration for implementation.

3.2.4.10. Benefits and Trade-offs to Farmer/Land manager

The most obvious benefit of minimising the use of artificial N fertiliser and subsequent reduction in GHG emissions and improved environmental footprint. Overall, these strategies have the potential to result in much more efficient production systems. Reseeding with clover could cause loss of soil carbon if ploughing/cultivation is used, whilst direct drilling can require the use of herbicides to reduce competition from the existing grasses/vegetation. Further challenges can also arise from the use of clovers, such as impacts on ewe fertility (Mustonen *et al.,* 2014) or impacts on animal digestive health under certain conditions (AHDB Knowledge Library 2021: Potential Health Problems Associated with Clover).

3.2.4.11. Uptake

There is one key factor likely to limit uptake and longevity and reduce the effectiveness of implementation which is the management required to maintain swards and subsequent benefit.

3.2.4.12. Other Notes

Farm assurance could be used as a tool to verify that farm interventions are occurring and that a fertiliser reduction plan is in place (probably as part of a nutrient use plan).

3.3. RESTORATION, MANAGEMENT AND ENHANCEMENT

The Restoration, Management and Enhancement section is focused on identification of methods which can enable nature to restore and enhance the environment.

Summary
It is very clear that management of coastal habitats will positively impact Carbon Storage. However, evidence around ideal interventions and the extent of impact of those interventions on Carbon storage, and economic or leisure activity in those areas. Further research is required around these topics. As for Bundle 3.6, farmers have little locus on the coastal habitats apart from saltmarsh. A key issue is to identify who has management responsibility for these areas – is it the Crown Estate?

3.3.1. ECCA-033M: Manage/enhance coastal habitats to compensate for losses to climate change as part of a coastal management plan

This bundle is focused on exploiting the potential for the development and management of coastal habitats to mitigate climate change. Human activities are responsible for the degradation of many of these environments and a report by Ulster Wildlife (Strong *et al.,* 2021) estimates that approximately 50% of seagrass has disappeared from the NI coastline since 1930 due to habitat disturbance and destruction/damage to marine ecosystems. Estimates from The Deep (a non-profit, conservation organisation) suggest that up to 92% of seagrass across the UK may have been lost (Fenn *et al.,* 2021).

According to WWF, seagrass beds, macroalgae, reefs and saltmarshes sequester and store carbon. The protection and restoration of coastal vegetation could make a valuable contribution to the UK's nationally determined contributions (NDC) target and provide coastal and island communities with important economic opportunities on the carbon offset market (Hastings *et al.,* 2014). WWF Suggest that the financial benefit of restoring the UK seas is in excess of £50 billion (Fenn *et al.,* 2021).

The activity within this bundle crosses more than one Ecosystem service but can be predominantly classified as being in "*Maintaining habitats, nursery populations (and other stages of life cycles".*

This bundle is focused on the management and enhancement of Coastal Habitats to enable regeneration or development of ecosystems which contain species which sequester carbon in particular.

Coastal regions are typically defined as areas within 1 nautical mile of the land-sea interface, and include a range of marine, terrestrial and freshwater habitats. These habitats provide a number of ecosystems services including the support of charismatic and endangered animal and plant species, remediation of anthropogenic pollutants, support for fisheries, agriculture and aquaculture. More recently, coastal habitats have recognised for their potential to sequester carbon (locking away carbon dioxide and other Green House Gases) across a range of ecosystems.

These habitats have been shown to substantially increase the ability of ecosystems to sequester carbon if appropriate protection and management procedures can be put in place, including restrictions on specific land use practises and human extractive activities such as fishing (refs needed here). As such, the effective management of these systems to enhance carbon sequestration represents one facet within a complex matrix of environmental planning decisions.

3.3.1.1. Causality

Rating: Amber

The Evidence is strong for Causality between GHG mitigation and intervention, management and enhancement of specific ecosystems. However the evidence around ideal interventions is not yet complete and therefore this section is rated Amber. The literature provides strong evidence that intervention can be effective, particularly around the prevention of disturbance.

A study by Ulster Wildlife showed that existing marine protected areas (essentially well managed habitats) around the coast of Northern Ireland have the ability to sequester 31,595 tonnes of Carbon per year – and by extension the creation of these habitats around the UK are capable of sequestering many times this amount. The maintenance and enhancement of these sites has been demonstrated to significantly increase the amount of carbon sequestered. Carbon sequestration rate of the inshore Marine Protected Area (MPA) network in Northern Ireland is estimated to be 14,707 t C per year but is suggested that there is the potential to triple the blue carbon value of the MPA network to 52,958 (t C yr-1) through effective protection and habitat restoration/creation within the MPA network. This also shows the potential for the coastal areas around Great Britain. These ecosystems currently sequester and store around 2% of UK emissions per year but have the potential to store much more.

Scottish Parliament (Shaifee, 2021) documents outline the value of blue carbon to Scotland, and reference the sources from which quote the value:

- Collectively, Scotland's blue carbon environments store 9,636 Mt CO_2-eq (Megatonnes of CO_2-equivalent). This is roughly equivalent to the total of carbon stored in Scotland's land-based ecosystems (9,546 Mt CO_2-eq) such as peatlands, forestry (Chapman *et al.,* 2009) and soils (Aitkenhead *et al.,* 2016).

- Annually, Scotland's blue carbon stores sequester 28.4 Mt CO_2-eq, (Burrows *et al.,* 2014). which is approximately three times greater than the annual carbon sequestration of Scottish Forestry (9.6-11 Mt CO_2-eq per year (Thistlethwaite *et al.,* 2020).

- Geological seafloor and sea loch sediments store 99.84% of Scotland's blue carbon. Scotland's biological habitats and species store the remaining 0.16% of Scotland's blue carbon. Despite their small contribution to Scotland's blue carbon sequestration and storage, biological habitats and species play a crucial role in supporting Scotland's biodiversity and resilience to climate change.

A range of habitats and ecosystems can be managed to capture carbon, including seagrass beds, saltmarsh, shellfish beds and kelp. Each of these require separate and alternative management practices.

The main threats to blue carbon habitats are physical disturbances, climate change, and land-use and land management changes. In the UK, it is estimated that seagrass loss amounts to between 84 and 92% (Green *et al.,* (2021).

If in a poor state of health or unprotected from threats, blue carbon habitats may release their stored carbon, becoming a future source of carbon emissions (Green *et al.,* 2021).

Management and restoration activities need to be carefully planned as coastal habitats can also be a source of greenhouse gases such as methane (CH_4) and nitrous oxide (N_2O). There is not compelling evidence surrounding the level of such emissions however, and the long-term benefits of restoration are expected to outweigh any damaging emissions in the shorter term (WWF 2021).

3.3.1.2. Co-Benefits and Trade-offs

A range of co-benefits are likely to emerge from correct management of coastal and other water based environments. Enhancing marine ecosystems to improve carbon sequestration provides a significant range of other benefits including raised biodiversity, flood protection and support for valuable fish and shellfish populations. Part of the process of improving conditions to allow saltmarsh to flourish will also mean that water quality will also improve as a result of reduced run-off from agricultural land.

3.3.1.3. Magnitude

Seagrass

Green *et al.,* (2018) state that the significance of the role of seagrass beds in carbon sequestration is now widely acknowledged and that subtidal seagrass beds in the UK contribute substantially at the European level. Fourqurean et al. (2012) concluded that seagrass beds were of an equivalent importance to forests in terms of carbon storage capacity, with an estimated global carbon pool of 4.2 and 8.4 Pg (10^{15}) being associated with seagrass beds. They also stated that as forests are vulnerable to carbon release from forest fires, carbon storage within seagrass beds is considered more permanent.

Fourqurean et al. (2012) also stated that whilst seagrass beds occupy just 0.2% of the area of the World's oceans, they account for an estimated 27.4 Tg (10^{12}) carbon burial each year, accounting for approximately 10% of the carbon buried annually in marine habitats. 60% of Carbon in living tissue is associated with the roots and rhizomes (Fourqurean et al. 2012).

On the south coast of England, Green *et al.,* (2018) estimated sedimentary carbon stocks in *Zostera marina* meadows to be between 98.01 and 140.24 t C ha^{-1} (within the top 100 cm), a value just below the global average of 194.2 t C ha^{-1}. They calculated a standingstock of 66,337 tonnes of Carbon (within the top 100 cm), across 549.79 ha. They estimated this to be equivalent to the annual CO_2 emissions of 10,512 people. This study did not account for living seagrass tissues which have been shown to represent significant carbon sequestration potential.

The improvement and management of seagrass ecosystems to store blue carbon requires buy-in from a range of people, businesses and organisations which operate in local areas. Many of the habitat areas for restoration tend to be multiple use e.g. fishing, diving, boating etc. and the restriction of activities in these areas will impinge on a range of people and organisations.

Saltmarsh

A remarkable fact is that saltmarshes have one of the highest carbon burial rates of any natural system on the planet (with the highest carbon burial rate per unit area of all blue carbon habitats). They store a mean of 244.7 ± 26.1 g C m−2 yr−1, much larger than long-term burial rates from temperate, tropical, and boreal forests, which range from 0.7 to 13.1 g C m−2 yr−1 (Theuerkauf *et al.,* 2015), ten times larger than that of typical fjord systems (22.5 ±15.6g OC m−2 yr−1) and two orders of magnitude higher than the deltaic and non-deltaic continental shelves (2.6±0.9g C m−2yr−1) (Cui *et al.,* 2016) . This highlights the important role these fringing marshes do in mediating terrestrial nutrient fluxes into the marine environment (50-60% of carbon buried in fjord systems is terrestrially sourced). As an example of this disproportionate importance; average farmland stores one tonne of carbon per hectare compared to 60 tonnes per hectare in the top 0.1 m of saltmarsh . As for carbon sequestration, farmland can act as a net emitter of carbon, whilst saltmarsh can sequester 0.64–2.19 t C ha-1 y-1 (equivalent to 2.35–8.04 t CO2e ha-1 y-1) (Gregg *et al.,* 2021).
Like Seagrass, Saltmarsh also has a high capacity for carbon sequestration, with the vast majority being associated with the soil rather than the actively growing vegetation. In a UK-wide study, Beaumont *et al.,* (2014) estimated the total carbon stock to be 5995 t, with 5413 t being associated with the soil and 452 t being associated with the below ground biomass. Sequestration rates in UK saltmarsh are estimated to range from 64 to 219 g C $m^{-2}yr^{-1}$, which equates to 8.04 tonnes CO_2 / ha /year (Beaumont *et al.,* 2014).

Like Seagrass, Saltmarsh has a high capacity for carbon sequestration, with the majority being associated with the soil rather than the actively growing vegetation. Beaumont *et al.,* (2014) estimated the total carbon stock in saltmarsh in the UK to be 5995 t, with 5413 t being associated with the soil and 452 t being associated with the below ground biomass. Sequestration rates in UK saltmarsh are estimated to range from 64 to 219 g C $m^{-2}yr^{-1}$, which equates to 8.04 tonnes CO_2 / ha /year (Beaumont *et al.,* 2014). Enhancement of these saltmarsh areas can improve the sequestration rates, but there is limited evidence about how much improvement can be delivered by a range of different interventions.

According to Burden *et al.,* (2019), the carbon sequestration capacity of saltmarsh is age-dependent with created or restored marshes taking approximately 100 years to achieve the rates of carbon accumulation measured in natural marshes.

Burden *et al.,* (2019) highlighted an extremely important issue in that for coastal vegetated habitats (e.g. mangrove, saltmarsh and seagrass), sedimentary conditions that favour organic carbon storage (through reducing the rate of aerobic microbial degradation) may enhance the release of other potent greenhouse gases such as methane and nitrous oxide (Roughan *et al.,* 2018; Rosentreter *et al.,* 2021).

Roughan *et al.,* (2018) stated that this issue has been found to be exacerbated in hypernutrified systems and that excess nitrogen in saltmarsh ecosystems has been found to reduce the below ground biomass leading to accelerated microbial decomposition of organic matter, increasing emissions. They emphasised that there is a high degree of spatial variability and a high degree of uncertainty regarding the role of these habitats in greenhouse gas regulation and climate change mitigation.

The literature acknowledges that the restoration of saltmarsh through managed realignment can have a rapid impact on Carbon absorption. However, the cost can be high, sometimes requiring land purchase or the purchase of access.

Shellfish beds

Shellfish beds are also acknowledged as an important Carbon Sink. Fodrie et al. (2017) and Lee *et al.,* (2020) both describe oyster beds as being a significant carbon sink,although Fodrie et al. (2017) also found that they could act as a source of carbon, depending on location and substratum characteristics. Carbon deposition rates of 21 t C ha^{-1} yr^{-1} were recorded in shallow subtidal and saltmarsh fringing oyster beds, respectively, whereas 7.1 t C ha^{-1} yr^{-1} was released from oyster beds on intertidal sandflats (Fodrie *et al.,* 2017). However, these figures suggest that accumulation outweighs loss. Lee *et al.,* (2020) found that oyster beds could enhance sedimentation and carbon deposition three-fold. However, more recent AFBI work suggests that this is not always the case, and the evidence remains inconclusive.

Literature relevant to the blue mussel's (*Mytilus edulis*) potential contribution to blue carbon storage is sparse. In optimal conditions *Mytilus edulis* can reach a shell length of 60-80 mm within two years, but in the high intertidal zone growth rate is significantly lower, and mussels may take 15-20 years to grow to nearly 20-30mm in length (Seed & Suchanek, 1992). Standing stock biomass and carbonate production rate will therefore be heavily dependent on local conditions and no single set of values can accurately represent all cases.

Kelp and Other Seaweeds

Kelp has potential to fix carbon (Wilmers et al, 2012) but is not able to store carbon because it grows on hard substances and is unable to bury or accumulate Carbon. However, Kelp does have a high above ground biomass and, as a result is a dynamic reservoir for Carbon. The ultimate fate of Carbon produced from marine algae will depend on local conditions, with some being quickly recycled into the marine and coastal environments whilst at least some has the potential to be transported to deeper water and become locked into the sedimentary deposits.

Coastal sediments

As we have seen above with kelp and other sources of marine carbon the proportion which is recycled compared to sequestered is uncertain but we do know that deep or undisturbed sediments lock Carbon for thousands of years. Of particular relevance to this carbon accounting is the amount held in the undisturbed sediments in nearshore environments such as loughs (Table 1).

Table 1: Comparison of estimated carbon stocks in fjord systems UK/Ireland (Smeaton & Austin 2019).

LOCATION	ORGANIC CARBON STOCK IN TOP 10 CM OF SEDIMENT (TONNES)
LOUGH FOYLE	316,765
BELFAST LOUGH	228,882
WEXFORD BAY	213,091
LARNE LOUGH	206,962
LOUGH SWILLY	199,772
STRANGFORD LOUGH	190,359

Depth integrated carbon stores are typically two orders of magnitude larger than surficial sediments so Strangford may contain ~20 Mt of organic carbon (depends on volume and composition of post-glacial sedimentation). For comparison Lough Torridon, which is slightly smaller in area, is estimated to contain 14.2

Mt of organic carbon (Smeaton & Austin 2019). Understanding the carbon stock (first order estimate is that 45% of total biomass consists of C) and metabolism of coastal wetlands depends on having an accurate understanding of their spatial distribution. As well as subtidal sediment intertidal mudflats are also part of the continuum of important sedimentary carbon stores and may be impacted by future climate change and sea level rise.

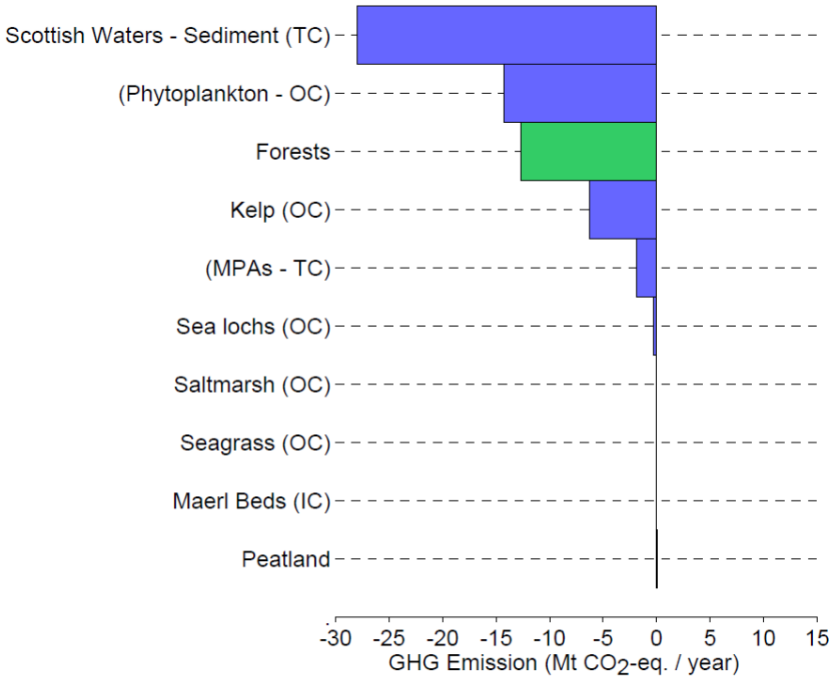

Figure 1: The importance of various marine habitats for carbon storage in Scottish waters (Turrell, 2020).

The importance of sediment is clearly demonstrated.

3.3.1.4. Timescales

Timescales from implementation to recovery is dependent on the species which are targeted for recovery and the condition of the existing ecosystem. The literature indicates the following:

- Recovery of below-ground biomass (Seagrass) could take between 4-6 years. (Ulster Wildlife).
- The literature is divided on the timescales for recovery of kelp grounds, and it seems that this is affected by the specific local conditions. Some literature suggests that recovery could occur on a timescale between 4-6 years (Guiry, 1997, McLaughlin et al 2006), whereas others suggest that recovery might take decades (Hill and White 2008).
- Timelines for recovery of saltmarsh are unclear, particularly if the key challenge is around nutrient overload, but existing literature indicates a requirement for multiple decades. Garbutt and Wolters (2008) found that 0-50 and 51-100 year old sites had reduced species richness than 101+ year old sites, showing that protection measures around saltmarsh must be designed decades ahead.
- Building of shellfish beds can take 10-20 years (Seed & Suchanek, 1992).

3.3.1.5. Spatial Issues

A range of areas around the UK coast are suitable for the creation of habitats which can sequester carbon. Obviously specific and appropriate areas must be chosen for each type of habitat as only certain areas are suitable for certain ecosystems or habitats. As previously discussed, a range of human activities must be considered when specific areas are being chosen. Commercial activity impacts heavily on potential seagrass areas (particularly sea bed trawling), while nutrient flows (and the prevention of run-off) are critical to the restoration and high performance of Saltmarsh areas.

3.3.1.6. Displacement

The literature is unclear around displacement, but it seems likely that the prevention of trawling in particular are is likely to result in trawling activity taking place in another region. However, if the altered trawling locations are away from seagrass areas it is likely that the benefits will outweigh any costs.

3.3.1.7. Maintenance and Longevity

Specific steps may be required to protect sensitive areas or habitats from human and commercial practices. Creation and maintenance of habitats involves the identification of appropriate areas to implement regulation to create, protect and develop habitats. Policing of the restrictions is required to enable the ongoing success of protected areas. Upstream work may be required to minimise and prevent run-off into sensitive areas like Saltmarsh.

Ultimately a significant amount of maintenance and intervention is required on an ongoing basis to manage the restoration and enhancement of coastal areas. The following activity is recommended by the team which created the “Blue Carbon Restoration in Northern Ireland – Feasibility Study”.

1. Recognise the full extent of blue carbon ecosystems present in MPAs
2. Act on operations likely to cause deterioration or disturbance and take the additional management measures needed not to secure blue carbon values of well documented blue carbon ecosystems
3. Map extent and quality of the carbon value of less well documented carbon ecosystems within current MPAs and implement relevant management measures
4. Designate new MPA based primarily on the carbon values for blue carbon ecosystems that lie outside existing MPAs rather than just focusing on traditional biodiversity value alone
5. Take measures to complement the MPAs using tool such as MSP and fisheries management to recognise, protect and best manage blue carbon across seascapes

The following information is specific to seagrass recovery and was created by the same team:

- Fully understand local conditions and pressures prior to selecting a restoration site, including sediment type (<57% silt and clay content and not too much gravel), proximity to shellfish reefs that may improve local conditions (Strong *et al.,* 2021).

- At a localised spatial scale, replicate planting in plots at (for example) different depths or elevations, over tens to hundreds of meters, which can mitigate against localised variation in habitat condition whereas variation in choice of habitat type (e.g. variation is sediment type, hydrodynamic regime) can improve success at a kilometre scale;

- Try staggered planting between years or on different dates throughout a planting season within a year can mitigate against stochastic events such as storms. This approach to ‘spreading risk’ implies a requirement for large scale restoration;

- Optimise techniques to account for ecosystem engineering effects of seagrass. For example, anchoring techniques or the use of biodegradable matting/hessian bags can facilitate plant establishment and promote sediment stabilisation especially in areas with bioturbators such as the lugworm Arenicola marina;

- Commit to long-term monitoring as recovery of below-ground biomass could take between 4-6 years.

3.3.1.8. Climate Adaptation or Mitigation

There is the potential for some aspects of climate change to alter coastal habitats. Some species are temperature sensitive and any significant rise in sea temperature or permanent change in current flows could alter the species balance and consequently, the carbon sequestration potential of the habitats.

3.3.1.9. Climate Factors / Constraints

There are no apparent environmental constraints around considered intervention and protection of coastal habitats. The intervention contributes mainly to mitigation and the outcomes do not appear to be at risk from climate change.

3.3.1.10. Benefits and Trade-offs to Farmer/L-and manager

The protection of marine protected environments bring no apparent benefits to those who make a commercial living in the sea, beyond the unproven benefits around species regeneration. The potential loss of commercial fishing grounds is a significant negative for those who make a commercial living around these habitats.

There may be some small associated benefits for farmers whose land drains into Saltmarsh areas. Action to prevent run-off may lead to more effective use of nutrients on those farms, reducing nutrient input and cost of production. Incentives (new or existing) for altering farming activity to facilitate the natural development of coastal wetlands should be considered.

3.3.1.11. Uptake

There are significant barriers around the ongoing management and enhancement of coastal habitats. Much of the current damage is a result of commercial operations and legislation or regulation is often necessary to prevent these operations taking place. Policing of any regulations is necessary to prevent damage taking place particularly at Seagrass sites, but also around shellfish beds and Saltmarsh areas.

The prevention of run-off (necessary to manage salt-marsh areas) requires that individual inspection or extension officers to work with farmers in catchment areas for this type of habitat. This carries significant social challenge, a significant economic cost through the requirement for investment in advice and regulation and potentially grant funding to address identified structural faults.

Regulation can be difficult to implement and can face opposition from those whose livelihoods could be affected. In addition, the prevention of run-off and groundwater contamination (necessary to manage salt-marsh areas) requires that individual extension officers work with farmers in catchment areas for this type of habitat. This carries significant challenge and requires investment in advice and regulation.

A key issue is that farmers have little influence on coastal habitats such as seagrass since they are usually outside the farm area and are considered to be non-productive within the farming context. Saltmarsh is likely to be the only habitat where farmers have a management role. The main influence by farmers is the input of nutrients, manure and pollutants to the coastal areas particularly estuaries.

3.3.1.12. Other Notes

The key metrics will include total area of habitat restored, area under effective management, plant and species density, root volume etc.

3.3.1.13. Summary and Table

It is very clear that management of coastal habitats will positively impact Carbon Storage. However, evidence around ideal interventions and the extent of impact of those interventions on Carbon storage, and economic or leisure activity in those areas. Further research is required around these topics. An important issue is to identify who has management responsibility.

This bundle is focused on exploiting the potential for the development of coastal habitats to mitigate climate change through the restoration of coastal habitats. Human activities are responsible for the degradation of many of these environments and in the UK, it is estimated that seagrass loss amounts to between 84 and 92% (Green *et al.,* 2021).

The activity within this bundle crosses more than one Ecosystem service, but can be predominantly classified as being under "*Maintaining habitats, nursery populations (and other stages of life cycles)".*

3.3.2. ECCA-033C: Create coastal habitats to compensate for losses to climate change as part of a coastal management plan

This section is focused on the creation and protection of coastal habitats and ecosystems, enabling population by species which mitigate or reverse GHG release into the atmosphere.

Coastal regions are typically defined as areas within 1 nautical mile of the land-sea interface, and include a range of marine, terrestrial and freshwater habitats. These habitats provide a number ecosystems services including the support of charismatic and endangered animal and plant species, remediation of anthropogenic pollutants, support for fisheries, agriculture and aquaculture. More recently, coastal habitats have recognised for their potential to sequester carbon (locking away carbon dioxide and other Green House Gases) across a range of ecosystems.

These habitats has been shown to substantially increase the ability of ecosystems to sequester carbon if appropriate protection and management procedures can be put in place, including restrictions on specific land use practises and human extractive activities such as fishing (refs needed here). As such, the effective management of these systems to enhance carbon sequestration represents one facet within a complex matrix of environmental planning decisions.

3.3.2.1. Causality

Blue Carbon refers to carbon which is captured within marine and coastal environments. These environments contain habitats such as saltmarshes, seagrasses, kelp beds, biogenic reefs and, most importantly, sedimentary stores, all of which have the ability to store and lock up carbon (Strong *et al.,* 2021)

Causality is firmly established in the scientific literature. Well managed coastal environments have the ability to sequester large amounts of carbon. A study by Ulster Wildlife showed that existing marine protected areas (essentially well managed habitats) around the coast of Northern Ireland have the ability to sequester 31,595 tonnes of Carbon per year – and by extension the creation of these habitats around the UK are capable of sequestering many times this amount.

The maintenance and enhancement of these sites has been demonstrated to significantly increase the amount of carbon sequestered. Carbon sequestration rate of the inshore MPA network in Northern Ireland is estimated to be 14,707 t C per year, but is suggested that there is the potential to triple the blue carbon value of the MPA network to 52,958 (t C yr-1) through effective protection and habitat restoration/creation within the MPA network. This also shows the potential for the coastal areas around Great Britain. These ecosystems currently sequester and store around 2% of UK emissions per year, but have the potential to store much more.

Disturbance of marine ecosystems may result in release of stored carbon and thereby contribute to climate change, but the exact volume released is unknown. The UK Government needs to pilot new approaches to protecting blue carbon, particularly though the creation of Marine Protected Areas.

Blue carbon is not yet included in the UK's Nationally Determined Contributions (NDCs) to the Paris Agreement, in the first round of NDCs 28 countries included some kind of reference to 24 coastal wetlands in their mitigation actions, while 59 countries included coastal ecosystems or coastal zones in their adaptation strategies. Guidance is also now available for incorporating blue carbon ecosystems in NDCs: https://www.thebluecarboninitiative.org/policy-guidance10 and it is likely that blue carbon will be considered by the UK (and Northern Ireland) in the NDCs in the near future as part of the strategy to reach net zero by 2050.

The main threats to blue carbon habitats are physical disturbances, climate change, and land-use and land management changes. In the UK, it is estimated that between 84 and 92% of seagrass has been lost due to human intervention (Green *et al.,* 2021). Similar drastic reductions are found in the other major coastal carbon store: saltmarshes. Recent studies have found that up to one third of saltmarsh area has been lost globally (Gedan *et al.,* 2009) and changes in sea level means that the saltmarshes in Northern Ireland will come under unprecedented pressure.

The delicate balance of these coastal systems is such that if they become degraded or unprotected from threats, blue carbon habitats may release their stored carbon, becoming a future source of carbon emissions rather than providing a highly efficient ecosystem service of carbon sequestration (Green *et al.,* 2021)

3.3.2.2. Co-Benefits and Trade-offs

Marine ecosystems also provide a significant range of benefits including raised biodiversity, flood protection and support for valuable fish and shellfish populations.

There may be some trade-offs associated with the creation of protected coastal habitats, mainly around the prevention of fishing or other economic activity in the specific marine environment. The creation and maintenance of protected marine environments may also require changes to economic activity on coastal land, and potentially also infrastructure change.

3.3.2.3. Magnitude

The earliest studies on blue carbon focussed on three coastal habitat types: saltmarsh, seagrass, and mangroves. Obviously mangroves do not have relevance to the UK, but saltmarsh and seagrass are very important to the UK environment. All three of these habitats have guidelines in the Intergovernmental Panel on Climate Change (IPCC) to allow them to be included in national GHG inventories.

Effect of Seagrass
The importance of the role of seagrass beds in carbon sequestration is now widely recognised (Green *et al.,* 2018; Fourquean *et al.,* 2012). Fourquean *et al.,* 2012 stated that seagrass beds were of equivalent importance to forests in terms of their ability to store carbon. They suggested that there was an estimated global carbon pool for seagrass areas between 4.2 and 8.4 Pg (10^{15}). As previously stated, seagrass areas are vulnerable to a rage of disturbances. Fourquean *et al.,* (2012) estimated that seagrass beds occupy 0.2% of global ocean area, they account for 10% (27.4 Tg 10^{12}) of the total carbon absorbance.

Carbon sequestration varies between species (Fourquean *et al.,* 2012), with large rooted organisms having the greatest potential to store Carbon.

On the south coast of England, Green *et al.,* (2018) estimated sedimentary carbon stocks in *Zostera marina* meadows to be between 98.01 and 140.24 t C ha^{-1} (within the top 100 cm), a value just below the global average of 194.2 t C ha^{-1}. They stated that *"For southern England, this was translated into a standingstock of 66,337 t C (within the top 100 cm), over an area of 549.79 ha and is thought to be equivalent to the annual* CO_2 *emissions of 10,512 people".*

Saltmarsh

A remarkable fact is that saltmarshes have one of the highest carbon burial rates of any natural system on the planet (with the highest carbon burial rate per unit area of all blue carbon habitats). They store a mean of 244.7 ± 26.1 g C m−2 yr−1, much larger than long-term burial rates from temperate, tropical, and boreal forests, which range from 0.7 to 13.1 g C m−2 yr−1 (Theuerkauf *et al.,* 2015), ten times larger than that of typical fjord systems (22.5 ±15.6g OC m−2 yr−1) and two orders of magnitude higher than the deltaic and non-deltaic continental shelves (2.6±0.9g C m−2yr−1) (Cui *et al.,* 2016) . This highlights the important role these fringing marshes do in mediating terrestrial nutrient fluxes into the marine environment (50-60% of carbon buried in fjord systems is terrestrially sourced). As an example of this disproportionate importance; average farmland stores one tonne of carbon per hectare compared to 60 tonnes per hectare in the top 0.1 m of saltmarsh. As for carbon sequestration, farmland can act as a net emitter of carbon, whilst saltmarsh can sequester 0.64–2.19 t C ha-1 y-1 (equivalent to 2.35–8.04 t CO2e ha-1 y-1) (Gregg *et al.,* 2021).
Like Seagrass, Saltmarsh also has a high capacity for carbon sequestration, with the vast majority being associated with the soil rather than the actively growing vegetation. In a UK-wide study, Beaumont *et al.,* (2014) estimated the total carbon stock to be 5995 t, with 5413 t being associated with the soil and 452 t being associated with the below ground biomass. Sequestration rates in UK saltmarsh are estimated to range from 64 to 219 g C $m^{-2}yr^{-1}$, which equates to 8.04 tonnes CO_2 / ha /year (Beaumont *et al.,* 2014).

It is important to note that the carbon sequestration capacity of saltmarsh is age-dependent with created or restored marshes taking approximately 100 years to achieve the rates of carbon accumulation measured in natural marshes (Burden *et al.,* 2019).

Furthermore, in coastal vegetated habitats (e.g. mangrove, saltmarsh and seagrass), sedimentary conditions that favour organic carbon storage (through reducing the rate of aerobic microbial degradation) may enhance the release of other potent greenhouse gases such as methane and nitrous oxide (Roughan *et al.,* 2018; Rosentreter *et al.,* 2021). This issue has been found to be exacerbated in hypernutrified systems (Roughan *et al.,* 2018). Furthermore, excess nitrogen in saltmarsh ecosystems has been found to reduce the below ground biomass leading to accelerated microbial decomposition of organic matter, thus increasing emissions (Roughan *et al.,* 2018). Therefore, there is a high degree of spatial variability and a high degree of uncertainty regarding the role of these habitats in greenhouse gas regulation and climate change mitigation.

It is clear from the literature that the ongoing management of Saltmarsh areas is critical to the ability of the habitat to sequester/retain GHG.

Shellfish beds

Shellfish beds are also acknowledged as an important Carbon Sink. Fodrie *et al.,* (2017) and Lee *et al.,* (2020) both describe oyster beds as being a significant carbon sink,although Fodrie *et al.,* (2017) also found that they could act as a source of carbon, depending on location and substratum characteristics. Carbon deposition rates of 21 t C ha^{-1} yr^{-1} were recorded in shallow subtidal and saltmarsh fringing oyster beds, respectively, whereas 7.1 t C ha^{-1} yr^{-1} was released from oyster beds on intertidal sandflats (Fodrie *et al.,* 2017). However, these figures suggest that accumulation outweighs loss. Lee *et al.,* (2020) found that oyster beds could enhance sedimentation and carbon deposition three-fold. However, more recent AFBI work suggests that this is not always the case, and the evidence remains inconclusive.

Literature relevant to the blue mussel's (*Mytilus edulis*) potential contribution to blue carbon storage is sparse. In optimal conditions *Mytilus edulis* can reach a shell length of 60-80 mm within two years, but in the high intertidal zone growth rate is significantly lower, and mussels may take 15-20 years to grow to nearly 20-30mm in length (Seed & Suchanek, 1992). Standing stock biomass and carbonate production rate will therefore be heavily dependent on local conditions and no single set of values can accurately represent all cases.

Kelp

Kelp has potential to fix carbon (Wilmers et al, 2012) but is not able to store carbon because it grows on hard substances and is unable to bury or accumulate Carbon. However, Kelp does have a high above ground biomass and, as a result is a dynamic reservoir for Carbon. The ultimate fate of Carbon produced from marine algae will depend on local conditions, with some being quickly recycled into the marine and coastal environments whilst at least some has the potential to be transported to deeper water and become locked into the sedimentary deposits.

Coastal sediments

As we have seen above with kelp and other sources of marine carbon the proportion which is recycled compared to sequestered is uncertain but we do know that deep or undisturbed sediments lock Carbon for thousands of years. Of particular relevance to this carbon accounting is the amount held in the undisturbed sediments in nearshore environments such as loughs (Table 1).

Table 1 Comparison of estimated carbon stocks in fjord systems UK/Ireland (Smeaton & Austin 2019).

LOCATION	ORGANIC CARBON STOCK IN TOP 10 CM OF SEDIMENT (TONNES)
LOUGH FOYLE	316,765
BELFAST LOUGH	228,882
WEXFORD BAY	213,091
LARNE LOUGH	206,962
LOUGH SWILLY	199,772
STRANGFORD LOUGH	190,359

Depth integrated carbon stores are typically two orders of magnitude larger than surficial sediments so Strangford may contain ~20 Mt of organic carbon (depends on volume and composition of post-glacial sedimentation). For comparison Lough Torridon, which is slightly smaller in area, is estimated to contain 14.2 Mt of organic carbon (Smeaton & Austin 2019). Understanding the carbon stock (first order estimate is that 45% of total biomass consists of C) and metabolism of coastal wetlands depends on having an accurate understanding of their spatial distribution. As well as subtidal sediment intertidal mudflats are also part of the continuum of important sedimentary carbon stores and may be impacted by future climate change and sea level rise.

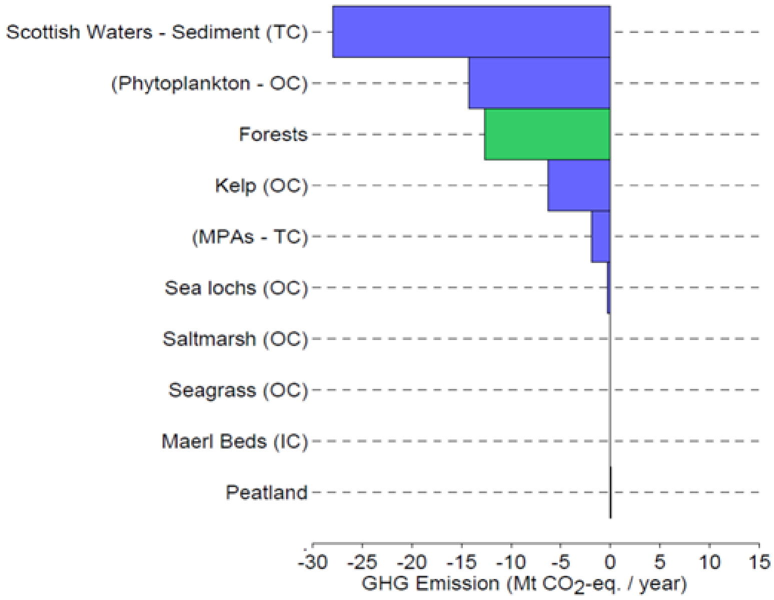

Figure 2: Representing the importance of various marine habitats for carbon storage in Scottish waters (Turrell, 2020). The importance of sediment is clearly demonstrated.

3.3.2.4. Timescales

Timescales from implementation to recovery is dependent on the species which are targeted for recovery and the condition of the existing ecosystem. The literature indicates the following:

- Recovery of below-ground biomass (Seagrass) could take between 4-6 years. (Strong *et al.,* 2021).
- The literature is divided on the timescales for recovery of kelp grounds, and it seems that this is affected by the specific local conditions. Some literature suggests that recovery could occur on a timescale between 4-6 years (Guiry, 1997, McLaughlin et al 2006), whereas others suggest that recovery might take decades (Hill and White 2008).
- Timelines for recovery of saltmarsh are unclear, particularly if the key challenge is around nutrient overload, but existing literature indicates a requirement for multiple decades. Garbutt and Wolters (2008) found that 0-50 and 51-100 year old sites had reduced species richness than 101+ year old sites, showing that protection measures around saltmarsh must be designed decades ahead.
- Building of shellfish beds can take 10-20 years (Seed & Suchanek, 1992), but, with careful management, aquaculture can deliver the building of beds more quickly.

3.3.2.5. Spatial Issues

A range of areas around the UK coast are suitable for the creation of habitats which can sequester carbon. Obviously specific, appropriate areas must be chosen for each specific habitat as only certain areas will be suitable for certain ecosystems or habitats.

A range of human activities must be considered when specific areas are being chosen. Commercial activity impacts heavily on potential seagrass areas (particularly sea bed trawling), while nutrient flows (and the prevention of run-off) are critical to high performance of Saltmarsh areas.

3.3.2.6. Displacement of fishing activity

The literature is unclear around displacement, but it seems likely that the prevention of trawling in particular are is likely to result in trawling activity taking place in another region. However, if the altered trawling locations are away from seagrass areas it is likely that the benefits will outweigh any costs.

3.3.2.7. Maintenance and Longevity

Specific steps may be required to protect sensitive areas or habitats from human and commercial practices. Creation and maintenance of habitats involves the identification of appropriate areas to implement regulation to create, protect and develop habitats. Policing of the restrictions is required to enable the ongoing success of protected areas. Upstream work may be required to minimise and prevent run-off into sensitive areas like Saltmarsh.

Ultimately a significant amount of maintenance and intervention is required on an ongoing basis to manage the restoration and enhancement of coastal areas. The following activity is recommended by the authors of the “Blue Carbon Restoration in Northern Ireland – Feasibility Study” (Strong *et al.,* 2021).

1. Recognise the full extent of blue carbon ecosystems present in MPAs
2. Act on operations likely to cause deterioration or disturbance and take the additional management measures needed not to secure blue carbon values of well documented blue carbon ecosystems
3. Map extent and quality of the carbon value of less well documented carbon ecosystems within current MPAs and implement relevant management measures
4. Designate new MPA based primarily on the carbon values for blue carbon ecosystems that lie outside existing MPAs rather than just focusing on traditional biodiversity value alone

5. Take measures to complement the MPAs using tool such as MSP and fisheries management to recognise, protect and best manage blue carbon across seascapes

The following information is specific to seagrass recovery and was created by the same team:

- Fully understand local conditions and pressures prior to selecting a restoration site, including sediment type (<57% silt and clay content and not too much gravel), proximity to shellfish reefs that may improve local conditions (e.g. via improving water quality)
- At a localised spatial scale, replicate planting in plots at (for example) different depths or elevations, over tens to hundreds of meters, which can mitigate against localised variation in habitat condition whereas variation in choice of habitat type (e.g. variation is sediment type, hydrodynamic regime) can improve success at a kilometre scale;
- Try staggered planting between years or on different dates throughout a planting season within a year can mitigate against stochastic events such as storms. This approach to 'spreading risk' implies a requirement for large scale restoration;
- Optimise techniques to account for ecosystem engineering effects of seagrass. For example, anchoring techniques or the use of biodegradable matting/hessian bags can facilitate plant establishment and promote sediment stabilisation especially in areas with bioturbators such as the lugworm Arenicola marina;
- Commit to long-term monitoring as recovery of below-ground biomass could take between 4-6 years.

3.3.2.8. Climate Adaptation or Mitigation

There is the potential for some aspects of climate change to alter coastal habitats. Some species are temperature sensitive and any significant rise in sea temperature or permanent change in current flows could alter the species balance and consequently, the carbon sequestration potential of the habitats.

3.3.2.9. Climate Factors / Constraints

There are no apparent environmental constraints around considered intervention and protection of coastal habitats. The intervention contributes mainly to mitigation and the outcomes do not appear to be at risk from climate change.

3.3.2.10. Benefits and Trade-offs to Farmer/Land manager

The development of marine protected environments brings no apparent benefits to those who make a commercial living in the sea, beyond the unproven benefits around species regeneration. The potential loss of commercial fishing grounds is a significant negative for those who make a commercial living around these habitats.

There may be some small associated benefits for farmers whose land drains into Saltmarsh areas. Action to prevent run-off may lead to more effective use of nutrients on those farms, reducing nutrient input and cost of production. Incentives (new or existing) for altering farming activity to facilitate the natural development of coastal wetlands should be considered.

Seabed Sediment

98% of the total organic carbon is stored in seabed sediments like sand and mud. Seabed sediments are thus by far the most important habitat for carbon storage in the region. We have no mechanism for 'restoring' these habitats – their protection relies on spatially managing activities so as not to disturb these sediments (Burrows *et al.,* 2021). Thus, measures which prevent disturbance contribute to maintaining Carbon storage. Measures which encourage the laying down of sediment promote the storage of Carbon in the seabed.

Salt Marsh

In a review to inform a feasability study for blue carbon restoration in Northern Ireland Strong *et al.,* (2021) stated that *"Restoration of saltmarsh through managed realignment seems the most valuable coastal blue carbon initiative in terms of quick impact. Still, it comes at a high cost due to land prices, coastal access etc. To overcome this, restoration practitioners must have good community negotiations. Furthermore, the infrastructure is visible and of public interest, and reclamation of land for restoration can be seen as loss of agricultural land, reaffirming that community engagement and education is vital. There is an opportunity to demonstrate the ecological and economic benefits of using land in this way which should include sea defence renewal costs and be incorporated into any decision making on where and when managed realignment of salt marsh should be selected."*

Sea Grass

Strong *et al.,* (2021) stated that **"***There is a growing body of evidence to suggest that restoration measures should be possible for Seagrass. Community buy-in is important for seagrass restoration projects to reduce pressures as these habitat areas tend to be multiple use e.g. fishing, diving, boating etc. Community support can also be an excellent source of person power. The process of collecting seeds, preparing materials (e.g. hessian bags with seeds), planting and monitoring requires not only monetary resources, equipment and time, but also many working hands. However, experts are required and this adds to the cost of a seagrass restoration project. Surveying and monitoring of the planted seagrass is required approximately every 2 months, and this may have to be done by divers."*

Shellfish Beds

Strong *et al.,* (2021) stated that **"***For some habitats, there is a strong body of evidence to suggest that restoration measures should be possible. Some restoration and creation methods rely on the sourcing or harvesting of seed or brood stock (e.g. establishing Zostera spp. or O. edulis beds), and in many cases suitable sources may be scarce or themselves located within existing marine protected areas. However, there may be opportunities to partner with organisations that have expertise or management oversight of these existing resources. Measures of success should be set in a historic context and baseline data is required which is not available for all blue carbon habitats. Measures of habitat extent, carbon sequestration rates, estimated total carbon storage and pressure layers are required. An inventory of all blue carbon habitats should be developed as well as a national strategy which prioritises blue carbon habitats and areas for creation, restoration and preservation.*

Preservation of habitats through the removal of anthropogenic pressures such as pollution, mooring or fishing can be a highly efficient approach and must be considered alongside the creation of new blue carbon habitats in places they are currently not existing, and the restoration of current habitats. And while there are limitations to blue carbon habitat data there must be a balance between gaining evidence while also putting protection in place to prevent further habitat degradation."

Kelp and other seaweeds

Strong *et al.,* (2021) stated that **"***Kelp has potential to fix carbon (the process by which inorganic carbon is converted to organic compounds by living organisms), but unlike other vegetated coastal ecosystems like seagrass, do not have the ability to store carbon. This is because kelp grows on hard substrates like rock and so cannot bury or accumulate carbon in soils or sediments. Nevertheless, kelp habitat has a large aboveground biomass with high detritus export rates and therefore represent substantial carbon stocks that could sequester carbon through processes other than local burial, such as burial of allochthonous detritus in deep sea sediments in coastal areas (>400 m).*

Across the UK the most common approach to managing kelp forests is through preservation i.e. to avoid, prevent or limit habitat degradation and loss primarily caused by anthropogenic activities. For example, 'Help Our Kelp' plans to restore Sussex kelp forests through the introduction of a new bylaw to prevent trawling within 4km of the coastline, which will allow natural regeneration. The 'Help The Kelp' project successfully campaigned for the prohibition of dredging of kelp in the context of increasing demands for wild kelp from pharmaceutical, food processing and textile industries."

3.3.2.11. Uptake

There are significant barriers around the ongoing management and enhancement of coastal habitats. Much of the current damage is a result of commercial operations and legislation or regulation is often necessary to prevent these operations taking place. Policing of any regulations is necessary to prevent damage taking place particularly at Seagrass sites, but also around shellfish beds and Saltmarsh areas.

The prevention of run-off (necessary to manage salt-marsh areas) requires that individual inspection or extension officers to work with farmers in catchment areas for this type of habitat. This carries significant social challenge, a significant economic cost through the requirement for investment in advice and regulation and potentially grant funding to address identified structural faults.

Regulation can be difficult to implement and can face opposition from those whose livelihoods could be affected. In addition, the prevention of run-off and groundwater contamination (necessary to manage salt-marsh areas) requires that individual extension officers work with farmers in catchment areas for this type of habitat. This carries significant challenge and requires investment in advice and regulation.

3.3.2.12. Other Notes

The key metrics will include total area of habitat restored, area under effective management, plant and species density, root volume etc.

3.4. LIVESTOCK MANAGEMENT/FEEDING STRATEGIES

This management bundle considers the effectiveness of optimised livestock feeding as a tool for reducing GHG emissions. It includes (but is not limited to)

Active diet and feed planning management to match animal requirements
Using more high starch and reduced crude protein in diet
Using ad lib feeding system
Using phase feeding of livestock

3.4.1. **ECCM-013 Active diet and feed planning management to match animal requirements:**

This action considers the impact of active diet and feed planning to match animal requirements on the GHG production of that animal. It includes consideration of precision feeding in terms of requirement-based allocation and the use of ruminant feed additives.

In 2019 the UK adopted a binding target to achieve Net Zero greenhouse gas (GHG) emissions by 2050. The production of food is associated with emission of Greenhouse Gases which are contributing to climate change. Agricultural activities were responsible for 10% of total UK GHG emissions (45.4 of 451 $MtCO_2e$) in 2018, while forests and grasslands sequestered 27 $MtCO_2e$, and other land use activities released 17 $MtCO_2e$ emissions (Brown *et al.,* 2020). To achieve the Net Zero emission target, agriculture will need to reduce emissions from its production activities and increase its potential to sequester carbon, both directly, on agricultural land, and indirectly, via increasing its productivity and thus reducing demand for land.

There are many strategies which have the potential to greatly reduce GHG production per unit of output and to quantify the on-farm emissions reduction potential, practices must be fully evaluated to quantify the mitigation cost, calculate the cost-effectiveness, and the cumulative GHG abatement. This systems approach needs to consider all aspects of mitigation on-farm and the costs of implementation.

One approach is precision livestock feeding which aims to match nutrient supply precisely with the nutrient requirements of the individual animal. The benefits include greater economic returns, reduced excretion to the environment, and improved efficiency of resource utilisation. Producers will become more competitive and have more market opportunities if they can demonstrate increased resource use efficiency, whilst reducing the environmental footprint.

Within any system, the most efficient animals are consuming less feed than the average of the group but maintaining similar or better levels of production. In any group of animals there will be a proportion over consuming which results in inefficiency. Furthermore, over-consumption, especially in ruminants, has been shown to impair digestibility; digestibility decreases as DMI increases (Sauvant *et al.,* 2018).

3.4.1.1. Causality

The relationship between animal feeding and GHG emissions is established and is rated green.

- Precision feeding provides opportunities for reducing the feed conversion ratio of animals, and as less feed would be used, GHG emissions from feed production would be reduced. Applying a feed restriction to the less efficient animals may then improve their feed efficiency without compromising their production performance. Historically, studies into feed restriction have resulted in significant reductions in production; however, these studies applied restrictions to all animals (Herve *et al.,* 2019). The use of technology now allows the development of feeding programmes for individual animals, allowing those less efficient to be feed restricted (whilst still meeting the essential nutrient requirements of the animal to ensure that health and welfare are not compromised). Precision feeding improves feed efficiency without impairing performance (Pino *et al.,* 2018) by reducing the intake of less efficient animals. This approach will reduce overall methane output per animal and it can also reduce the rate of nitrogen and volatile solid excretion and therefore the N_2O and CH_4 emissions arising during manure management. This approach is applicable primarily to housed animals that can be monitored at regular intervals, and the information used to adjust rations, i.e. dairy cattle and pigs, and chicken. Precision feeding can improve the environmental sustainability of the production system.

The relationship between the use of ruminant feed additives and GHG emissions is established and is rated green.

- 3NOP (3-nitrooxypropanol) is a chemical that reduces the production of enteric methane by ruminants when added to their rations. It does so by reducing the rates at which rumen archaea convert the hydrogen in ingested feed into methane. Specifically, 3NOP inhibits methyl-coenzyme M reductase, the final step of CH_4 synthesis by archaea (Duin *et al.,* 2016).
- Nitrate addition can modify rumen processes to act as a hydrogen sink (Hristov *et al.,* 2013a; Leng, 2008), reducing the availability for Ch_4 production. The nitrate would (partially) replace other sources of nitrogen, such as non-protein nitrogen and soya, further improving nitrogen efficiency.

3.4.1.2. Co-Benefits and Trade-offs

The most obvious benefit of optimising livestock feeding systems to match animal requirements is the improved nutrient use efficiency, improved environmental footprint, and improved profit margins. This extends to drivers of whole farm efficiency such as reduced disease, lower replacement rates, improved fertility, improved age at first calving etc. Overall, these strategies have the potential to result in much more efficient production systems.

Trade-offs occur in through the requirement to spend additional management time on diet planning and monitoring of performance but have benefit for air and water quality.

3.4.1.3. Magnitude

The magnitude of impact is very difficult to estimate accurately as most models have limited data on actual methane outputs. However, based on current scientific data, these following estimates are as accurate as they can currently be.

- **Precision feeding**
    - This mitigation is estimated to reduce the gross energy requirement of dairy cows by 2% and reducing the nitrogen and volatile solid excretion of pigs by 2%.
    - Based on cost-effectiveness estimates, there was an annual benefit of £8.2 / head in profit across animal categories (Pellerin *et al.,* 2013; Pomar *et al.,* 2011).

- **Ruminant feed additives**
    - 3NOP (3-nitrooxypropanol): In a meta-analysis, Dijkstra *et al.,* (2018) found that the effect on enteric CH_4 emissions is as follows:
        - Dairy
            - -38.8%
        - Beef
            - -17.1%
    - Nitrate
        - The enteric CH_4 conversion factor is reduced by 17.5% (Eory *et al.,* 2015)

3.4.1.4. Timescale

These interventions represent significant changes within current farm practices, but are very achievable with the correct incentive for a farmer to implement each mitigation. The table below shows the expected timescales for response:

Component	Expected timescale	Reason	Size of benefit
Active diet and feed planning	Year 2	Active diet and feed planning promotes production efficiency and optimal nutrient utilisation, all of which can contribute significantly to reduced GHG emissions.	2-5%
Ruminant feed additives	Year 1	Ruminant feed additives offer almost immediate benefit.	17.5% reduction in CH_4

3.4.1.5. Spatial Issues

This management practice is broad-scope and can be applied to almost any geographical region.

3.4.1.6. Displacement

In general, the practices implemented will not result in displacement, and in actual fact may free up land for alternative use.

3.4.1.7. Maintenance and Longevity

The improvement of resource use efficiency at farm level will not only mitigate GHG emissions, but will also improve business sustainability and improve animal performance at farm level. This has multiple secondary benefits including better performance, reduced disease, and improved lifetime production.

The practice of implementing nutrient use efficiency strategies on-farm should become part of regular farm activity, and it is possible that incentives could be designed around the reporting and validation of these.

3.4.1.8. Climate Adaptation or Mitigation

The proposed strategies contribute to both adaptation and mitigation. These strategies are not affected by climate change, but have a positive impact on reducing emissions from agriculture systems.

3.4.1.9. Climate Factors / Constraints

The intervention contributes to both adaptation and mitigation. The implementation of improved farming practices is not affected by climate change, but some of the factors which would be recommended by the plan will be impacted.

3.4.1.10. Benefits and Trade-offs to Farmer/Land manager

The most obvious benefit of optimising livestock feeding systems to match animal requirements is the improved nutrient use efficiency, improved environmental footprint, and improved profit margins. This extends to drivers of whole farm efficiency such as reduced disease, lower replacement rates, improved fertility, improved age at first calving etc. Overall, these strategies have the potential to result in much more efficient production systems. Trade-offs occur in through the requirement to spend additional management time on diet planning and monitoring of performance.
Although proven to be effective in reducing CH_4 emissions, feed additive strategies can occasionally disrupt the natural rumen function and their misuse could lead to rumen disorders and potential health and other welfare problems (Llonch *et al.,* 2017).

3.4.1.11. Uptake

There are a number of factors which are likely to reduce the effectiveness of implementation. Many farms only measure feed consumption at a highly macro level, and do not carry out extensive monitoring of animal performance. As a consequence it may be difficult for many farms to assess the potential value of precision feeding which will lead to challenge around the assessment of cost benefit prior to investment and reduced uptake of the practice. Many farms are unaware of the financial effectiveness of active diet and feed planning. This lack of awareness means that there is limited or no drive for uptake.

Implementation for animals that are only grazed is not practical, however nearly all livestock in the UK are supplemented in some way, therefore it may still be implemented to some degree. Zero grazing may have some potential depending on accurate and timely analysis of the harvested grass.

3.4.1.12. Other Notes

Links to farm software / farm data from technologies implemented to deliver these mitigations should be part of the cross-compliance specification as a means of validating improvements and reduced emissions.

3.5. ENERGY OPTIMISATION TO REDUCE GREENHOUSE GASES

This bundle is focused on the delivery of control measures around energy which can reduce on-farm usage of energy, impacting the production of greenhouse gases.

This report considers only one main action – the effectiveness of an energy optimisation plan as a tool for reducing GHG emissions. The plan, in and off itself, will not reduce energy use (and hence emissions). Instead it will highlight areas of high energy usage and will cause farmers to investigate methods of energy (and cost) reduction. The value of the plan will vary according to farm type, with low intensity farms benefitting much less than intensive, high energy use farms.

The plan should cause farmers to consider multiple aspects of their farming practice from livestock management practices, farm installations, machinery type and use, farm inputs, land tillage procedures. An energy plan will work best when implemented in conjunction with well thought through machinery replacement plans and crop rotation/management plans.

3.5.1. ECCM-061: Create and use an energy consumption optimisation plan

Introduction

The production of food is associated with emission of Greenhouse Gases which are contributing to climate change. With farming systems there are a wide range of GHG emissions caused by differences in practice, machinery usage and inputs. The creation of an energy optimisation plan can identify areas for reduction in energy usage. This topic is almost stand alone. However a correctly produced energy management plan may recommend significant management or infrastructural changes at farm level. The size of any saving is dependent on the starting point of the farm and the actual interventions which are a) possible and b) actually implemented.

It is worth noting that GHG emissions arising from agricultural systems also include those resulting from the manufacture of inputs such as fertiliser and concentrate feed production. These emissions occur remotely and are not included in agriculture and LULUCF inventory reporting categories being accounted for in other countries' emissions inventories, or within the sub-inventories for other sectors e.g., chemical industry. A systems approach to GHG carbon footprinting can identify options for emissions reduction.

This systems approach needs to consider all aspects of energy use on-farm, and the energy costs of inputs purchased off-farm. Consideration of all areas of energy usage can identify hot-spots on which a farm manager can focus to reduce the energy cost of production.

Reductions in energy usage are associated with a drop in Greenhouse Gas production, but the exact volumes are dependent on the type and amount of fuel saved.

Intended outcomes include:

1) Measurement of all areas of energy use on-farm
2) Identification of areas of high energy use
3) Prompting of farmers to consider alternative practices or equipment to reduce energy use
4) Creation of an investment plan to replace inefficient machinery and practices
5) Implementation of new practice, equipment and machinery to reduce energy use
6) Ongoing measurement of energy usage on farm, ideally demonstrating a reduction in energy usage per unit of output.

3.5.1.1. Causality

The link between the creation of an energy consumption optimisation plan and a reduction in GHG output is proven because it guides the implementation of practices which are already proven to reduce consumption. Consequently the creation and implementation of an energy optimisation plan is given a green rating. The monitoring of energy usage is foundational to the ongoing reduction of energy usage at farm level.

As stated in the write-up for **ECCM-063**, target setting and monitoring around energy usage is associated with a strong reduction in energy utilisation. However, this requires the design of an appropriate plan. Any plan will involve the creation of targets which are themselves dependent on the creating of baselines through effective monitoring. Delivery against these targets is dependent on the robust monitoring of energy use and the implementation of measures to reduce energy use.

Where an optimisation plan can fail is in that many farmers do not recognise its effectiveness and treat it like another paper exercise. Consequently, at a whole industry level the causality rating may fall to amber.

3.5.1.2. Co-Benefits and Trade-offs

A range of economic, social and environmental benefits are likely to arise from the creation and implementation of an energy efficiency plan. These include reduced spend on fuel, improved business profitability, reduced GHG emissions and improved air quality.

There are no immediately identifiable trade-offs at an overview level, other than the management time which is necessary to create and effectively implement the plan.

Although the changes which may be implemented as a result of an energy optimisation plan are hugely disparate and the actual impact on a single farm is almost impossible to predict. However, it is possible to speculate and give examples of some specific trade-offs which may result from changes in management practice. One of the most obvious would be if a farmer moved to a minimum tillage system which is associated with a large reduction in fuel usage, but also, on many occasions, a reduction in yield. This would necessitate careful calculations around cost/benefit before it was implemented. Other trade-offs include the cost of purchase/lease of new, more efficient equipment and the environmental costs associated with the manufacture of this new equipment.

Each of these instances has to be considered on its own merits, within the specific context of each farming operation.

3.5.1.3. Magnitude

As previously stated, the magnitude of impact of effective farm energy optimisation plans is very difficult to estimate. The plans will cover a multiplicity of farm types, production systems, management systems and equipment that it is almost impossible to estimate the impact on an individual farm.

The best guide can be taken from case studies where the following potential benefits have been identified:

1. Reductions of up to 33% in fuel savings are possible if the engine revolutions are kept as low as possible (Farming for a Better Climate)
2. A blocked air cleaner could reduce power output by 30%, increasing fuel wasted to deliver the same job. (Farming for a Better Climate)
3. Direct drilling uses around 12 litres of fuel per hectare while ploughing, sowing and cultivating consume 60 litres/ha. (Farming for a Better Climate)
4. Taki *et al.,* (2016) identified potential energy savings delivered by the use of thermal screens in greenhouses. They state that *'The results of using thermal screen at night (12 h) in autumn showed that this method can decrease the use of fossil fuels up to 58% and so decrease the final cost and air pollution. This movable insulation caused about 15 °C difference between outside and inside air temperature…… The experimental results showed that inside thermal screen can decrease the crop temperature fluctuation at night.'* The reduction of temperature fluctuation improves growth of plants and reduces need for artificial temperature management which consumes energy.
5. Close monitoring of fuel use, identifies areas where potential savings can be made (Bangor University: Managing Energy and Carbon). It provides an early warning of potential/actual equipment or system failure. Potential savings of up to 50%.
6. A cross-flow drier with recirculation can save up to 30% compared to a basic cross-flow drier (Bangor University: Managing Energy and Carbon).
7. a mixed flow drier can save up to 50% compared to a basic cross-flow drier (Bangor University: Managing Energy and Carbon).
8. Dry aeration could save between 12-17%. Conversion of existing round bin system could be considered (Bangor University: Managing Energy and Carbon).
9. Use of an appropriate fan can save up to 60% of energy for ambient storage (Bangor University: Managing Energy and Carbon).
10. Avoiding unnecessary use of hot washing and too high a temperature, without compromising hygiene can deliver savings of up to 50% (Bangor University: Managing Energy and Carbon).

11. Pre-cooling through a plate cooler can reduce milk to within 2-3 °C of cooling water temperature and reduce electricity demand. Potential savings of up to 50 % are available (Bangor University: Managing Energy and Carbon).

The Bangor University document "Managing Energy and Carbon The farmer's guide to energy audits" identifies a wide range of potential savings which give an indication of the magnitude of potential energy savings. Some of these are shown above.

In reality, the magnitude of impact of a farm energy plan on GHG emissions for a livestock farm is relatively low as the main GHG factors are Nitrous Oxide and Methane. There will be much greater impact for greenhouses and vertical farming.

3.5.1.4. Timescale

As previously identified, a range of practices will be impacted by the introduction of a farm energy plan. If correctly implemented, impacts will be seen almost immediately. 15% of agricultural production costs are related to energy use[2] *(Introduction to Sustainable Farm Energy Use, Conservation and Generation* – farm-energy.extension.org)). This represents a significant proportion of farm profitability which can act as an incentive for a farmer to implement an energy optimisation plan. Any reduction in fuel is associated with a reduction in GHG emissions.

The table below shows the expected timescales for response:

Component	**Expected timescale**	**Reason**
Optimum fertiliser application	Year 1	Reduced fertiliser usage, reduced energy usage associated with its production and distribution to land
Optimisation of land operations	Year 1	Reduced fuel usage can result from the implementation of new land management strategies. This can be implemented in year 1.
Optimisation of animal systems	Years 2-5	Increasing growth rates of animals will reduce the amount of time taken to finish and the amount of feed used per unit of output. Suitable animals must be selected or bred to suit new systems.
Replacement of machinery with more fuel efficient equipment	Years 3-10	Equipment replacement is usually carried out on a planned basis, meaning that it takes longer to implement this recommendation.
Replacement of static equipment with more efficient equipment	Years 3-10	Equipment replacement is usually carried out on a planned basis, meaning that it takes longer to implement this recommendation.
Reduction of heated washes (without compromising hygiene).	Year 1	This system can be implemented almost immediately as it does not require replacement of equipment.
Implementation of energy meters	Years 1-5	Energy meters are designed to highlight significant energy loss. They do not save energy in an off themselves.
Replacement of energy inefficient lighting	Years 1-3	Lighting replacement will take place over time rather than a full replacement at one point in time.

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[2] https://farm-energy.extension.org/introduction-to-sustainable-farm-energy-use-conservation-and-generation/#:~:text=The%20quickest%2C%20cheapest%2C%20and%20cleanest%20way%20to%20lower,using%20high-efficiency%20motors%20%2C%20fans%20%2C%20and%2For%20lighting

The above table shows the expected timescale for the delivery of benefits following implementation of an energy optimisation plan. As can be seen from the above table, the timescales are dependent on the amendments which are chosen to reduce energy usage.

3.5.1.5. Spatial Issues

Farming practice and equipment are highly varied, but the application of energy plans is broadscale and can be applied to almost any business. Greatest scope for savings is for intensive farming operations e.g. dairy, poultry, arable, horticulture and indoor pigs, compared with more extensive operations e.g. sheep and beef.

3.5.1.6. Displacement

In general the practices implemented under an energy optimisation plan will not result in displacement. The focus of an energy optimisation plan is on the reduction of energy use. However, the replacement of equipment or machinery with more efficient equipment does have an energy cost associated with production.

Provided that replacement takes place on a planned basis and does not take place sooner than usual, there is no impact on overall energy production at a global level, but early replacement is associated with a raised cost. A calculation needs to be done under the energy efficiency plan for each piece of equipment to be replaced (from a lightbulb to a tractor) to determine the overall lifetime impact.

3.5.1.7. Maintenance and Longevity

The practice of implementing energy optimisation on-farm should become part of regular farm activity, and it is possible that incentives could be designed around the ongoing reduction of energy usage as a proportion of farm output.

The implementation, updating and operation against an Energy Optimisation plan does require the ongoing application of management time, and, ideally, a culture of continuous improvement.

3.5.1.8. Climate Adaptation or Mitigation

This action is not affected by climate change. It is stand alone and is part of a range of climate mitigation measures.

3.5.1.9. Climate Factors / Constraints

The intervention contributes to both adaptation and mitigation. The design of an energy optimisation plan is not affected by climate change, but some of the factors which would be recommended by the plan will be impacted.

3.5.1.10. Benefits and Trade-offs to Farmer/Land manager

A range of benefits can accrue from the creation and implementation of an energy reduction plan. The most obvious benefit of the energy optimisation plan is a reduction in energy usage on farm, reducing the cost of production.

A range of Trade-offs must be considered. These include:

1) The management time required to research, design and implement the energy optimisation plan
2) The economic value of improvements against the cost of putting those improvements in place
3) The environmental/energy benefits of new equipment against the cost of manufacture of that equipment
4) The energy reduction/yield implication of reducing land management or tillage practices.

3.5.1.11. Uptake

There are a number of factors which are likely to reduce the effectiveness of implementation. In general, most farms do monitor energy use at a macro level, but are unable to identify specific areas or hot spots. This is primarily due to the lack of metering or measurement of energy use of specific pieces of equipment or specific zones on farm.

Additionally, the administrative burden will be an issue for some farmers. A lot of farm business owners avoid paperwork wherever possible and this will impact the creation of some farm energy optimisation plans and will greatly reduce the accuracy of many other plans where farmers may input inaccurate figures to speed the process. Ideally some sort of verification of input data should be required.

A clear understanding of the benefits of an energy optimisation plan is critical to uptake. If farmers can be persuaded of the genuine benefits of reduced energy usage and the general ease of achieving this, uptake will be rapid and benefits will quickly accrue. If, on the other hand, the plan is seen as a ‘tick-box’ exercise, it will be treated as such and will not quickly impact practical activity. The increase in energy costs will provide an additional incentive to reduce energy consumption by auditing of farm operations.

3.5.1.12. Other Notes

Farm assurance could be used as a tool to verify that a farm energy plan has been completed, or a requirement to submit one could be a condition of receiving farm support.

Verification of the figures input can be verified through submission of meter readings, electricity bills, fuel bills, fertiliser bills etc. This could be checked during a farm assurance inspection, or a requirement could be made to submit these as a condition of farm support.

3.6. CLIMATE MEASURES

Introduction

CO_2 supplementation is the process of adding CO_2 to a captive environment to increase the rate of photosynthesis in plants. The benefits of CO_2 supplementation are well established in both scientific literature and commercial practice. One technique that could limit CO_2 emissions from human activities into the atmosphere is Carbon dioxide capture and storage, as opposed to the creation of CO_2 for the specific task. It involves collecting, at source, the CO_2 that is produced by power plants or industrial facilities and storing it away for a long time in underground layers, in the oceans, or in other materials

Development within the horticultural sector has included a focus on the introduction of advanced technologies, LED lighting, automation and balanced nutrient supplementation. In many cases the limiting factor to growth of plants is the availability of CO_2 for photosynthesis. There is a clear link between CO_2 concentration and plant growth, provided that other conditions for plant growth are optimal. The graph below shows this relationship, and has been produced by Poudell & Dunn from Oklahoma State University in 2017.

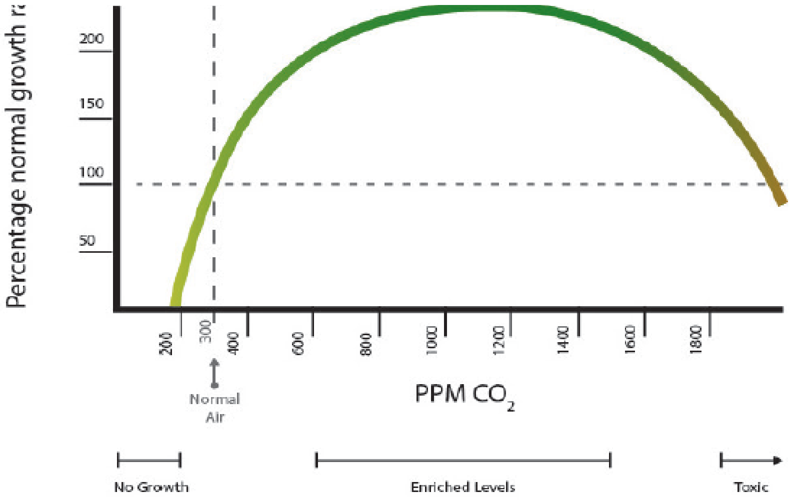

Figure 3: Relation between CO_2 concentration and rate of plant growth. Source: Roger H. Thayer, Eco Enterprises, hydrofarm.com. Redrawn by Vince Giannoti

Significant quantities of CO_2 are used in the process of atmospheric enrichment of the greenhouse environment. The current report examines published literature on the GHG effect of replacing the manufactured CO_2 with captured CO_2.

The Climate Measures section focuses on activity which can mitigate, reduce or reverse climate change.

Energy Optimisation to Reduce greenhouse gases
This section focuses on reducing or optimising energy usage to reduce the emissions of Greenhouse Gases or to reduce energy usage per component

3.6.1. **ECCM-062** Reuse of captured CO2 in greenhouses

This project is aimed at the reuse of captured CO_2 and the reduction in need to manufacture additional CO_2 with its associated impact on Climate.

3.6.1.1. Causality

The link between reuse of CO_2 and reduction of GHG emissions is Green. It is obvious that if CO_2 is re-used rather than created that there will be a reduction in overall CO_2 emissions. There is also a clearly established link in the literature between higher CO_2 concentration in Greenhouses and plant performance (where all other conditions are optimal).

Carbon Dioxide enrichment was originally implemented in vegetable production and then later in flower cultivation to increase yield and produce larger flower heads, stronger stems and decreased production times. Greenhouse vegetable, strawberry and flower crops grown in cold winter climates often show substantial increases in performance when additional CO_2 is added to the environment. However, the benefits of CO_2 supplementation reduce severely if the climate is very warm and high levels of greenhouse ventilation are required (Tjosvold, 2018). This finding is less applicable to England, but it is still possible that areas of the South East could become very hot at the height of summer and the benefits of CO_2 supplementation can be lost. The technique can also be successfully employed in vertical farming, with a similar effect on Carbon Dioxide usage.

Carbon Dioxide enrichment in greenhouses is now common practice in some European countries. It is achieved through a number of methods including; The supply of pure (liquid CO_2), Combustion of fossil fuel with Air Heaters, Combustion of fuels with a central burner, in combination with a heat storage tank.

To achieve the overall aim of reducing the amount of GHG's emitted and to reuse captured carbon dioxide rather than create more, the enrichment of greenhouses in the UK with CO_2 must come from captured CO_2. However, the extent of this practice in the UK is unknown and before any decisions can be made around incentivisation of the practice, work needs to be carried out to establish the current position.

Additionally, the method of capture of CO_2 is important because it impacts cost, quantity of CO_2 produced and the overall climate impact. Capturing GHG's was the focus of a recent UK Government report *Greenhouse gas removal methods and their potential UK deployment.* The report highlights the various methods that can be used to capture Greenhouse Gases and maps the current state of GHG capture in the UK.

Besides capturing carbon from fossil fuel plants directly, there are a variety of ways to remove CO_2 from the atmosphere (Cho, 2019). The problem is that many of these strategies are still relatively expensive and therefore will find little commercial traction.

Keith *et al.,* (2018) state that Direct Air Carbon Capture and Sequestration (*DACCS) is the removal of CO_2 directly from ambient air through chemical or physical methods, with an assumption of subsequent storage. This generally occurs in two stages – ambient air comes into contact with a chemical which captures the CO_2 from the air, and then the CO_2 is released from the chemical and collected for processing and permanent storage."*

Keith *et al.,* (2018) also state that *"There are relatively wide ranges of possible technology configurations for both the solid and liquid options (using different heat/electricity sources) which amplify the uncertainty around costs of CO_s capture. There is a wide range in the literature for DACCS costs – from ambitious cost targets of technology developers (\$100/tCO_2 or lower in the long-term) through to older evaluations used in some academic sources. The high end of cost estimates is likely to be out of date due to the fast rate of DACCS technology development, and the low end of the range is likely to be influenced by commercial considerations of technology developers and not applicable to the UK context"*

3.6.1.2. Co-Benefits and Trade-offs

The main benefit of captured CO_2 is seen in the reduction of CO_2 produced. Trade-offs are seen in the level of energy used to recover the CO_2 and in the overall cost of the process. The current methods of capturing CO_2 are costly, leading in most cases to commercial uncompetitiveness. This will change in the future as technology improves and the cost reduces.

3.6.1.3. Magnitude

The magnitude of the overall effect is fully dependent on the amount of CO_2 capture facilities which are implemented in the UK. The total volume of CO_2 used within Greenhouses in the UK is unknown, and there does not appear to be any literature to estimate this. Consequently the magnitude of the effect of this programme is difficult to estimate without additional information. There is considerable potential for the magnitude of effect to increase if the amount of vertical farming increases in the UK. This is a distinct possibility, although growth in this sector will initially be slow before accelerating.

3.6.1.4. Timescale

Captured CO_2 can immediately replace manufactured CO_2 in any greenhouse system, if it is available. However, the volume of recovered CO_2 produced in the UK is unknown, as is the total use of CO_2 in Greenhouses in the UK.

3.6.1.5. Spatial Issues

There are no spatial issues – the plan is Broad Scope, although it will be focused in specific parts of the country where there is a high concentration of greenhouse production.

3.6.1.6. Displacement

Displacement effects will not result from implementation of captured CO_2.

3.6.1.7. Maintenance and Longevity

The project does not require additional maintenance on behalf of the operators. It simply requires that the operator continues to purchase CO_2 from recovered sources.

3.6.1.8. Climate Adaptation or Mitigation

Capturing CO_2 is a mitigation policy which will not in itself be affected by climate change.

3.6.1.9. Climate Factors / Constraints

Use of captured CO_2 is affected by environmental temperature as greenhouses may have to be vented to control temperature, requiring additional CO_2 to be introduced into the system.

3.6.1.10. Benefits and Trade-offs to Farmer/Land manager

There are a significant range of benefits to farmers from the use of CO2 (regardless of its status as captured vs manufactured). The following benefits have been listed by Oklahoma State University (Poudell & Dunn 2017).

Advantages of use of CO2 in Greenhouses

- CO_2 enrichment enables an increase in photosynthesis resulting in increased growth rates and biomass production.
- Plants have earlier maturity and more crops can be harvested annually. The decrease in time to maturity can help in saving heat and fertilisation costs.
- In flower production, supplemental CO_2 increases the number and size of flowers, which increase the sales value because of higher product quality.
- It helps to reduce transpiration and increases water use efficiency, resulting in reduced water use during crop production.

Advantages of use of Captured CO2 in Greenhouses

- The use of captured CO_2 offers no advantage to the producer when compared to ordinary CO_2.
- The only advantage of captured CO_2 is the reduction of overall CO_2 production from unsustainable sources.

Disadvantages of use of Captured CO2

- Higher costs of captured CO_2 can raise costs of production
- Plants may not show a positive response to supplemental CO_2 because of other limiting factors such as nutrients, water and light. All factors need to be at optimum levels, requiring careful management
- CO_2 supplementation is more beneficial in younger plants.
- Additional costs are required for greenhouse modification. Greenhouses need to be properly sealed to maintain a desirable level of CO_2.
- Excess CO_2 level can be toxic to plants as well as humans.
- On warmer days, it is difficult to maintain desirable higher CO_2 levels because of venting to cool the greenhouses.

3.6.1.11. Uptake

A number of factors are relevant to the uptake of the captured CO_2 in Greenhouses in England.

- There are relatively few barriers to uptake at farm/producer level beyond any additional cost of recovered CO_2 and the cost of upgrading greenhouses to make them more air tight.
- A ready supply of captured CO_2 is necessary to enable widespread uptake at farm level. Without enough product, captured CO_2 cannot become an important part of the production chain.
- There is, however, a need to balance transport of the CO_2 from recovered sources against that for manufactured sources and the equation will differ for different units distributed across the country.
- A knowledge and expertise around how to best utilise CO_2 enrichment in greenhouses is a requirement, as is close consideration of the application within future vertical farms.
- At the Budget 2020, the Chancellor announced at least £800 million for a Carbon Capture and Storage Infrastructure Fund to develop Carbon Capture, Usage and Storage (CCUS) clusters in the UK. The Prime Minister's Ten Point Plan announced a further £200 million, increasing the fund to £1 billion, to establish four CCUS clusters by 2030, with the first two in the mid-2020s. This investment could help to support up to 50,000 jobs, potentially in areas such as the Humber, North East, North West, Scotland and Wales (UK Government, 2021).

3.6.1.12. Other Notes

None

3.6.2. **ECCM-063: Monitor Energy Consumption and Implement Targets**

Introduction

We exist in a world which has limited resource, but continually growing demand. The production of food is associated with emission of Greenhouse Gases which are contributing to climate change. With farming systems there is a wide range of GHG emissions caused by differences in practice, machinery usage and inputs. The creation of an energy optimisation plan can identify areas for reduction in energy usage. This topic is almost stand alone. However, a correctly produced energy management plan may recommend significant management or infrastructural changes at farm level. The size of any saving is dependent on the current performance of the farm. A high performing farm will have less improvement to make, whereas an underperforming farm will be able to improve much more easily.

It is worth noting that GHG emissions arising from agricultural systems also include those resulting from the manufacture of inputs such as fertiliser and concentrate feed production. These emissions occur remotely and are not included in agriculture and LULUCF inventory reporting categories being accounted for in other countries' emissions inventories and other sector inventories e.g. chemical industry. A systems approach to GHG carbon footprinting can identify options for emissions reduction.

This systems approach needs to consider all aspects of energy use on-farm, and the energy costs of inputs purchased off-farm. Consideration of all areas of energy usage can identify hot-spots on which a farm manager can focus to reduce the energy cost of production.

Reductions in energy usage are associated with a drop in Greenhouse Gas production, but the exact volumes are dependent on the type and amount of fuel saved.

Outcomes

The intended outcomes are as follows:

1) Measurement/audit of all areas of energy use on-farm
2) Identification of areas of high energy use
3) Prompting of farmers to consider alternative practices or equipment to reduce energy use
4) Creation of an investment plan to replace inefficient machinery and practices

5) Implementation of new practice, equipment and machinery to reduce energy use
6) Ongoing measurement of energy usage on farm, ideally demonstrating a reduction in energy usage per unit of output.

Climate Measures
The Climate Measures section focuses on activity which can mitigate, reduce or reverse climate change.

Energy Optimisation to Reduce Greenhouse Gases
This bundle is focused on the delivery of control measures around energy which can reduce usage, impacting the production of greenhouse gases.

Monitor Energy Consumption and Implement Targets
This report is very closely linked to **ECCM-061** "Create and use an energy consumption optimisation plan" and is essentially the practical implementation component of it.

Target setting and monitoring of progress is important and is a key component of reduced energy use (and hence emissions). Monitoring will highlight areas of high energy usage and will cause farmers to investigate methods of energy (and cost) reduction and to work towards targets for the farm. The value of the plan will vary according to farm type, with low intensity farms benefitting much less than intensive, high energy use farms.

3.6.2.1. Causality

The link between monitoring energy utilisation, target setting and a reduction in GHG output is proven and is rated Green. The monitoring of energy usage is foundational to the ongoing reduction of energy usage at farm level, albeit that the magnitude of the effect will be low if energy is a minor component of farm production.

As stated in **ECCM-061**, implementation of on-farm Energy Optimisation plans is associated with a strong reduction in energy utilisation, provided that the plan is implemented effectively. Effective creation of a plan is dependent on the creation of targets which are themselves dependent on the creating of baselines through effective monitoring. Effective implementation of a plan to deliver against targets is dependent on robust monitoring of energy use.

3.6.2.2. Co-Benefits and Trade-offs

A range of economic, social and environmental benefits are likely to arise from the monitoring of energy consumption and the setting of reduction or efficiency targets around them. Benefits include reduced cost of fuel, improved business profitability, reduced GHG emissions and improved air quality.

There are no immediately identifiable trade-offs at an overview level, other than the management time which is necessary to monitor energy utilisation and to implement the required changes.

At a more specific level, some trade-offs can be identified which may result from changes in management practice. As stated in the linked report (**ECCM-061**), one of the most obvious would be if a minimum tillage system was implemented. Minimum tillage is associated with a large reduction in fuel usage, but also, on many occasions, a reduction in yield. This would necessitate careful calculations around cost/benefit before it was implemented. Other trade-offs include the cost of purchase/lease of new, more efficient equipment and the environmental costs associated with the manufacture of this new equipment.

Implementation of farm energy optimisation plans is also being considered by the Air Quality review group.

3.6.2.3. Magnitude

The magnitude of impact of effective farm energy optimisation plans is very difficult to estimate. The plans will cover a multiplicity of farm types, production systems, management systems and equipment that it is almost impossible to estimate the impact on an individual farm.

The best guide can be taken from case studies where the following potential benefits have been identified:

1. Reductions of up to 33% in fuel savings are possible if the engine revolutions are kept as low as possible (Farming for a Better Climate)
2. A blocked air cleaner could reduce power output by 30%, increasing fuel wasted to deliver the same job. (Farming for a Better Climate[3])
3. Direct drilling uses around 12 litres of fuel per hectare while ploughing, sowing and cultivating consume 60 litres/ha. (Farming for a Better Climate)
4. Taki *et al.,* (2016) identified potential energy savings delivered by the use of thermal screens in greenhouses. They state that *'The results of using thermal screen at night (12 h) in autumn showed that this method can decrease the use of fossil fuels up to 58% and so decrease the final cost and air pollution. This movable insulation caused about 15 °C difference between outside and inside air temperature…… The experimental results showed that inside thermal screen can decrease the crop temperature fluctuation at night.'* The reduction of temperature fluctuation improves growth of plants and reduces need for artificial temperature management which consumes energy.
5. Close monitoring of fuel use, identifies areas where potential savings can be made (Bangor University: Managing Energy and Carbon). It provides an early warning of potential/actual equipment or system failure.
6. A cross-flow drier with recirculation can save up to 30% compared to a basic cross-flow drier (Bangor University: Managing Energy and Carbon).
7. a mixed flow drier can save up to 50% compared to a basic cross-flow drier (Bangor University: Managing Energy and Carbon).
8. Dry aeration could save between 12-17%. Conversion of existing round bin system could be considered (Bangor University: Managing Energy and Carbon).
9. Use of an appropriate fan can save up to 60% of energy for ambient storage (Bangor University: Managing Energy and Carbon).
10. Avoiding unnecessary use of hot washing and too high a temperature, without compromising hygiene can deliver savings of up to 50% (Bangor University: Managing Energy and Carbon).
11. Pre-cooling through a plate cooler can reduce milk to within 2-3 °C of cooling water temperature and reduce electricity demand. Potential savings of up to 50 % are available (Bangor University: Managing Energy and Carbon).

The Bangor University document "Managing Energy and Carbon The farmer's guide to energy audits" identifies a wide range of potential savings which give an indication of the magnitude of potential energy savings. Some of these are shown above.

In reality, the magnitude of impact of a farm energy plan on GHG emissions for a livestock farm is relatively low as the main GHG factors are Nitrous Oxide and Methane. There will be much greater impact for greenhouses and vertical farming.

3.6.2.4. Timescale

As previously identified, a range of practices will be impacted by the introduction of a farm energy plan. If correctly implemented, impacts will be seen almost immediately. 15% of agricultural production costs are related to energy use (Farm Energy, 2019). This represents a significant proportion of farm profitability which

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[3] Farming for a Better Climate - Farming for a Better Climate

can act as an incentive for a farmer to implement an energy optimisation plan. Any reduction in fuel is associated with a reduction in GHG emissions.

The table below shows the expected timescales for response:

Component	**Expected timescale**	**Reason**
Optimum fertiliser application	Year 1	Reduced fertiliser usage, reduced energy usage associated with its production and distribution to land
Optimisation of land operations	Year 1	Reduced fuel usage can result from the implementation of new land management strategies. This can be implemented in year 1.
Optimisation of animal systems	Years 2-5	Increasing growth rates of animals will reduce the amount of time taken to finish and the amount of feed used per unit of output. Suitable animals must be selected or bred to suit new systems.
Replacement of machinery with more fuel efficient equipment	Years 3-10	Equipment replacement is usually carried out on a planned basis, meaning that it takes longer to implement this recommendation.
Replacement of static equipment with more efficient equipment	Years 3-10	Equipment replacement is usually carried out on a planned basis, meaning that it takes longer to implement this recommendation.
Reduction of heated washes (without compromising hygiene).	Year 1	This system can be implemented almost immediately as it does not require replacement of equipment.
Implementation of energy meters	Years 1-5	Energy meters are designed to highlight significant energy loss. They do not save energy in an off themselves.
Replacement of energy inefficient lighting	Years 1-3	Lighting replacement will take place over time rather than a full replacement at one point in time.

The above table shows the expected timescale for the delivery of benefits following implementation of an energy optimisation plan. As can be seen from the above table, the timescales are dependent on the amendments which are chosen to reduce energy usage.

3.6.2.5. Spatial Issues

Farming practice and equipment are highly varied, but monitoring and target setting is Broadscale and can be applied to almost any business. Savings may be greater for more intensive sectors – arable, horticulture, dairy, poultry compared with more extensive system – sheep and beef

3.6.2.6. Displacement

In general the practices implemented through monitoring and target setting for energy reduction will not result in displacement. The focus is on the reduction of energy use.

3.6.2.7. Maintenance and Longevity

The practice of implementing energy optimisation on-farm should become part of regular farm activity, and it is possible that incentives could be designed around the ongoing reduction of energy usage as a proportion of farm output.

The implementation, updating and operation against an Energy Optimisation plan does require the ongoing application of management time.

3.6.2.8. Climate Adaptation or Mitigation

This action is not affected by climate change.

3.6.2.9. Climate Factors / Constraints

The intervention contributes to both adaptation and mitigation. Monitoring and target setting is not affected by climate change, but some of the factors controlled as a result of monitoring, mitigation procedures will be in place.

3.6.2.10. Benefits and Trade-offs to Farmer/Land manager

The most obvious benefit of monitoring and setting is a reduction in energy usage on farm, reducing the cost of production. There are no trade-offs associated with the creation of a plan.

3.6.2.11. Uptake

There are a number of factors which are likely to reduce the effectiveness of implementation. In general most farms do monitor energy use at a macro level, but are unable to identify specific areas or hot spots. This is primarily due to the lack of metering or measurement of energy use of specific pieces of equipment or specific zones on farm. Farms will have to invest in appropriate monitoring equipment to ensure that baselines can be established and targets set. Without the implementation of monitoring equipment, uptake and progress is likely to be slow.

3.6.2.12. Other Notes

Farm assurance could be used as a tool to verify that a farm energy plan has been completed, or a requirement to submit one could be a condition of receiving farm support.

Verification of the figures input can be verified through submission of meter readings, electricity bills, fuel bills, fertiliser bills etc. This could be checked during a farm assurance inspection, or a requirement could be made to submit these as a condition of farm support.

3.6.3. ECCM-069: Use more high starch and reduced crude protein in diets

Introduction

The European Union has outlined a strategy to reduce greenhouse gas (GHG) emissions to net-zero by 2050 with a number of plans are in place to reduce CO_2, methane (CH_4) and nitrous oxide (N_2O) emissions (European Commission, 2018). There are also direct Carbon reduction targets and agriculture in Europe must reduce its output from 461 Mt CO_2-eq in 2016 to 284 or even 237 Mt CO_2-eq in 2050 (European Commission, 2018b; European Environment Agency, 2018). To meet these targets, significant change must take place within meat and dairy supply chains, as they are responsible for 80% of the total agricultural CH_4 and N_2O through enteric fermentation, manure production and fertiliser application. Dairy production systems are the largest agricultural source of the greenhouse gases methane (CH_4) and nitrous oxide (N_2O) in Europe (Weiske *et al.,* 2006).

Ruminal digestion of fibre-rich diets increases hydrogen production, which are substrates for methanogenesis in the rumen. In contrast, starch-rich diets change the bacterial ecology by favouring propionic-acid producing bacteria over methanogens (Bannink *et al.,* 2006; Ellis *et al.,* 2008). Rapidly-fermenting diets reduce methane production by decreasing ruminal pH, which affects the growth of methanogens, protozoa (Hook *et al.,* 2011), and cellulolytic bacteria (Sung *et al.,* 2007).

Animal husbandry results in considerable N losses to the atmosphere in terms of ammonia (NH_3) and nitrous oxide (N_2O) emissions (Amon *et al.,* 2006). Nitrogen emissions from agriculture are of major environmental concern and loss of nitrogen to the environment through agricultural processes has received a great deal of attention in terms of reducing the need for fertilisers and mitigation of nitrogen emissions. On average, 75%

of total nitrogen consumed by cattle is lost through excretion (Wonfor, 2018). More feed N can be incorporated into rumen microbial crude protein if carbohydrates are readily available (Schwab *et al.,* 2005).

The intended outcomes of this section is to explore the GHG effect of the use of more high starch diets and the use of reduced crude protein in diets.

Livestock management
This management bundle considers the effectiveness of optimised soil management and protection as a tool for reducing GHG emissions.

Livestock Management to reduce greenhouse gases
This management bundle considers dietary manipulation as an effective method of reducing GHG emissions. It will consider the use of high starch, low protein diets can be used as GHG mitigation approaches within livestock production, encouraging farmers to modify production practices to deliver GHG reduction.

Active diet and feed planning management to match animal requirements
Using more high starch and reduced crude protein in diet
Using ad lib feeding system
Using phase feeding of livestock
Maintaining genetic diversity by rearing rare breed livestock
Enabling farm animal genetic improvement
Improving animal health
Improving productivity

3.6.3.1. Causality

In general, the assessment of dietary fermentable energy and degradable protein in ruminants should be considered in tandem. The key to rumen efficiency is the careful balance of available energy and protein to ensure optimal protein utilisation and minimised excretion of volatiles. It is important to note that the relationship between CP and CH_4 output is not completely clear and is dependent on enough nutrients being available.

As a result, care is needed when low protein diets are proposed as a mitigation of enteric CH4 emissions. Information from AFBI cow chamber data shows a straight-line negative relationship between dietary CP concentration (kg/kg GM) and CH_4/DMI (g/kg). This may be because in a diet with similar ingredient and chemical composition, reducing CP contents to a level below requirement, would: (1) reduce rumen ammonia supply, then microbial activity and consequently feed intake and milk production; and (2), reduce rumen outflow rate, leaving more time for ruminal microbial action, with the consequent result that more CH_4 is produced. This twin actions can increase CH_4/DMI. The following two graphs have been produced by AFBI from calorimetry chambers. The X axis represents dietary CP concentration (kg/kg DM) and the Y axis represents CH_4/DMI (g/kg).

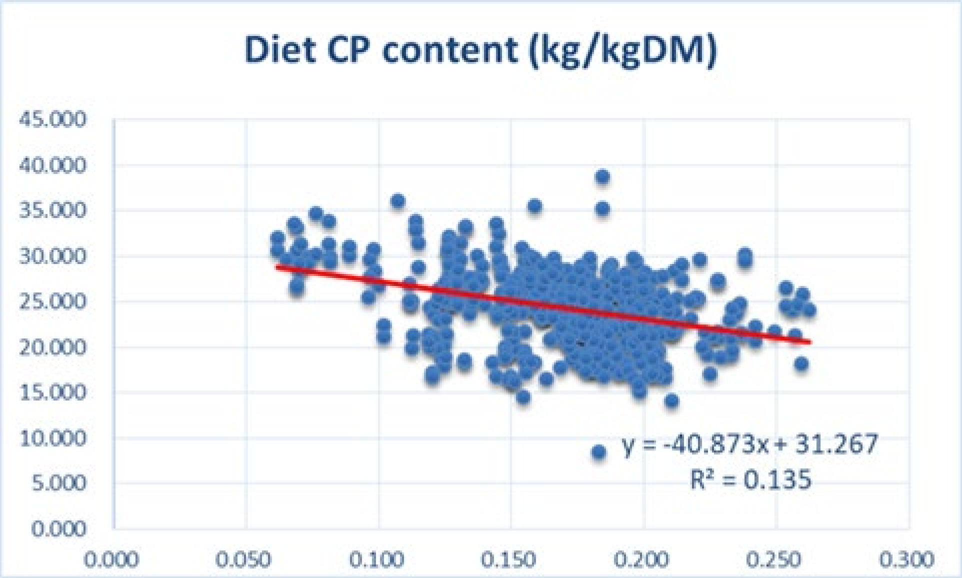

Figure 4

The figure below has been produced using AFBI dairy cow data and shows that reducing dietary CP content (kg/kgDM) increases urine N over N intake and reduces faecal N over N intake.

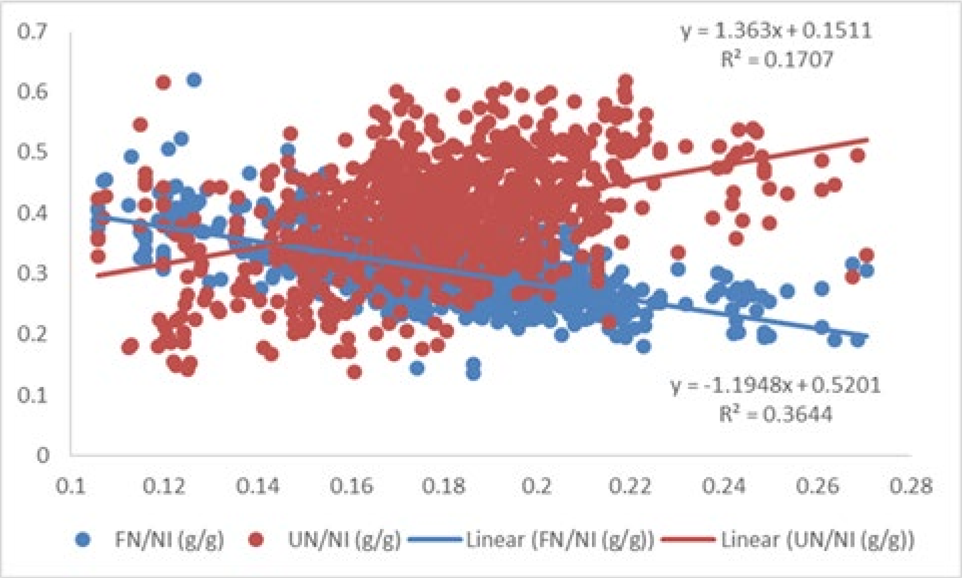

Figure 5

Generally however, the impact of the different types of diet on GHG is as follows;

High Starch Diets

- Rating: Green, the impact of high starch diets is understood
    - High levels of starch increase the digestible energy content of the diet, reducing the rate of enteric methane emissions. In practice, this can be achieved by replacing conserved grass with maize silage or concentrate to increase the digestibility of the ration. This will reduce enteric methane emissions and manure methane too (as less volatile solids will be excreted) (Hristov *et al.,* 2013).
    - The reduction of CH_4 plays a more important role than that of N_2O. CH_4 from enteric fermentation and manure management have more potential to decrease emission flows than N_2O (Aan den Toorn and Van der Broek, 2021).

Low Protein Diets

- Rating: Amber, the impact of low protein diets on GHG emissions is partially understood, but more study is required.
    - Dietary crude protein (CP) reduction is considered a useful strategy to minimise cow N excretion and NH_3 and N_2O emissions (Arriaga *et al.,* 2010). The extent of the impact is, amongst other factors, dependent on the performance level of the animal and the energy to protein balance of the diet.
    - CP reduction for other species is also recognised as important in minimising GHG emissions. Niu et al 2016 (cows), Sajeev et al 2018 (Cattle & Pigs), Ferguson et al 1998 (Poultry).
    - The measure requires technology to match the diet more closely to the animal's nutritional requirements.
        - For ruminants, emissions could be reduced through improved characterisation of forages to enable appropriate supplementation.
        - For pigs this may involve regular weighing of animals and adjustment of the ration protein content based on weight or age and growth rate, and supplementation of diets with synthetic amino acids.

3.6.3.2. Co-Benefits and Trade-offs

A number of benefits are associated with the correct management of protein and starch in the diet. These include reduced cost of ration formulation, improved animal growth rates, reduced ill-health due to dietary imbalance, reduced nitrogen wastage (though urine and manure). These will have significant benefit for water quality. There is no significant trade-offs, other than the potential for reduction of animal performance if protein supply is reduced too far. This is particularly so for high yielding dairy cows in which the requirement for metabolisable protein cannot be met by microbial protein synthesis in the rumen and an additional supply of rumen undegraded protein and/or essential amino acids is required. This is especially the case for methionine and lysine where protected supplementation has been shown to increase milk yield (Nichols *et al.,* 1998). On high-forage diets histidine is often first limiting due to the greater reliance on microbial protein (Lee *et al.,* 2014, Wilkinson and Lee, 2017).

[TOCB Report-3-1 AQ **ECCM-069**] Feeding strategies for ammonia emission reduction have also been assessed for positively abating nitrous oxide emissions (Sanchez-Martin *et al.,* 2017). Reduction in crude protein (CP) diets can reduce need for supplements in feed and reduction of other costs (Abassi *et al.,* 2018).

3.6.3.3. Magnitude

The magnitude of impact is very difficult to estimate accurately as most models have limited data on actual methane outputs.

High Starch Diets

- High starch diets favour the production of propionic acid in the rumen. On high fibre diets, the formation of both acetic and butyric acids is accompanied by the production of H_2 and CO_2, whereas propionic production involves a net uptake of H. Increased propionic acid reduces method production (Chen *et al.,* 2020).
- The redirection of hydrogen from methane to propionate significantly reduces the potential for methane production; however, there is another effect which reduces H supply. This is the decrease in digestibility of the fibre due to high starch rations. Generally, the substitution of forage with concentrates in ruminant diets can be accompanied by an increase in total feed intake and, therefore, the concentrate effect on methane reduction could be more accentuated. (Benchaar et al 2000)
- The mitigation is represented by a 5% reduction in the rumen methane conversion factor: "*The methane conversion factor was significantly reduced with increased content of starch and fat in the ration, whereas neutral detergent fibre content surprisingly did not have a significant effect in any*

> *model. On the basis of compiled data from practical Danish farms, the predicted methane energy output was 6.02% and 5.98% of gross energy intake (Ym) for Holstein and Jersey cows, respectively. In conclusion, the Intergovernmental Panel on Climate Change default Ym of 6.5% (IPCC, 2016) overestimates methane emissions for both Holstein and Jersey cows fed rations typically used in intensive dairy producing countries in northern Europe."* (Hellwing et al 2016)

Reduced Dietary Protein

- Nitrogen (N) excretion rates, which affect N_2O and NH_3 emissions from manure, are based on dry matter consumption (DMC), its N content (Vergé *et al.,* 2012) and the overall dietary quality (which influences feed intake irrespective of production levels). Therefore, dietary manipulation to optimise protein consumption, and thus improve the efficiency of N utilisation, is one of the most effective measures to reduce emissions from manure (Novak and Fiorelli, 2010).
- In dairy models, it has been shown that NH_3 concentration could be reduced by 13% per unit reduction in dietary CP content (Arriaga *et al.,* 2010). The reduction occurs by optimising microbial fermentation in rumen which significantly improves the use of N.

A meta-analysis of the effects of dietary protein concentration and degradability on milk protein yield, and efficiency of utilisation of dietary N for milk protein synthesis, concluded that the Crude Protein (CP) concentration of the diet is the most important dietary factor influencing milk N efficiency, and that reducing dietary CP is the most significant means to increase efficiency of dietary protein utilisation (Huhtanen and Hristov, 2009). In some cases excess crude protein is fed as Rumen Undegraded Protein which is important for high yielding dairy cows. The practical effect of reducing crude protein was shown for dairy cows fed a 14% CP diet. The cows excreted 45% more urinary N for a 19% CP diet compared with excretion from cows fed a 14% CP diet (Misselbrook *et al.,* 2005a). There was also a small decrease in faeces N at the lower CP diet.

3.6.3.4. Timescale

These interventions represent significant changes within current farm practices, but are very achievable with the correct incentive for a farmer to implement each mitigation. The table below shows the expected timescales for response:

Component	**Expected timescale**	**Reason**
High Starch Diets	Year 1	High starch diets promote rumen conditions that favour H incorporation into volatile fatty acids rather than Methane. This strategy can be implemented immediately with immediate impact
Reduced Dietary Protein	Year 1	Reduced dietary protein improved nitrogen use efficiency, provided the diet is balanced for both energy and protein. This strategy can be implemented immediately with immediate impact

3.6.3.5. Spatial Issues

Farming practice and facilities are highly variable; however, implementation of nutritional strategies is relatively uninhibited by farming system, farming size, or geographical location. These mitigations are based on more targeted and precise nutritional programmes which can be implemented in the majority of systems. Nutrition strategies will be easier to implement for animals which have diets of cereals and concentrates whereas there is very little control for animals using ad-lib grass-based systems. As nearly all livestock in the UK are supplemented in some way, it may be possible to implement to some degree.

3.6.3.6. Displacement

The strategies proposed; high starch, low protein diets, could displace forage in the ration of ruminants. However, from a strategic viewpoint, these strategies may increase land availability for alternative use.

3.6.3.7. Maintenance and Longevity

The improvement of resource use efficiency at farm level will not only mitigate GHG emissions, but will also improve business sustainability and improve animal performance at farm level. This has multiple secondary benefits including better performance, reduced disease, and improved lifetime production.

The practice of implementing nutrient use efficiency strategies on-farm should become part of regular farm activity, and it is possible that incentives could be designed around the reporting and validation of these.

3.6.3.8. Climate Adaptation or Mitigation

The proposed strategies contribute to both adaptation and mitigation. These strategies are not affected by climate change, but have a positive impact on reducing emissions from agriculture systems.

3.6.3.9. Climate Factors / Constraints

The implementation of these strategies is not affected by current climatic factors; however, energy production (in the case of high starch diets) requires a strategic approach and be aligned to energy objectives. Constraints to high starch diets will include cost and availability of feed. Furthermore, the fragmentated nature of the agriculture industry could increase the difficulty of implementing low protein rations that are balanced for rumen efficiency and production.

3.6.3.10. Benefits and Trade-offs to Farmer/Land manager

The most obvious benefit of high starch, low protein diets is the improved animal productivity, increasing output from a given base and improving profit margins. This extends to drivers of whole farm efficiency such as reduced disease, lower replacement rates, improved fertility, improved age at first calving etc. Overall, these strategies have the potential to result in much more efficient production systems.

3.6.3.11. Uptake

There are a number of factors which are likely to reduce the effectiveness of implementation. These include accuracy of dietary formulation to ensure the maintenance of high levels of production, especially at lower dietary protein levels. Another barrier to uptake is the quantification of change: in general, most farms don’t record data or implement change that can be quantified quickly, especially in terms of carbon footprint. This is primarily due to the lack of measurement at livestock level.

3.6.3.12. Other Notes

Farm assurance could be used as a tool to verify that farm interventions are occurring.

3.6.4. ECPW-115: Switch to efficient / precision fertiliser application machinery (e.g. trailing hose, trailing shoe or injection, GPS)

Introduction

Emissions from agriculture will increase if no mitigation actions are taken. Improving nitrogen use efficiency is a key focus for improving farm efficiency and sustainability, as well as reducing the ammonia, nitrate and greenhouse gas (GHG) footprint of agriculture. Mitigation pathways include the switch from traditional chemical fertilisers to protected urea formulations and the switch from slurry application by the traditional splash plate method to low emission slurry spreading equipment (LESSE), such as a trailing shoe or hose.

Organic manures (such as slurry, solid manure, poultry litter, digestate, sludge and compost) are natural sources of nitrogen and are used to build soil fertility and support plant growth. However, nitrogen in the form of ammonia is lost from organic manures when they come into contact with air, particularly on warm or windy days. The land spreading of animal manures accounts for approximately one-third of the total NH_3 emissions from agriculture (Misselbrook *et al.,* 2000). The more nitrogen lost as ammonia, the less effective the manure will be as a fertiliser.

The application of manure is not generally considered to be very precise when compared to the application of artificial fertilisers. Key reasons for this include the lack of understanding of slurry dry matter content and nutrient concentration. Feedback from farm advisors and consultants suggest that the majority of farms do not analyse slurry or manure prior to application.

Slurry application is a key component of effective nutrient delivery on-farm; however, it also requires careful management to ensure it is applied in the right place at the right time so as to avoid losses to the environment (or to groundwater). Optimising soil nutrients and increasing the effectiveness of utilisation of slurry is vitally important, particularly in relation to nitrogen (N), phosphorus (P) and potassium (K). AFBI research has shown that applying slurry with LESSE; using either dribble bar or trailing shoe technology, grass yields were improved by up to 25%. This is due to an increase in the amount of available nitrogen and a reduction in the amount of N lost via ammonia emissions compared to traditional splash plate systems.

Low emission slurry spreading equipment can play a significant part in increasing the nitrogen content of slurry by reducing ammonia emissions. These systems will have an increasing role in reducing ammonia emissions from farms. In addition to the improvements in nutrient use, the use of LESSE will have wider benefits such as improved human health and reduced eutrophication of water bodies.

Soil Management and Protection
This management bundle considers the effectiveness of optimised soil management and protection as a tool for reducing GHG emissions.

Soil Input Management to Reduce Greenhouse Gases
This management bundle will consider GHG mitigation approaches within soil management and protection provoking farmers to modify production processes to deliver GHG reduction. Factors considered within this include (but are not limited to)

Soil Input Management to Reduce Greenhouse Gases
Switch to efficient / precision fertiliser application machinery (e.g. trailing hose, trailing shoe or injection, GPS)
Use no fertiliser
Export manure and slurry
Cover slurry, sludge, and digestate stores where business is not regulated under IED
Increase the capacity of farm slurry and manure stores to improve timing of slurry applications
Dilute slurry to improve soil infiltration, coupled with irrigation
Replace nitrogen fertiliser application by using clover in pasture or arable cropping systems
Use very low inputs on permanent grassland

Switch to Efficient/Precision Fertiliser Application Machinery
Ammonia loss is significantly increased when the manure has a high surface area and when there is a lot of air movement which is the case when slurry is sprayed into the air by a splash plate spreading system and afterwards when it covers all of the soil or crop surface.

Low emissions slurry spreading is a technique used to minimise these losses and improve nutrient utilisation efficiency.

3.6.4.1. Causality

Key considerations within this subheading include the use of precision techniques to improve efficient / precision fertiliser application machinery.

The following causalities are recognised in the literature.

- Trailing hose
    - Green
        - This system distributes slurry directly onto the ground greatly reducing ammonia emissions and reducing sward contamination.
        - This system is suitable for arable crops as it less damaging to the crop.
- Trailing shoe
    - Green
        - Trailing shoes ride along the soil surface, parting the vegetation and ensuring that the slurry is placed on the soil surface. In addition to delivering a higher nutrient value from the slurry there is much lower leaf contamination compared to both splash plate and trailing hose systems, which helps to reduce contamination at ensiling and allows earlier availability for grazing. However, as the slurry is in bands it can be more susceptible to surface run-off after rainfall if the bands run down the slope. This system allows slurry spreading into a grass sward with a cover of up to 2250kg DM/ha (i.e. longer grass) which also shelters the slurry from wind and so help to reduce ammonia emissions after spreading and reduce the risk of run-off.
- Slurry Injection
    - Green
        - Shallow injectors; suitable for arable land or grassland. Shallow injectors place the organic manure typically 4-6 cm deep in narrow slots cut into the soil, typically 25-30 cm apart.
        - Deep Injectors; only suited to arable land immediately prior to sowing (due to the damage that can occur to grass or crops). Deep injectors should only be used when the soil is sufficiently dry and not on land with a drainage system shallower than 70 cm depth in order to prevent water pollution. Deep injectors cut slots 10-30 cm deep and are spaced about 50 cm apart.
- Bacterial Slurry Additive
    - Amber
        - Bacterial slurry additive breaks down solid matter and produces a more homogenous and nutrient rich fertiliser.

3.6.4.2. Co-Benefits and Trade-offs

A range of co-benefits will emerge from the use of precision techniques. These include improved air quality, reduced run-off, improved water quality, better soil nutrient content, reduced wastage.

There are also a range of trade-offs which need to be considered. These include the cost of the precision equipment (which is almost always greater than less precise equipment), the need for raised skill levels (and hence training) to effectively utilise the equipment and the raised management time which can be associated with the use of precision equipment.

In addition, the equipment will function best when geolocated, requiring additional investment in soil sampling and control of nutrient application.

[TOCB Report-3-1 AQ **ECPW-115**] Potential pollution swapping needs to be considered and any nutrient and manure management actions have implications for soil quality.

Thorman *et al.,* (2020) compared slurries broadcast on the soil surface with application using bandspreading techniques (trailing hose and trailing shoe) to minimise NH_3 losses. For the spring application, mean NH_3 losses were lower from the bandspread slurry treatments compared to the surface broadcast slurry. The higher N pool in the soil would be expected to lead to higher N_2O emissions, but this was found only for spring applications, possibly when soils are saturated and anaerobic.

3.6.4.3. Magnitude

The magnitude of impact is estimated accurately and based on current scientific data, these estimates are as accurate as can be at present.

In general, research indicates that the recently developed surface placement application techniques for slurry (shallow injection, band spreading and trailing shoe), have resulted in reductions in NH_3 emission of between 70 and 95% compared with surface spread-plate application (Huijsmans *et al.,* 1997; Lorenz & Steffens, 1997).

Duncan *et al.,* (2016) also showed relative NH_3 emissions were dramatically lower on injection-applied plots treated with cattle slurry. Injecting manure reduced emissions by up to 98% compared with broadcast slurries. N_2O emissions increased for injected plots by up to 2.5 times because soil anaerobic conditions that are favourable for denitrification can result in increased N_2O emissions compared with surface broadcasting. But under aerobic soil conditions slurry injection has the potential to reduce NH_3 emissions without increasing N_2O emissions.

Chadwick *et al.,* (2011) concluded that soil and environmental conditions that give rise to N_2O production and emission (e.g., warm and wet soils) can be more important than the application method in controlling N_2O emissions. This places an emphasis on applying manure in dry weather conditions to growing crops which can utilise the manure immediately. A secondary benefit is that the reduction of ammonia emissions means that less N fertiliser needs to be applied to meet crop needs – reducing N_2O emissions from the fertiliser application.

- Trailing Hose
    - Grassland
        - Ability to achieve a 26% reduction in ammonia emissions compared to splash plate slurry application (Misselbrook *et al.,* 2002).
    - Arable
        - Ability to achieve a 27% reduction in ammonia emissions compared to splash plate slurry application (Misselbrook *et al.,* 2002).
        -
- Trailing shoe
    - Grassland
        - Ability to achieve a 57% reduction in ammonia emissions compared to splash plate slurry application (Misselbrook *et al.,* 2002).
    - Arable
        - Ability to achieve a 38% reduction in ammonia emissions compared to splash plate slurry application (Misselbrook *et al.,* 2002).
        -
- Slurry Injection
    - Grassland

        - Ability to achieve a 73% (shallow) and 90% (deep) reduction in ammonia emissions compared to splash plate slurry application (Misselbrook *et al.,* 2002, Edwards, 2020).
        - Ability to achieve a 23% (shallow) reduction in ammonia emissions compared to splash plate slurry application (Misselbrook *et al.,* 2002).
    - Arable
        - Ability to achieve a 27% reduction in ammonia emissions compared to splash plate slurry application (Misselbrook *et al.,* 2002).

- Slurry Treatment / Additive
    - Acidification
        - Acidification clearly reduces NH_3 emissions by ca. 70% during storage compared to untreated cattle and pig slurry (Kupper *et al.,* 2020). Fangueiro *et al.,* (2015) found that acidified slurry had other benefits when applied to soils. A delay of ammonium N nitrification was observed in soils amended with acidified slurries, relative to non-acidified ones. This delay lasted for about 20 days, for both pig and cattle slurry. Furthermore, for more than 60 days, the NH4 + concentration in soil amended with acidified slurry or the liquid fraction of slurry remained significantly higher than in soil amended with the raw materials. N fertilisation is easier to manage with acidified slurry, since the NH4 + content is more constant relative to non-acidified slurry due to minimal NH3 losses. Roboredo *et al.,* (2012) observed a significant effect of acidification on the Phosphorus (P) availability in soil as well as its evolution with time. Slurry acidification increased the most labile fraction of P. Petersen *et al.,* (2013) also reported an increase of P availability in soils amended with acidified slurry, relative to non-acidified slurry.
    - Bacterial Inoculant
        - Addition of bacterial innoculants showed a positive effect on the reduction of N_2O and NH_3 (Amon *et al.,* 2004).

3.6.4.4. Timescale

These interventions represent significant changes within current farm practices, but are very achievable with the correct incentive for a farmer to implement each mitigation. The table below shows the expected timescales for response:

Component	Expected timescale	Reason
Trailing hose	Year 1	Technology freely available
Trailing shoe	Year 1	Technology freely available
Slurry Injection	Year 1	Technology freely available
Bacterial slurry additive	Year 1	Technology freely available

3.6.4.5. Spatial Issues

There are limited spatial issues, as these technologies are well established and can be used in most locations. This will be most applicable to intensive livestock systems whereby slurry / manure management is a significant aspect of the business.

3.6.4.6. Displacement

In general, the practices implemented will not result in displacement and will enhance land productivity.

3.6.4.7. Maintenance and Longevity

The implementation of efficient or precision application equipment is associated with an increase in maintenance and training requirements. The equipment is usually more complex and has additional wearing parts. Longevity of equipment is variable, but with appropriate maintenance should be no different from non-precision equipment. The practice of implementing nutrient use efficiency strategies on-farm should become part of regular farm activity, and it is possible that incentives could be designed around the reporting and validation of these.

3.6.4.8. Climate Adaptation or Mitigation

The proposed strategies contribute to both adaptation and mitigation. These strategies are not affected by climate change but have a positive impact on reducing emissions from agriculture systems. Note that these techniques may increase N_2O emissions in anaerobic soils

3.6.4.9. Climate Factors / Constraints

Application of precision nutrient management through the use of LESSE is relevant to all farming systems. A possible constraint is the initial investment required to acquire LESSE. In addition to the efficiency of NH_3 emission abatement, the cost of the machines and the agronomic benefits need consideration (Smith *et al.,* 2000).

3.6.4.10. Benefits and Trade-offs to Farmer/Land manager

The improvement of resource use efficiency through the use of LESSE will not only mitigate GHG emissions but will also improve business sustainability and soil performance. This has multiple secondary benefits including reduced cost associated with artificial fertilisers, better soil health, better soil organic matter, and improved public goods.

The most obvious benefit of optimising nutrient application is improved resource use efficiency, improved environmental footprint, and improved profit margins. Overall, these strategies have the potential to result in much more efficient production systems.
Fangueiro *et al.,* (2015) found that acidified slurry had other benefits when applied to soils. A delay of ammonium N nitrification was observed in soils amended with acidified slurries, relative to non-acidified ones. This delay lasted for about 20 days, for both pig and cattle slurry. Furthermore, for more than 60 days, the NH_4 + concentration in soil amended with acidified slurry or the liquid fraction of slurry remained significantly higher than in soil amended with the raw materials. N fertilisation is easier to manage with acidified slurry, since the NH_4 + content is more constant relative to non-acidified slurry due to minimal NH_3 losses.

3.6.4.11. Uptake

One main factor is likely to limit uptake and reduce the effectiveness of implementation. The initial cost of acquiring LESSE can be high and significant amounts of information on the cost benefit are often required before farmers are prepared to invest in the technology.

LESSE equipment is also less effective on steep hill land or land with a high quantity of stones, again reducing the willingness of farmers to invest in the equipment. Heavy saturated soils can lead to increased N_2O emissions, so timing of use is critical. Acidification is a specialised technique with health and safety implications, although it is used significantly in Denmark.

3.6.4.12. Other Notes

Farm assurance could be used as a tool to verify that precision equipment is being used, and soil analysis data can enable the nutrient status of the land to be assessed, enabling multi-year monitoring of progress and long term assessment of good environmental behaviour.

3.7. ECPW-131 SEPARATE SLURRY AND DIGESTATE (LIQUID AND SOLID) AND STORE SEPARATELY

Introduction

Under the Nitrates Action Programme regulations, farmers are restricted to a total farm limit of 170 kg/ha/year of organic nitrogen which limits the number of animals farms can carry, particularly pig units. One possible solution is to separate the slurry and transport the nutrients in the solids to e.g. arable farms where required. The liquid fraction is easily utilised for irrigation, injection or trailing-shoe application.

Mechanical separation of slurry results in a liquid fraction with low dry matter content, and a solid fraction that can be stored and transported easily. The liquid fraction has a lower viscosity and flows more easily through band-spreading hoses. Amon *et al.,* (2006) indicated that slurry separation reduces CH_4 emissions, but is likely to result in an increase in N_2O and NH_3 emissions during composting of the solid fraction; however, mitigation of this would be to limit application to when conditions do not favour NH_3 volatilisation (cooler periods of day). Application timing does not deal with the storage issue of increased emissions
Chadwick et al, (2011) commented that it was difficult to conclude if separation increased or decreased CH_4 emissions. Whether methane emissions are reduced depends on the storage conditions of the fractions, and the composition of the manure. For N_2O, the solid fraction behaves as untreated solid manure showing higher emissions in storage (Hansen *et al.,* 2006). Kupper *et al.,* (2020) also concluded that N_2O emissions were increased. The process can lead to aeration which induces nitrification and denitrification to nitrite/nitrate with the aim of a complete denitrification to N_2. If the process is not properly controlled, aeration can produce substantial amounts of NH_3 and N_2O (Loyon *et al.,* 2007). A reduction of CH_4 by ca. 50% to almost 100% emissions was observed by Amon *et al.,* (2006) if slurry aeration was applied. Sommer and Olesen (2000) have calculated that avoiding applications during times of the day with a high potential for NH_3 losses could reduce the total emission of NH3 from applied slurry by half. However, the efficiency of this technique depends on the farmer’s flexibility in the choice of application date and time (Sommer and Hutchings, 2001).

The liquid fraction represents 90–95 % of initial mass and has a high concentration of total nitrogen, especially in the form of ammonium (NH_4+) (Chadwick *et al.,* 2011). Due to the lower dry matter concentration of the liquid fraction, the efficiency of use of the ammonia-N concentration increases, even if applied by splash-plate. This is because it will percolate into the soil more readily than raw slurry, thus decreasing the amount of time exposed to the atmosphere and, as a consequence, volatilisation of ammonia should be reduced.

Slurry separation make materials easier to handle and spread over a wider land area. It is more viable to transport manures with higher nutrient values per kg further, and slurry separation facilitates this.

However, mechanical separation of slurry has the potential to increase GHG and NH3 emissions compared to traditional slurry management (Amon *et al.,* 2006; Dinuccio *et al.,* 2008; Fangueiro *et al.,* 2008a), mainly due to high emissions during storage of the solid fraction. Combining losses during storage and after soil application of both liquid and solid fractions, CO2-eq emissions of combined fractions were 11% higher than from raw cattle slurry (Dinuccio & Balsari, 2011).

Soil Management and Protection

This management bundle considers the effectiveness of optimised soil management and protection as a tool for reducing GHG emissions.

Soil Input Management to Reduce Greenhouse Gases

This management bundle will consider GHG mitigation approaches around soil nutrient input and the potential for farmers to modify production processes to deliver GHG reduction.

Separate Slurry and Digestate (Liquid and Solid) and Store Separately

This action investigates the impact on GHG of separating slurry and digestate (liquid and solid) and storing it separately. Slurry separation make materials easier to handle and spread over a wider land area as it is more viable to transport manures with higher nutrient values per kg further, and slurry separation facilitates this.

3.7.1.1. Causality

- Slurry Separation is rated as Amber as the literature contains conflicting information.
    - Separating the solids from the liquid means that slurry can be managed more easily- the solid portion can be heaped up, stored and transported easily and the liquid portion is then much lower in volume which saves slurry storage requirement.
    - The ability to transfer the solid component of manure more easily can contribute to the reduction of environmental challenge at a local level by encouraging removal from the farm. This removal would have GHG emissions from transport. Slurry separation can benefit the farm's nutrient management planning and reduce the environmental impact.
    - Solids contain the majority of the valuable nutrients that the crop needs; therefore, due to separation the pollution risks from storing and spreading the liquid are reduced.
    - However, there is evidence to suggest that GHG emissions actually increase following mechanical separation, both in storage and after application (Amon *et al.,* 2006; Dinuccio *et al.,* 2008; Fangueiro *et al.,* 2008a).
    -

3.7.1.2. Co-Benefits and Trade-offs

Co-benefits of slurry separation include improved nutrient management and resource utilisation efficiency, as well as more targeted spatial application. Trade-offs centre around the cost of the system and the long-term nature of payback.

[TOCB Report-3-1 AQ **ECPW-131** and others] Actions have trade-offs with greenhouse gas emissions, especially nitrous oxide and methane (Kupper *et al.,* 2020).

3.7.1.3. Magnitude

Slurry separation appears to have a negative impact on GHG emissions, with the process increasing the overall emission of GHG and NH_3. However, its overall effectiveness will only be realised if coupled with other technologies and practices (particularly around storage and application).

- Mechanical separation of slurry has the potential to increase GHG and NH_3 emissions compared to traditional slurry management (Amon *et al.,* 2006; Dinuccio *et al.,* 2008; Fangueiro *et al.,* 2008a), mainly due to high emissions during storage of the solid fraction.
- Combining losses during storage and after soil application of both liquid and solid fractions, CO_2-eq emissions of combined fractions were 11% higher than from raw cattle slurry (Dinuccio & Balsari, 2011).

Pederson *et al.,* (2022) reviewed the available papers which investigated the effect of slurry separation. They found considerable variation in the results and concluded that "slurry separation under some circumstances reduces NH_3 loss after field application, but there are very few measurements giving absolute emission factors after field application of the liquid fraction and corresponding raw slurry." They also stated that "It is evident from the literature data compilation that more research is needed to make more confident conclusions about the effect of separation. There is a need for experiments that systematically evaluate how different combinations of soil and slurry properties influence slurry infiltration and exposed surface area after application, and thereby emissions. Furthermore, it is crucial to have more measurements with methods that provide absolute emissions estimates, as only one of the studies in the literature compilation does this."

3.7.1.4. Timescale

These interventions represent significant changes within current farm practices, but may not be beneficial in terms of reducing emissions. The table below shows the expected timescales for response:

Component	Expected timescale	Reason	Size of benefit
Slurry separation	Year 2	Implementation of technology and facilities	Medium (negative)

3.7.1.5. Spatial Issues

Farming practice and facilities are highly variable; however, implementation of slurry separation equipment would be applicable to the majority of systems. However, other GHG emission reduction measures would be required if this mitigation was adopted for management purposes.

3.7.1.6. Displacement

In general, the practices implemented will not result in displacement.

3.7.1.7. Maintenance and Longevity

After initial set-up, regular maintenance would be required to ensure the upkeep of the equipment.

3.7.1.8. Climate Adaptation or Mitigation

These strategies are not affected by climate change, but could negatively impact progress if the correct GHG emission reduction measures are not put in place.

3.7.1.9. Climate Factors / Constraints

A possible constraint is the initial investment required to acquire separation equipment

3.7.1.10. Benefits and Trade-offs to Farmer/Land manager

The most obvious benefit is the improved management of nutrients on farm; however, this strategy could have negative environmental implications if other GHG emission reduction measures are not adopted.

3.7.1.11. Uptake

Uptake is likely to be slow given the potential negative environmental implications and the overall cost of implementation of a separation system. The technique adds complexity to the farm operations making it difficult to justify.

3.7.1.12. Other Notes

None

3.7.2. ECPW-137: Export manure and slurry

Introduction

The effect on the environment of the manure produced in a particular agricultural system can be detrimental; however, if the import and export of nutrients within the system is in balance, there is a positive impact, especially in terms of nutrient utilisation efficiency. Poor nutrient management can lead to high levels of NH_3

volatilisation and NO_3, P and K leaching, particularly when rainfall is high, and decreases the value of animal manure. Nutrients are valuable and vital resources, which can replenish productive grazing lands and crops. From an economical point of view, it is important to match the nutrient application to requirements, minimising nutrient loss as much as possible. This in turn could limit the additional costs (e.g., tractor fuel, spreading equipment, labour, etc.) incurred when nutrients are applied beyond the crop and grass requirements.

The Nitrates Directive has the objective of reducing water pollution caused or induced by nitrates from agricultural sources and preventing further such pollution. Measures include limiting application rates of manure nitrogen, limiting periods when nitrogen can be applied, conditions for application (not on frozen soil, water saturated soils, steep slopes, close to water bodies etc.) and techniques for application. The maximum manure application rate of 170 kg N / ha / year applies to all countries while the other measures may vary. This emphasises the importance of nutrient management and the benefit of being able to import / export nutrients.

Where there is a surplus of nutrients, manure export will optimise nutrient use, and potentially substitute the use of chemical fertilisers, and decrease the environmental impact. The importance of improved use and handling of manure in order to reduce nutrient surpluses and eutrophication risk has been highlighted in a number of studies (Buckwell and Nadeu, 2016; Oenema *et al.,* 2007; Tybirk *et al.,* 2013). The benefits of manure to soil fertility and soil structure are well established (Diacono and Montemurro, 2010; Haynes and Naidu, 1998; Zavattaro *et al.,* 2017). However, it can be challenging to manage manure in a resource-efficient way. Slurry application also maximises Carbon sequestration on grassland.

A recent survey of agriculture practices in Ireland found that 4% of all farmers imported slurry and/ or farmyard manure and 1% exported slurry and/or farmyard manure. Of those importing, 20% were tillage farmers and three-quarters imported pig slurry. Demand for manure import may be lower in areas where tillage is not common practice.

Soil Management and Protection

This management bundle considers the effectiveness of optimised soil management and protection as a tool for reducing GHG emissions.

Soil Input Management to Reduce Greenhouse Gases

This management bundle will consider GHG mitigation approaches within soil management and protection provoking farmers to modify production processes to deliver GHG reduction.

Export Manure and Slurry

The export of manure and slurry from a farm can reduce the release of GHG and pollutants into the atmosphere and reduce nutrient run-off to water, if the slurry/manure is transported to areas which can make more effective use of it. This action investigates the GHG effect of the export of manure and slurry on local and national GHG emissions.

3.7.2.1. Causality

The export of manure and slurry can positively impact the environmental performance at a localised level. (Freeman et al 2020, Asai et al 2014). Causality is established for the export of manure and the process is rated green. However, its effectiveness is closely linked to a number of other practices. Soil analysis is critically important because manures (or fertiliser) should only be applied to land requirement. If the soil on the origin farm is capable of absorbing the slurry/manure and utilising the nutrients, export of the slurry is unnecessary and potentially damaging. If the land is incapable of safely absorbing and utilising the nutrients in the slurry, export must take place.

It is essential to note that benefits will only be realised if the nutrient is moved from an area where the soil is not able to absorb the nutrients to an area where there is significant crop and soil need, and displacement of artificial fertiliser use takes place. Otherwise, the transportation of manures and slurries has a positive localised effect at the exporting farm, but a potentially negative one at the receiving farm.

Broadly, the following applies

- Movement of manure can potentially have environmental benefits local to the farm of production.
- Movement of manure can potentially have a negative environmental effect at the receiving farm if a range of conditions are not met. Transport and handling of manures have negative GHG effects given the large weights involved – depending on transfer distances. Practically the main surplus of manure occurs for intensive dairy, pig and poultry farms – often distant from arable farms requiring manure.
- Exporting manure off farm is a potential means of moving nutrients from areas where there is environmental risk due to over-application to other areas where there is less risk and there is a crop requirement for the nutrients.
- Export of manure from farm provides additional organic nitrogen for use in other crop production systems.
- Exporting manure carbon provided an additional environmental benefit by reducing net farm greenhouse gas emission.
- Manure Phosphorus is also removed when manure is exported, reducing the accumulation within soil.

3.7.2.2. Co-Benefits and Trade-offs

Benefits of exporting manure and slurry include the reduction of GHG to the atmosphere and excess nutrients to water, provided that the slurry is exported to an area which can make more effective use of it. The export of surplus nutrients to an appropriate region will optimise nutrient use, displace chemical fertilisers, and decrease the environmental impact. This depends on the transport distances between livestock farms producing excess manure and the importing arable farms with a deficit of manure fertiliser. In addition to greenhouse gas reductions, other benefits around reduction of nutrient loading of land will accrue. Based on average values of N content of raw slurry at 7% DM, the export of 500 t of raw slurry would result in the removal of 300kg of P_2O_5. If the same amount of N is exported in separated slurry solids, 189 t of solids would have to be exported containing 378 kg of P_2O_5 (Lyons *et al.,* 2021).

If, however, the slurry is moved to an area which cannot make more effective use of it than the farm of origin, benefits will be seen locally to the farm of origin, but negative impacts are likely locally to the receiving farm.

Trade-offs centre around the cost of storage and transport of excess nutrients, as well as the risk of spillage during transport.

[TOCB Report-3-4 Water **ECPW-137**] Crop available nutrient supply from the manures will reduce the need for manufactured fertiliser inputs to meet optimum crop requirements on the receiving farm. On arable soils, the addition of organic matter from the manures has the potential to improve soil quality. Manure storage and application equipment will be required on the receiving farm to ensure manure applications are made at appropriate timings and rates.

[TOCB Report-3-1 AQ **ECPW-137** and others] Actions have trade-offs with greenhouse gas emissions, especially nitrous oxide and methane (Kupper *et al.,* 2020).

3.7.2.3. Magnitude

As previously discussed, the magnitude of the effect is predominantly related to the ability of the soil to absorb and utilise the nutrients from manures and slurries which are applied. Assuming that transport takes place from an area which is unable to absorb and effectively utilise the nutrients to an area where they can be, GHG emissions benefits will result from the displacement of artificial fertiliser.

UK Government statistics from 2021 show that Nitrogen use on tillage crops has been on a decline kg N/ha

Year	Usage (Kg/Ha)
2016	141
2017	137
2018	142
2019	137
2020	121

British Government, 2021, National statistics: British survey of fertiliser practice 2020. Available at: https://www.gov.uk/government/statistics/british-survey-of-fertiliser-practice-2020

It can be seen that although the average use of artificial fertiliser is decreasing, there is still considerable potential for further reduction. The following figures show the approximate Nitrogen content of different types of manure. At a 40% dry matter content, one tonne of poultry manure contains 19kg of nitrogen, meaning that the application of six tonnes per hectare would totally replace artificial fertiliser.

Using figures from Skowrońska and Filipek (2014), Elsayed *et al.,* (2003) and Kongshaug and Tech (1998), around 6.5kgs of Carbon Dioxide accrue for every 1kg of artificial Nitrogen which is created. This means that the Carbon cost per Ha in the UK in 2020 was 786kgs. A reduction of 30kgs application in Nitrogen per Ha will reduce the Carbon cost per Ha of 195kgs, or potentially 1.144 million tonnes if applied across one third of the UK's farmed landscape.

The following graphs are drawn from the AHDB, 2021, RB209 Section 2 Organic materials reference book and shows the analysis of typical manure at a range of different dry matters.

Poultry manure

Typical total nitrogen content of poultry manure (fresh-weight basis)

Dry matter	**Total nitrogen[a]**
%	**kg N/t**
20	9.4
40	19.0
60	28.0
80	37.0

Pig slurry

Typical total nitrogen content of pig slurry (fresh-weight basis)

	Dry matter	**Total nitrogen[a]**
	%	**kg N/m^3 or /t**
Pig slurry – liquid	2	3.0
	4[b]	**3.6[b]**
	6	4.4

Separated pig slurry(liquid portion)	3	3.6
Separated pig slurry(solid portion)	20	5.0

3.7.2.4. Timescale

These interventions represent significant changes within current farm practices, but are very achievable with the correct incentive for a farmer to implement each mitigation. The table below shows the expected timescales for response:

Component	**Expected timescale**	**Reason**	**Size of benefit**
Export manure and slurry	Year 1	This process is already common practice within the UK livestock systems	small

3.7.2.5. Spatial Issues

The introduction of nitrogen vulnerable zones will induce a heavily reliance on exporting slurry to comply with NVZ regulations. Correct record keeping and application of slurries to areas with the correct nutritional status is important.

Export of manures and slurries is not geographically dependent. It is applicable to almost any unit which has excess nutrient production for the land which is being farmed. It is geographical dependent in that major livestock areas have an excess to manure, but in many UK areas, these are distant from the major arable farm areas.

3.7.2.6. Displacement

In general, the export of farm manure/slurry will result in the displacement of artificial fertiliser use on the receiving farm, and this will enhance overall environmental sustainability and land productivity. This is a direct result of the reduction in nutrient overloading on farms with high concentrations of livestock and the moving of nutrients to farms which can more effectively use it.

3.7.2.7. Maintenance and Longevity

For engagement in the import or export of organic manure or slurry, all records of imports and exports including dates of import/export, manure type and Nitrogen content must be kept. Overall though, the export of slurries and manure is not a practice which requires significant management time to maintain. The main impediment is the cost of handling and transport of manures.

3.7.2.8. Climate Adaptation or Mitigation

The proposed strategies contribute to both adaptation and mitigation. These strategies are not affected by climate change but have a positive impact on reducing emissions from agriculture systems, delivered through increased efficiency of nutrient use, again provided that the slurry or manure is moved to land where it can be more effectively used.

3.7.2.9. Climate Factors / Constraints

In general, there are few climate factors which impact the movement of slurries and manures to other farms.

Manures and slurries should not be applied in very wet weather due to potential run off, and should not be applied to land where there is already high nutrient loading.

3.7.2.10. Benefits and Trade-offs to Farmer/Land manager

The most obvious benefit of moving manures and slurries to locations where they can be more effectively used is in minimising the use of artificial N fertiliser and subsequent reduction in GHG emissions and improved environmental footprint. Overall, these strategies have the potential to result in much more efficient production systems.

As previously discussed, long term work reported by Fornara *et al.,* in 2020 found that N applications either maintained or increased (up to three times) soil C accumulation compared to unfertilised soils after five decades of intensive management.

3.7.2.11. Uptake

Potential constraints to uptake will include the level of record keeping required: type and amount of livestock manure; the date it is sent off or brought onto the holding; the nitrogen content; name and address of recipient; and details of any contingency plan if export refused. Furthermore, if a TB breakdown occurs slurry cannot be exported. Biosecurity of exported slurry is also important, because it can transmit disease. In an ideal world, slurry and manure would be exported only to arable farms, greatly reducing the likelihood of disease transmission.

Recognition of the benefits of replacement of artificial fertiliser with manures/slurries is likely to encourage uptake, but ultimately businesses act in their own best interests and the reduction of GHG is not likely to be a driver for uptake. Cost savings and soil benefits resulting from the displacement of artificial fertiliser will be a much more powerful argument for uptake. The benefit will be mainly for the importing farm, not the exporting farm, so defining the costs to be borne by the beneficiary.

The introduction of legislation will also drive uptake of practices such as slurry/manure export. Increased record keeping, submission of records and inspection/audit are likely to be required to ensure widespread compliance.

3.7.2.12. Other Notes

None

3.7.3. ECPW-141 Use of ad lib feeding systems

Introduction

Given the significance of CH_4 as a GHG, reducing enteric CH_4 emissions from farming systems whilst maintaining levels of output is an important strategy to meet reduction targets in global emissions. Enteric CH_4 is produced as a by-product of anaerobic fermentation (methanogenesis) and accounts for a substantial proportion of the gross energy intake, with the latter being largely dependent on composition of the animal's diet and level of feed intake.

Important components of a diet that influence methane emissions are known to be fermentable carbohydrate, fibre, fat, and digestible energy intake. Increasing dry matter intake increases CH_4 emissions and, in particular, increasing the forage content of diets results in an increase in ruminal acetate production, which promotes CH_4 production. Ultimately, improved animal productivity and dietary manipulation are strategies that have shown potential for reduced emissions and that appear to be the most viable options in mitigating GHG emissions (Clemens and Ahlgrimm, 2001). Ad lib feeding systems have been shown to improve productivity as an indirect approach to reducing GHG emissions per unit of output. Under ad libitum feeding parameters, animals consume feed frequently in many small feeding events throughout the day (Manafiazar *et al.,* 2020) which will improve rumen efficiency.

However, feed is a significant cost in animal production systems, particularly dairy systems, and feed efficiency is vitally important. Within dairy systems in particular this has been achieved most dramatically through selection based on higher milk production, which has dilution effect on maintenance requirements, resulting in more energy being converted into milk (Vandehaar, 1998). Essentially an overall reduction in emissions would be driven through fewer animals being needed to deliver the same level of output.

Improving feed efficiency on an individual animal level can be developed through precision feeding systems. Precision feeding can improve feed efficiency without impairing performance and can be achieved by adjusting effective dietary formulation and presentation. However, in general, dry matter intake (DMI) is strongly correlated with CH_4 production, and ad lib feeding systems promote higher dry matter intakes. The key is to ensure this feeding strategy in optimising production and therefore decreasing CH_4 emissions per unit of output. But, as noted, ad lib feeding will only reduce overall emissions if coupled with lower levels of livestock to create the same or higher levels of output. If efficient systems allow an increase in the number of animals, a reduction in overall emissions is unlikely (although a reduction in emissions per unit of output will still result).

Livestock Management
This management bundle considers the effectiveness of livestock management as a tool for reducing overall environmental impact.

Livestock Management to reduce greenhouse gases
This management bundle considers the use of ad lib feeding as an effective strategy to reduce GHG emissions. Ad lib feeding can be used as GHG mitigation approach providing dietary formulation is correct and a production response results.

Active diet and feed planning management to match animal requirements
Using more high starch and reduced crude protein in diet
Using ad lib feeding system
Using phase feeding of livestock
Maintaining genetic diversity by rearing rare breed livestock
Enabling farm animal genetic improvement
Improving animal health
Improving productivity

This section focuses on the impact of ad-lib feeding of animals on the GHG output of the animals.

Use of ad lib feeding systems
This action considers the impact of active diet and feed planning to match animal requirements on the GHG production of that animal. It includes consideration of precision feeding in terms of requirement-based allocation and the use of ruminant feed additives.

3.7.3.1. Causality

Ad lib feeding

- Amber
    - The aim of feeding ad libitum, as opposed to limit feeding, is to optimise rumen function, energy intake, and subsequent production, with the dilution of maintenance requirements contributing to improved efficiency. However, it has been shown that feed efficiency can be improved by reducing DMI and increasing nutrient density (Hoffman *et al.,* 2007; Zanton and Heinrichs 2009). Diets that reduce DMI, condense energy, and use highly digestible feedstuffs are often referred to as limit-fed or precision-fed diets.

    - The effectiveness of ad libitum feeding in managing GHG emissions can be affected by the nutrient content and presentation of diet. The ME of mixed diets can be utilised with a higher efficiency than the ME of forages with the same metabolisability, consuming more ME from mixed diets (Tolkamp, 2010).

    - Ad lib feeding *per se* is not necessarily a solution for GHG reduction. However, in conjunction with careful management of the dietary ingredients (adjusting for digestibility, fibre content, available energy), it can be a contributing factor.

3.7.3.2. Co-Benefits and Trade-offs

The most obvious benefit of optimising livestock feeding systems by ad lib feeding is rumen stability and subsequent efficiency. There are other co-benefits in terms of management and animal health. This extends to drivers of whole farm efficiency parameters such as reduced disease, improved fertility, improved age at first calving etc. Overall, these strategies have the potential to result in much more efficient production systems; however, this feeding system may need to be linked to precision feeding to yield optimal environmental benefits, as well as reduced livestock numbers for the same, or increased, level of production.

3.7.3.3. Magnitude

The magnitude of impact is very difficult to estimate accurately as most models have limited data on actual methane outputs. However, based on current scientific data, these estimates are as accurate as can be at present.

Ad lib feeding

- The aim of ad lib feeding is to increase production, feed conversion efficiency, and improve the quantity of output (beef and dairy). However, it can often lead to overconsumption, especially when genetic potential / underlying health issues limit production.

- In this case the magnitude of the effect is negligible and may be negative.

3.7.3.4. Timescale

These interventions can represent significant / costly changes within current farm practices but are very achievable with the correct incentive for a farmer to implement each mitigation. The table below shows the expected timescales for response:

Component	**Expected timescale**	**Reason**
Ad lib feeding	Year 1	Ad lib feeding promotes production and maximises energy intake, rumen function and animal health. However, it can lead to inefficiency at farm level if genetics and management are not optimised. This strategy can be implemented immediately.

3.7.3.5. Spatial Issues

Farming practice and facilities are highly variable; however, implementation of ad lib feeding strategies are mainly applicable to intensive systems particularly dairy and housed beef finishing units. As most livestock in the UK are supplemented in some way, the option may be applicable to grazing systems. These mitigations are based on more targeted and precise nutritional programmes which can be implemented in the majority of systems.

3.7.3.6. Displacement

The strategies proposed will not cause any displacement, unless forced by legislation, regulations or customer requirements.

3.7.3.7. Maintenance and Longevity

The potential improvement in production at farm level can dilute energy required for maintenance and improve resource use efficiency as well as mitigate GHG emissions. If improved production efficiency results, an improvement in business sustainability will also be apparent.

The practice of implementing nutrient use efficiency strategies on-farm should become part of regular farm activity, and it is possible that incentives could be designed around the reporting and validation of these.

3.7.3.8. Climate Adaptation or Mitigation

The proposed strategy has the potential to contribute to both adaptation and mitigation. These strategies are not affected by climate change but have a positive impact on reducing emissions from agriculture systems.

3.7.3.9. Climate Factors / Constraints

The implementation of these strategies is not affected by current climatic factors; however, constraints include effective implementation on farm, genetic potential of animals, diet formulation to suit animal potential etc.

3.7.3.10. Benefits and Trade-offs to Farmer/Land manager

The most obvious benefit of ad lib feeding systems is the improved animal productivity, which extends to whole farm efficiency such as reduced disease, lower replacement rates, improved fertility, improved age at first calving etc. However, this is assuming the response to ad lib feeding systems is realised.

3.7.3.11. Uptake

There are a number of factors which are likely to reduce the effectiveness of implementation. These include accuracy of dietary formulation to ensure the maintenance of high levels of production, especially at lower dietary protein levels. Another barrier to uptake is the quantification of change: in general, most farms don’t record data or implement change that can be quantified quickly, especially in terms of carbon footprint. This is primarily due to the lack of measurement at livestock level.

3.7.3.12. Other Notes

None

3.7.4. ECPW-145: Optimise livestock feeding strategy to match animal requirements, (e.g. protein, lipids) except where farms are subject to the provisions of the Industrial Emissions Directive

Introduction
Precision livestock feeding aims to match nutrient supply precisely with the nutrient requirements of individual animal. The benefits include greater economic returns, reduced excretion to the environment, and improved efficiency of resource utilisation. Producers will become more competitive and have more market

opportunities if they can demonstrate increased resource use efficiency, whilst reducing the environmental footprint.

Within any system, the most efficient animals are consuming less feed than the average of the group but maintaining similar or better levels of production. In any group of animals there will be a proportion over consuming which results in inefficiency. Furthermore, over-consumption, especially in ruminants, has been shown to impair digestibility; digestibility decreases as DMI increases (Sauvant *et al.,* 2018). Applying a feed restriction to the less efficient animals may then improve their feed efficiency without compromising their production performance. Historically, studies into feed restriction have resulted in significant reductions in production; however, these studies applied restrictions to all animals (Herve *et al.,* 2019). The use of technology now allows the development of feeding programmes for individual animals, allowing those less efficient to be feed restricted. Precision feeding improves feed efficiency without impairing performance (Pino *et al.,* 2018) by reducing the intake of less efficient animals. This approach will reduce overall methane output and improve the environmental sustainability of the production system (Fischer *et al.,* 2020) through the reduction

Livestock Management: This management bundle considers the effectiveness of optimised soil management and protection as a tool for reducing GHG emissions.

Livestock management /Feeding strategies : This management bundle sub-group considers the use of an optimised livestock feeding strategy as an effective strategy to reduce GHG emissions. Precision feeding can be used as GHG mitigation approach providing dietary formulation is correct and a production is not impaired by any restrictions.

This section considers the effectiveness of optimising livestock feeding strategies to match animal requirements in reducing GHG emissions. The strategy is aimed at identifying individual animal requirements and adjusting feeding approaches to match these requirements. The value of this approach is multifaceted and will result in improved production and environmental sustainability.

3.7.4.1. Causality

The aim of optimising livestock feeding strategies to match animal requirements is to optimise resource use efficiency and reduce the environmental impact of production.

It has been shown that feed efficiency can be improved by reducing DMI and increasing nutrient density (Hoffman *et al.,* 2007; Zanton and Heinrichs 2009). Approaches that reduce DMI, condense energy, and use highly digestible feedstuffs are adopting a precision-feeding approach.

Historically, feed formulation involved setting minimum nutritional requirement and then performing least cost formulations. However, formulation goals are now more complex and in addition to minimising the cost of the feed it is now more than ever appropriate to consider reducing methane production, and nitrogen and phosphorus excretion (Sudduth and Loveless, 2019).

Precision feeding requires technology to match the diet allocation more closely to the animal’s nutritional requirements. For pigs this may involve regular weighing of animals and adjustment of the ration protein content based on weight and growth rate, and supplementation of diets with synthetic amino acids. For ruminants, emissions could be reduced through improved characterisation of forages to enable appropriate supplementation ensuring that protein is not over-used, energy requirements are met and the overall protein:energy ratio is achieved. However, to effectively deliver precision nutrition in beef cattle, weighing is also necessary, but many beef farms do not have weighting facilities to enable this. Dairy cattle can be fed according to their individual milk output which is their strongest indicator of dietary required.

GHG emissions are related to the amount of feed that is metabolised. Efficient use of feed reduces emissions per unit of production (Waghorn and Hegarty, 2011).

3.7.4.2. Co-Benefits and Trade-offs

The most obvious benefit of optimising livestock feeding systems to match animal requirements is the improved nutrient use efficiency, improved environmental footprint, and improved profit margins. This extends to drivers of whole farm efficiency such as reduced disease, lower replacement rates, improved fertility, improved age at first calving etc. Overall, these strategies have the potential to result in much more efficient production systems.

Trade-offs occur through the requirement to spend additional management time on diet planning and monitoring of performance but have benefit for air and water quality.

[TOCB Report-3-1 AQ **ECPW-145**] Feeding strategies for ammonia emission reduction have also been assessed for positively abating nitrous oxide emissions (Sanchez-Martin *et al.,* 2017). Reduction in crude protein (CP) diets can reduce need for supplements in feed and reduction of other costs (Abassi *et al.,* 2018).

3.7.4.3. Magnitude

The magnitude of impact is very difficult to estimate accurately as most models have limited data on actual methane outputs. However, based on current scientific data, these estimates are as accurate as can be at present.

Optimise livestock feeding strategy to match animal requirements

- Precision feeding will lead to a saving in feed intake of 6.7% that in turn will reduce total methane production (Fischer *et al.,* 2020).
- Improved nutrient use efficiency will also result from precision feeding, particularly nitrogen use efficiency. Currently feed nitrogen use efficiency varies from 16% to 36% (Powell *et al.,* 2010), highlighting the opportunity available for improved nutrient utilisation.

3.7.4.4. Timescale

These interventions represent significant changes within current farm practices, but are very achievable with the correct incentive to provide farmers with the tools to allow the implementation of the proposed mitigation. The table below shows the expected timescales for response:

Component	**Expected timescale**	**Reason**
Optimise livestock feeding strategy to match animal requirements	Year 5	Precision feeding promotes production efficiency and optimal nutrient utilisation, all of which can contribute significantly to reduced GHG emissions. This strategy can be implemented immediately but will take considerable time to roll-out of farm on a large scale.

3.7.4.5. Spatial Issues

Farming practice and facilities are highly variable; however, implementation of this strategy will be limited to farming systems with large amounts of data which allows feeding regimes to be tailored to individual animals. This will be most applicable to intensive dairy systems whereby animals are individually allocated feed through robots or feed stations, but will also apply to intensive beef as well. In general, pig and poultry systems are already optimised (driven through the collection and use of data).

The mitigations discussed in this report are based on targeted and precise nutritional programmes which cannot always be implemented in the majority of systems because of the lack of individual data collection. It is possible that these systems can be implemented where there is measurement of small group performance, where animals with similar body size and levels of performance are grouped and fed together.

3.7.4.6. Displacement

The proposed activity will not cause displacement because it focused on improvement and refinement of existing systems.

3.7.4.7. Maintenance and Longevity

The improvement of resource use efficiency at farm level will not only mitigate GHG emissions, but will also improve business sustainability and improve animal performance at farm level. This has multiple secondary benefits including better performance, reduced disease, and improved lifetime production.

The practice of implementing nutrient use efficiency strategies on-farm should become part of regular farm activity, and it is possible that incentives could be designed around the reporting and validation of these.

3.7.4.8. Climate Adaptation or Mitigation

The proposed strategies contribute to both adaptation and mitigation. These strategies are not affected by climate change, but have a positive impact on reducing emissions from agriculture systems.

3.7.4.9. Climate Factors / Constraints

Application of precision feeding systems (nutrient precision / restricted intake systems) will only be applicable in field conditions with individual feed intake systems or feed efficiency monitoring systems. These systems will require individual feed dispensing systems and individual recording systems. Technological advances are facilitating this ability at farm level; however, individual feed intake recording does not represent precision feeding, such algorithms are in development and are being implemented slowly at farm level.

3.7.4.10. Benefits and Trade-offs to Farmer/Land manager

The most obvious benefit of optimising livestock feeding systems to match animal requirements is the improved nutrient use efficiency, improved environmental footprint, and improved profit margins. This extends to drivers of whole farm efficiency such as reduced disease, lower replacement rates, improved fertility, improved age at first calving etc. Overall, these strategies have the potential to result in much more efficient production systems.

3.7.4.11. Uptake

There are a number of factors which are likely to limit uptake and reduce the effectiveness of implementation. These include the initial cost of installing a individual intake feeding system to enable the required accuracy of dietary formulation and consistency of feed supplements offered. Another barrier to effective implementation is the processing of data once collected. Large volumes of animals with individual data attached will require good data handling and analysis and it is vitally important that support is offered in the implementation of such strategies.

Optimising diets will also require a significant input of management time and unless farm staff are prepared to commit to this, uptake or delivery is likely to be sub-standard.

3.7.4.12. Other Notes

None

3.8. ECPW-146 USE PHASE FEEDING OF LIVESTOCK

Introduction

Phase feeding is a term used to describe the feeding of diets in which the ingredient and nutritional composition is modified over time to more closely match the nutritional needs of the animal (Carter *et al.,* 2012). When one unchanged diet is fed for a long period of time there are periods of either under- or over-supply of nutrients relative to the animal's requirements. A one-diet system is detrimental to animal health when underfed and detrimental to the environment when overfed due to excess nutrient excretion. Through phase feeding, the nutrient supply can be more closely match the animal's nutrient requirements.

The dairy, poultry and pork industries have adopted phase feeding widely, changing the nutrient concentrations in a series of diets formulated to meet an animal's nutrient requirements more precisely at a particular stage of production. Phase feeding in the dairy industry is implemented by placing cows in multiple feeding groups based on their lactation status.

Phase feeding is a more adoptable approach than precision feeding when compared to a simple one diet system. Phase feeding manages animals on a group basis as opposed to an individual basis. The disadvantages of phase feeding is the greater management complexity when compared to a single diet system; however, with increased pressures on profitability and environmental compliance, this is a small hurdle to overcome. To a large extent, phase feeding is widely practiced in the UK and the benefits are already being realised when compared to one-diet system.

Livestock Management

This management bundle considers the impact of enhanced livestock management steps to reduce GHG emissions.

Livestock Management/Feeding Strategies

This action considers the use of feeding strategies as effective methods of mitigating GHG emissions.

Use phase feeding of livestock

This action considers the impact of phase feeding on the GHG production of that animal. It includes consideration of precision feeding in terms of requirement-based allocation and the use of ruminant feed additives, but it not specifically precision feeding at an individual animal level.

3.8.1.1. Causality

The relationship between phase feeding of livestock and GHG emissions is Green – the relationship is established.

- In all sectors, especially dairy, beef, pork and chicken, phase feeding has improved productivity
- A more accurate supply of nutrients has several positive outcomes; providing the required nutrients can increase the production potential, reduce feed cost, improve nutrient utilisation, reduce nutrient waste, and decrease the environmental footprint of food production (Lovarelli *et al.,* 2020).
- The cow herd's feed requirements amount to 54-75% of the annual maintenance costs for the herd (Houghton *et al.,* 1990). Phase feeding will facilitate the reduction in the proportion of feed contributing towards maintenance by improving production.
- Compared to a "one size fits all" management approach, phase feeding prevents over-and underfeeding, giving producers more flexibility to use feed resources and obtain a greater return on investment of feed resources.
- Phase is widely practiced on the majority of livestock enterprises within the UK and incentives should be focussing on further developing this into precision feeding.

3.8.1.2. Co-Benefits and Trade-offs

The most obvious benefit of phase feeding is the improved nutrient use efficiency, improved environmental footprint, and improved profit margins. This extends to drivers of whole farm efficiency such as reduced disease, lower replacement rates, improved fertility, improved age at first calving etc. Overall, these strategies have the potential to result in much more efficient production systems.

Trade-offs occur in through the requirement to spend additional management time on diet planning and monitoring of performance but have benefit for air and water quality.

3.8.1.3. Magnitude

The magnitude of impact is estimated and based on current scientific data:

Dairy

- Phase feeding has been shown to be effective for both dairy cattle. Grouping cows according to milk production levels decreased nitrogen excretion by 6% (St. Pierre and Thaen, 1999).

Beef

- Reducing the crude protein in beef cattle diets from 13% to 11.5% in the last 56 days of the feeding period reduced nitrogen emissions by 19% (Cole, 2006).

Pork

- Phase feeding and split-sex feeding have been shown to decrease air emissions from swine operations. For example, using three feed phases in grow-finish instead of one can reduce nitrogen excretion in manure by 15% and ammonia emissions by 17% (Sutton, 2008).

Chicken

- Using a combination of several techniques, such as phase feeding, split-sex feeding, minimising feed wastage, and targeting diets to specific genetic lines, can reduce ammonia and hydrogen sulphide emissions 30-50% and odours by 30% with little extra cost for the producer (Sutton, 2008).

However, in UK, there may be little improvement in GHG emissions through the incentivisation of phase feeding systems as they are already common practice within the UK livestock sector.

3.8.1.4. Timescale

These interventions represent significant changes within current farm practices, but are very achievable with the correct incentive for a farmer to implement each mitigation. The table below shows the expected timescales for response:

Component	**Expected timescale**	**Reason**	**Size of benefit**
Use phase feeding of livestock	Year 1	Effective at improving efficiency; however, already common place within UK livestock sector	Small

3.8.1.5. Spatial Issues

There are limited spatial issues. This mitigation is well established and is applicable almost anywhere livestock are being fed, provided that the appropriate equipment is in place to enable it.

3.8.1.6. Displacement

There will be minimal displacement with this mitigation strategy. More accurate nutrient allocation will allow for improved nutrient utilisation and may free up of land for alternative use.

3.8.1.7. Maintenance and Longevity

This mitigation is already common practice within a UK setting. The practice does not require significant additional maintenance. However, to effectively implement phase feeding it can often make sense to weigh livestock on a regular basis. This equipment will require ongoing maintenance and requires additional management time to execute the practice. Additional management time must be implemented to source appropriate diets for the specific phase of the animal's growth or performance level.

3.8.1.8. Climate Adaptation or Mitigation

The proposed strategies contribute to both adaptation and mitigation. This strategy is not affected by climate change and will have limited positive returns regarding reducing emissions from agriculture systems.

3.8.1.9. Climate Factors / Constraints

Additional management input may will be required, within this mitigation; however, it is likely that infrastructure, within a UK setting, is already in place to facilitate this.

3.8.1.10. Benefits and Trade-offs to Farmer/Land manager

The most obvious benefit of phase feeding systems is to closer match diets to animal requirements, which will improve nutrient use efficiency, improved environmental footprint, and improved profit margins. Overall, these strategies have the potential to result in much more efficient production systems.

3.8.1.11. Uptake

Uptake of this mitigation is widespread and proving very effective at farm level.

3.8.1.12. Other Notes

None

3.8.2. **ECPW-171: Use very low inputs on permanent grassland**

Introduction

Permanent grassland is land used for at least 5 consecutive years to grow grasses, legumes, herbs and wildflowers. It is land which is not included in the crop rotation. This system is usually maintained with very low inputs, minimising herbicide and nutrient loading.

To combat climate change and work our way towards a goal of Net Zero. It is necessary to find a way to balance the carbon emitted with the carbon sequestered. One of the most efficient ways to sequester carbon, is for growing plants to absorb carbon from the atmosphere via photosynthesis, storing it in the soil as live or dead plant material. Uplands and peat soils are the largest store of Soil Organic Carbon (SOC) here in the UK. They account for 42% of total SOC stores (NSA, 2016).

Soil carbon sequestration is the mechanism responsible for most of the greenhouse gas (GHG) mitigation potential in the agriculture sector. Abatement from soil organic carbon sequestration in permanent pastures supporting livestock can partially (Crosson *et al.,* 2011) or completely (Rutledge *et al.,* 2015; Meyer *et al.,* 2016) offset the emissions from livestock for up to two decades. However, as soil organic carbon concentrations approach equilibrium in the longer term, net emissions are likely to increase as CH_4 emissions from livestock systems dominate the GHG balance (Crosson *et al.,* 2011).

However, there are multiple other benefits from managing grassland well. One of these is the ability to use low inputs of fertilisers, pesticides and manures. Reducing the level of input of nutrients to land can continue to provide high-quality forage for livestock whilst reducing spending on artificial fertiliser, herbicides and pesticides. This can help protect soil from erosion, provide habitat for invertebrates, birds and mammals, increase species of wildflowers providing food for pollinators, reduce the loss of nutrients and pesticides to watercourses and groundwater, keep soil healthy and carbon-rich, retain grassland as part of the traditional landscape character and improve air quality by reducing ammonia emissions from artificial fertiliser.

The DEFRA definition of 'low input' is as follows:

To qualify as low or no input grassland, the sward composition across a land parcel should include at least 2 of the following:

- less than 30% cover of rye-grasses and white clover
- 9 or more species per m2, including grasses
- 10% or more cover of wildflowers and sedges, excluding white clover, creeping buttercup, docks, thistles and ragwort

Meeting these eligibility criteria is likely to mean it:

- has not been reseeded for at least 15 years
- receives no or low amounts of fertiliser, which may be mainly as animal manures and slurries - more improved fields may receive up to 100kg per hectare, as mainly compound fertiliser.
- has no or only localised herbicide application to treat weeds
- has unmaintained field drains or infrequently maintained field drains (hay meadows may be more actively drained)
- takes any conserved forage as hay or haylage once a year

Use very low inputs on permanent grassland

Soil Management and Protection: This management bundle considers the effectiveness of optimised soil management and protection as a tool for reducing GHG emissions.

Soil Input Management to Reduce Greenhouse Gases: This management bundle sub-group considers GHG mitigation approaches within soil management and protection provoking farmers to modify production processes to deliver GHG reduction.

Traditional grassland management in the UK is focused on high input-high output, with large quantities of nutrient being applied to land to drive production of grass to support high volumes of livestock production. Often the nutrient applied is surplus to requirements which results in the release of GHG emissions, as well as run-off into watercourses. If managed effectively, soil can be a very significant carbon sink. In fact, soil carbon sequestration is the mechanism responsible for a significant proportion of the greenhouse gas (GHG) mitigation potential in the agriculture sector and abatement from soil organic carbon sequestration in permanent pastures supporting livestock production can be very effective. Sequestration will be low for permanent pastures. Temporary pastures will have higher sequestration rates.

3.8.2.1. Causality

Low inputs on permanent grassland may have an impact on GHG balance. However, low inputs are only successful if the soil can provide enough nutrient to enable the desired level of production. We have rated the relationship as amber, because although there may be a relationship, there are many factors where additional knowledge is required.

Abatement from soil organic carbon sequestration in permanent pastures supporting livestock can partially (Crosson *et al.,* 2011) or completely (Rutledge *et al.,* 2015; Meyer *et al.,* 2016) offset the emissions from livestock for up to two decades. However, as soil organic carbon concentrations approach equilibrium in the longer term, net emissions are likely to increase as CH_4 emissions from livestock systems dominate the GHG balance (Crosson *et al.,* 2011). The ability of the soil to sequester Carbon is highly dependent on the geographic location, as well as current carbon status of the soil and management practices on the farm (Conant *et al.,* 2001).

A number of benefits are thought to result from managing grassland using very low inputs. These include the provision of high-quality forage for livestock, reduced spending on artificial fertiliser, herbicides and pesticides, protection of soil from erosion, provide habitat for invertebrates, birds and mammals, increased species of wildflowers providing food for pollinators, reduction of the loss of nutrients and pesticides to watercourses and groundwater, the ability to keep soil healthy and carbon-rich, retention of grassland as part of the traditional landscape character and improvement of air quality by reducing ammonia emissions from artificial fertiliser.

However, the literature is very divided on the benefits of low input. A comparison study in Norfolk (Dodd 1987) found higher diversity of plants on 20 grazing fields under the Broads Grazing Marshes Scheme than on five more intensively managed fields outside the scheme. Fields within Scheme had 14-31 plant species, those outside it 10-16 species. A long term study from 1967 to 1993 of a grassland at the University experimental farm, Meenthoeve in the Netherlands (Wind *et al.* 1994) found that plant species increased for six years following extensification, but then decreased in unfertilised plots. Species increased following sowing (1966) and extensification (1971), from 19 species in 1969 to 37 in 1977. Numbers then declined to below 25 species in unfertilised plots as weeds typical of intensive grassland decreased. A review by Fisher & Rahmann (1997) found that reduced management intensity on grassland can benefit plant and insect diversity, but it does not always.

A review paper by ‘Conservation Evidence’ (Reduce management intensity on permanent grasslands (several interventions at once) - Conservation Evidence) stated the following:

“Twenty-one studies from six European countries found no clear effects of reducing management intensity on some or all plants, invertebrates or birds. Seven studies (including two replicated paired site comparisons and a review) found no clear effect on plants. Ten studies (including four site comparisons and one paired site comparison) found mixed or no effects on some or all invertebrates. Two studies (one review, one site comparison) found invertebrate communities on less intensively managed grasslands were distinct from those on intensively managed grasslands. Four studies (including three site comparisons, of which one paired and two replicated) found no clear effects on bird numbers or species richness.”

Alldabe *et al.,* 2019 found that reducing inputs so that grazing height is increased can have negative effects on ground-nesting birds, e.g. the Golden Plover, which cannot nest in pasture >15 cm high.

A meta-analysis of the effects of grazing on grassland soil carbon confirmed the importance of the site-specific variables on sequestration (McSherry and Ritchie (2013). No easy judgements could be made about the relationship between grazing intensity and any single factor such as rainfall or soil type. They noted that the effects of grazing management on SOC can be large, with equally distributed gains or losses of about 5.5 t CO2/ha/yr (1.5 t C/ha/yr), with variability over time.

During the literature search for this (admittedly very high-level) paper, we found little to no evidence which considers overall **GHG** impact of low input practices at a systems level. Reduced inputs of fertiliser obviously has an effect, and so does the absence of ploughing, but the impact of reduced plant growth, reduced input of animal manures and reduced animal numbers can have confounding effects, and the overall impact is difficult to calculate.

3.8.2.2. Co-Benefits and Trade-offs

Benefits of low inputs on permanent grassland can include increased range of species and a reduction in emissions due to reduced inputs of artificial fertiliser. Trade-offs include lower output per hectare and an increased landmass per unit of livestock. However, these benefits do not always accrue and are dependent on a range of other factors being in place.

[TOCB Report-3-6 Carbon **ECPW-171** and others] According to Bai *et al.,* (2019), reduced nitrogen fertiliser inputs will likely lead to greater SOC storage benefits brought about by "climate-smart agriculture" interventions including:

- Use minimum-tillage or no-tillage cultivation [**ETPW-092**]
- Use green manures within the rotation [**ECCM-023**]
- Minimise bare soil to reduce soil loss e.g. cover crops, crop residues, trees coppice etc [**ECPW-002**].

[TOCB Report-3-4 Water **ECPW-171** and others] Reductions in fertiliser nitrogen inputs will reduce the risk of nitrous oxide and ammonia emissions from soils (Cardenas *et al.,* 2010). There would also be a significant impact on crop yields (other than legumes). For example, a 20% reduction in fertiliser N use (below the economic optimum rate) would typically result in a 2-10% reduction in crop yields. A complete cessation of nitrogen fertiliser use on arable crops will typically lead to halving of crop yields. Initially, the impact of reducing fertiliser P use would be greatest for responsive crops (e.g. potatoes and some vegetable crops). It is important that any reduction in fertiliser use should take account of the interactions between nutrients and not create an imbalance in the soil. A shortage of one nutrient may limit uptake of another and potentially increase losses of the second nutrient.
It is unclear to what extent nitrogen stimulates sequestration. Lu *et al.,* (2011) concluded from their meta-analysis that N stimulation of SOC storage primarily occurred in plant pools and less in soil pools. The small magnitude of the effect of N addition on SOC stocks was explained by the higher stimulation of above-ground biomass production than that of below ground biomass. Furthermore, the dataset gathered by Lu *et al.,* (2011) showed that N addition stimulated soil organic matter mineralisation to release carbon dioxide. This was consistent with results by Neff *et al.,* (2002). Manures transfer existing organic carbon to the soil pool (Chenu *et al.,* 2019). Additions of organic materials may also improve crop primary productivity via increased nutrient availability and labile C fractions. This represents a secondary pathway by which this measure can influence net atmospheric C removal. However net sequestration depends on the added carbon becoming locked into the soil

[TOCB Grassland **ECPW-171**-014] Positive benefits for biodiversity of grassland habitats and the species that are associated with them.

3.8.2.3. Magnitude

The literature indicates that the low inputs on permanent grassland result in the following:

- Abatement from soil organic carbon sequestration in permanent pastures supporting livestock can partially (Crosson et al., 2011) or completely (Rutledge et al., 2015; Meyer et al., 2016) offset the emissions from livestock for up to two decades.
    - The literature is divided on how long soil continues to sequester carbon, with some literature suggesting around 15/20 years and others suggesting well over 40 years (Fornaro et al. 2016; Conant et al. 2001). Virtually all literature does agree that the soil's capacity to sequester carbon must eventually tail off and plateau.

- Conversion of arable to grassland can increase SOC by up to 19% (Conant *et al.,* 2001).

Whilst the above are potentially true under certain circumstances, the literature is very divided over the ability to predict the effect. Much of the literature is conflicted around the predicted benefits, and this appears to be because the true impact is the result of a multiplicity of factors, and changes in one factor may be confounded by changes in another. Thus, while it appears that, on balance, low input management is likely to be beneficial from a total GHG output, this is not always the case.

3.8.2.4. Timescale

These interventions represent significant changes within current farm practices, but are very achievable with the correct incentive for a farmer to implement each mitigation. The table below shows the expected timescales for response:

Component	**Expected timescale**	**Reason**	**Size of benefit**
Low inputs on permanent grassland	Year 3	Methodology well established as large parts of the available land are unsuitable for land use change and remain permanent pasture.	Medium

3.8.2.5. Spatial Issues

There are limited spatial issues associated with managing land as low input. Low input (or precision input) management of land can take place in almost any geographical region. A much more important consideration is the quality of the soil on which the low input system is being implemented. Soil must be able to support the levels of production which are required from it and it is important that soil is not depleted because of excessive demands.

Low input systems are most applicable to large parts of the available land that are unsuitable for land use change and remain in permanent pasture.

3.8.2.6. Displacement

Increasing the proportion of permanent pasture will displace other more productive activities and has the potential to reduce national output / food production.

3.8.2.7. Maintenance and Longevity

Maintenance of permanent pasture is extremely important in realising the benefits. Grazing management is a very important factor in utilisation of grassland. Over-grazing and under-grazing have the potential to be extremely detrimental to pasture in the long-term, reducing environmental benefits. However, provided that the low input system is managed with appropriate stocking densities, it would not be expected that increased management time be required or the longevity of pasture will be affected.

Many low input systems are managed in conjunction with high clover/nitrogen fixing plants and these systems do required additional maintenance as clover is not as persistent as grasses. Without adequate management of swards, longevity will be negatively affected. This will also be the case if overgrazing is permitted.

Management time is required to ensure that the grassland is managed effectively, that soil nutrient status is adequate and that stocking densities are appropriate.

3.8.2.8. Climate Adaptation or Mitigation

The proposed strategies contribute to both adaptation and mitigation, with appropriately managed low-input grassland contributing to carbon capture. The implementation of low input grazing systems is not affected by climate change but may require different sward species under different climatic conditions.

3.8.2.9. Climate Factors / Constraints

Conversion to permanent pasture from rotational systems will reduce farm output and support will be required to encourage this transition.

3.8.2.10. Benefits and Trade-offs to Farmer/Land manager

The main benefit of low input systems is the increased carbon sequestration, along with reduced input costs to the land. Smith (2014) concluded that it is untenable that grasslands act as a perpetual carbon sink, and the most likely explanation for observed grassland carbon sinks over short periods is legacy effects of land use and land management prior to the beginning of flux measurement periods. Simply having grassland does not result is a carbon sink, but judicious management of previously poorly managed grasslands can increase the sink capacity. Given that grasslands are a large store of carbon, and that it is easier and faster for soils to lose carbon that it is for them to gain carbon, it is an important management target to maintain these stocks. Management of previously poorly managed grasslands can increase the sink capacity (though this will decrease over time).

However, the reduced input costs do not always translate into increased profitability due to reduced output. Low input systems generally work best on farms which have very large land areas, low labour requirements and stock which are suited to high forage production. The main trade-off is reduced output and, as a consequence, reduced income for the farm.

3.8.2.11. Uptake

Conversion to permanent pasture from rotational systems will reduce farm output and support will be required to encourage this transition. To make the system work farm managers will need to carry out an extensive cost-benefit analysis to determine if the decreased farm output can be offset by the potentially reduced costs which are enabled by a low input system.

The production of a range of case studies for similar farms, land conditions and enterprises could enable more effective uptake of low input systems.

3.8.2.12. Other Notes

None

3.8.3. ECPW-173: Use no fertiliser

Introduction

Cardenas *et al.,* (2019) wrote a paper on Nitrogen use efficiency and Nitrous Oxide emissions in the UK. They stated the following:

"During recent decades, the demand for global food has increased rapidly as a consequence of population growth and changes in patterns of food consumption. One of the most relevant changes in the global agro-food system has been the intensification of production systems and the increase of nitrogen (N) use and trades (Lassaletta et al., 2016). Cultivated grasslands are an example of this intensification process and constitute a significant share of the agricultural area in some temperate countries (FAOSTAT, 2018). It is expected that further intensification will occur to fulfil increasing global demand for livestock products, putting pressure on farming activities that will likely result in increased N use.
N fertilisation of grasslands has relevant productive and environmental effects. It has major effects on the nutritive value of fresh herbage, as well as on animal nutrition and N balance (Lee, 2018).
However, fertiliser rates exceeding crop requirements lead to an N surplus, reduced N use efficiency (NUE) and losses to the environment (Van Eerd et al., 2018). In terms of gaseous pollutants, N fertiliser applications are associated with emissions of nitrous oxide (N_2O) *(Reay et al., 2012), a powerful greenhouse gas (GHG) with a large global warming potential (Forster et al., 2007), and a gas that contributes to ozone* (O_3) *depletion in the stratosphere (Ravishankara et al., 2009). In the case of urea-based fertiliser applications, ammonia* (NH_3) *is also emitted (Pan et al., 2016), with* NH_3 *emissions directly implicated in detrimental environmental quality (Krupa, 2003). An improved NUE is required in intensively managed grasslands to reduce the negative effects of an N surplus while preserving productivity and soil fertility."*

Their paper gave a very strong outline of the challenges around the use of fertiliser, much of it driven globally by the intensification of agriculture. Overuse of fertiliser is a significant challenge and much of the surplus N is liable to be lost to the aqueous and atmospheric environments where it can become a serious pollutant and a conservation concern.

The main nutrient-related negative environmental impacts of pasture systems are eutrophication of fresh waters, estuaries, coastal water and nutrient-poor land habitats; emissions of 'greenhouse' gases to the atmosphere; and a decrease in biodiversity within and outside the pastures (Jarvis, 1993, Scholefield 2003, Firbank 2005). It is now a necessity to reduce the level of pollutants from agriculture and to promote biodiversity.

The challenge, especially for the intensive livestock sector, is to reduce the use of inorganic fertilisers and associated pollutants whilst maintaining economic viability. Currently, the quantity of Nitrogen (N) applied to land is high and with the rising cost artificial fertiliser, there is much merit in establishing alternatives such as clover swards. White clover is highly digestible and unlike perennial ryegrass, performs well with low fertiliser N inputs. White Clover, an N_2-fixing legume grown in association with the grass, is the main legume used, especially in long-term pasture (Hodgson & White, 2000). This approach is effectively utilised within organic systems and has the potential to become established as a priority mitigation for GHG emissions.

On-farm research has shown that where grassland has been converted over to clover-based swards on intensively stocked dairy farms, fertiliser N inputs have been halved while maintaining or increasing milk output (Johansen *et al.,* 2017). Furthermore, greenhouse gas emissions (NO_2 and Ammonia) resulting from N fertiliser production would be greatly reduced with the perennial ryegrass/white clover pasture systems.

Increasing the abundance of legume species in some grass swards can also improve sequestration and forage quality. In combination with legumes, a more diverse vegetation cover (>4 species/multi-species sward) can make grasslands more resilient in terms of climate change and may provide both a better forage quality and organic matter input (Peyraud J.L *et al.,* 2014).

Average biological Nitrogen fixation in grazed permanent clover/grass pastures in temperate regions of the world has been reported to be 80-100 kg N/ha/yr (range 10-270 kg N/ha/yr) (Ledgard et al, 2009). This fixed N becomes available slowly over time to the grass in pastures after it is released into soil via exudates from living legume roots, by mineralisation of legume tissues and in excreta after consumption by grazing animals (Ledgard *et al.,* 2009). Andrews *et al.,* (2007) concluded that herbage and milk production from white clover-based pastures (perennial ryegrass with 20% white clover in herbage DM) are likely to be similar to that from a perennial ryegrass pasture receiving annual input of 200 kg/ha of fertiliser N. AHDB RB209 estimates the contribution from white clover can be up to 180kgN/ha

Soil Management and Protection

This management bundle considers the effectiveness of optimised soil management and protection as a tool for reducing GHG emissions.

Soil Input Management to Reduce Greenhouse Gases

This management bundle will consider GHG mitigation approaches within soil management and protection provoking farmers to modify production processes to deliver GHG reduction. Factors considered within this include (but are not limited to)

Replacement of nitrogen fertiliser application by using clover in pasture or arable cropping systems
Use of very low inputs on permanent grassland

Use no fertiliser

This action focuses on the total removal of nitrogen fertiliser and its impact on GHG emissions. In reality the total removal of fertiliser is usually accompanied by other measures – particularly the use of clover in pasture systems. The use of no fertiliser is more difficult (and less feasible) for arable cropping systems. In particular it may reduce protein levels in cereals such as wheat, making it unsuitable for meeting milling quality.

3.8.3.1. Causality

The total removal of artificial fertiliser from land application is strongly associated with a reduction in GHG emissions. The production of fertiliser is associated with the production of large volumes of NO_2 and the application of the fertiliser is associated with the production of NO_2 and NH_3. From a theoretical perspective, this is rated Green. However, in true practical terms, mismanaged removal of nitrogen can lead to increased levels of GHG from grazing animals (per unit of production), as reduced available forage slows their rate of growth.

The inclusion of clover in pasture swards is also associated with a reduction in GHG emissions. This is rated green.

- Increasing the abundance of legume species in some grass swards can improve sequestration, forage quality, and reduce inorganic N inputs. This in turn will reduce losses to the environment, including GHG emissions. In combination with legumes, a more diverse vegetation cover (>4 species) can make grasslands more resilient in terms of climate change and may provide both a better forage quality and organic matter input.

- Forage legumes might also be capable or reducing enteric CH_4 emissions, partly through their condensed tannin content (Jayanegara *et al.,* 2012), though the evidence is not conclusive yet (Lüscher *et al.,* 2014).

3.8.3.2. Co-Benefits and Trade-offs

Benefits of reducing fertiliser use include the reduction of loss of N_2O into the atmosphere and reduced run-off, improving water quality. Trade-offs centre around the costs of establishing and maintaining clover / legumes in swards and the increased maintenance time required to manage the stock.

[TOCB Report-3-6 Carbon **ECPW-173** and others] According to Bai *et al.,* (2019), reduced nitrogen fertiliser inputs will likely lead to greater SOC storage benefits brought about by "climate-smart agriculture" interventions including:

- Use minimum-tillage or no-tillage cultivation [**ETPW-092**]
- Use green manures within the rotation [**ECCM-023**]
- Minimise bare soil to reduce soil loss e.g. cover crops, crop residues, trees coppice etc [**ECPW-002**].

[TOCB Report-3-4 Water **ECPW-173** and others] Reductions in fertiliser nitrogen inputs will reduce the risk of nitrous oxide and ammonia emissions from soils (Cardenas *et al.,* 2010). There would also be a significant impact on crop yields (other than legumes). For example, a 20% reduction in fertiliser N use (below the economic optimum rate) would typically result in a 2-10% reduction in crop yields. A complete cessation of nitrogen fertiliser use on arable crops will typically lead to halving of crop yields. Initially, the impact of reducing fertiliser P use would be greatest for responsive crops (e.g. potatoes and some vegetable crops). It is important that any reduction in fertiliser use should take account of the interactions between nutrients and not create an imbalance in the soil. A shortage of one nutrient may limit uptake of another and potentially increase losses of the second nutrient.

Based on studies in cropland, it seems that improving NUE cannot consistently reduce N_2O emissions (Phillips *et al.,* 2009), probably because the practices that improve NUE by reducing NH_3 and/or Nitrate losses may make more N available in the soil for both N uptake in crops and soil N_2O production (Venterea *et al.,* 2012). For the few N_2O response experiments in which more than two levels of N were applied, N_2O flux in response to increasing N rates has been described by both linear and nonlinear functions (Li *et al.,* 2015). For example, Cardenas *et al.,* (2010) showed that the N_2O emissions from applying AN fertiliser varied in a non-linear way – higher application rates leading to much higher emissions. However, Cardenas *et al.,* (2019) showed that the trend of non-linearity is not consistent. In a study of 5 sites, the effect of increasing N fertiliser rate on annual N_2O emissions showed linear responses for 3 sites, and exponential curves at the remaining 2 sites. For grassland, Cardenas et al, (2019) found that from grass N offtake amounts, not all N added was used by the plants, resulting in an average surplus of 0.32 kg N per additional kg N applied.

3.8.3.3. Magnitude

The magnitude of impact is estimated accurately and based on current scientific data, these estimates are as accurate as can be at present.

Inclusion of clover in pasture swards

- Clover will fix, on average, 80 kg N / ha / yr (Burchill *et al.,* 2014). Comparisons of biological nitrogen fixation in association with white clover (Trifolium repens L.) under four fertiliser nitrogen inputs as measured using two 15N techniques)
- Greenhouse gas emission reductions of 69 kt CO_2e can be achieved from avoided fertiliser emissions (direct and indirect N_2O) (Lanigan & Donnellan, 2019).

3.8.3.4. Timescale

These interventions represent significant changes within current farm practices but are very achievable with the correct incentive for a farmer to implement each mitigation. The table below shows the expected timescales for response:

Component	Expected timescale	Reason	Size of benefit
Inclusion of clover in pasture swards	Year 3	Including legumes in pasture swards will facilitate N_2-fixation and reduce the requirement for artificial fertilisers	Large

3.8.3.5. Spatial Issues

Clover is affected by soil temperatures and viability will depend on geographical location as higher soil temperature are required for growth compared to ryegrasses.

Furthermore, clover does not establish well in wet, peaty and acidic soils so once again geographical location will be a consideration for implementation.

3.8.3.6. Displacement

In general, the practices implemented will not result in displacement and will enhance the environment and land productivity and sustainability.

3.8.3.7. Maintenance and Longevity

Clover is a relatively vulnerable sward and requires a degree of management. It requires sown at the correct time of the year and maintained at a shallow depth. The use of artificial fertiliser N must be greatly decreased and allow the clover to supply N via biological fixation.

Mixed swards containing multiple species of grass and legumes show higher yield than average monocultures (Cardinale *et al.,* 2007, Cong *et al.,* 2018), and draught tolerance, an important aspect in adapting to the changing climate, particularly in south England (Finn *et al.,* 2018)

3.8.3.8. Climate Adaptation or Mitigation

The proposed strategies contribute to both adaptation and mitigation. These strategies are not affected by climate change, but have a positive impact on reducing emissions from agriculture systems.

3.8.3.9. Climate Factors / Constraints

Clover is affected by soil temperatures and viability will depend on geographical location as higher soil temperature are required for growth compared to ryegrasses.

Furthermore, clover does not establish well in wet, peaty and acidic soils so once again geographical location will be a consideration for implementation.

3.8.3.10. Benefits and Trade-offs to Farmer/Land manager

The most obvious benefit of minimising the use of artificial N fertiliser is the subsequent reduction in GHG emissions and improved environmental footprint. Overall, these strategies have the potential to result in much more sustainable production systems.

A key trade-off could be substantially reduced production from specific areas of land due to lower forage growth, leading to reduced economic output for the farmer. Alternatively, it could lead to increased use of imported feed to maintain the same level of production.

3.8.3.11. Uptake

There is one key factor likely to limit uptake and longevity and reduce the effectiveness of implementation which is the management required to maintain swards and subsequent benefit.

3.8.3.12. Other Notes

Farm assurance could be used as a tool to verify that farm interventions are occurring, focusing on examining soil analysis records and farm purchase records.

3.8.4. EBHE-227 Maintain genetic diversity by rearing rare breed livestock

Introduction

Native livestock breeds are autochthonous to a specific region and have adapted to suit their surroundings. Conserving this genetic resource guarantees food security and provides agroecosystem stability and biodiversity. Native breeds are largely threatened worldwide by agricultural intensification and rural areas abandonment. Conservation of this genetic resource is vitally important; genetic diversity is a key tool to help future generations guarantee food security for growing populations, deal with the effects of climate change, and safeguard against emerging diseases.

A new Convention on Biological Diversity post-2020 global framework focusing on the three pillars of biodiversity (genetic, species, and ecosystem diversity) is in draft stage and is set to be discussed further in April 2022. (Hoban et al 2020). The framework will include three new pragmatic indicators and modifications to two current indicators which should help benefit conservation and genetic diversity through policy in future years.

Sufficient genetic diversity can reduce negative inbreeding effects in populations (Frankham, 2005). Genetic diversity also allows for versatile options when breeding plants and animals which can help improve productivity and resilience in agriculture (Bhandari *et al.,* 2017), forestry (Potter *et al.,* 2017), fisheries (Houston *et al.,* 2020) and other biodiversity-dependent sectors (e.g. medicine, engineering).

A study by Pennsylvania State University had looked at the genetics of male lines in Holstein cattle and found that 99% of the roughly 9 million Holstein dairy cows in the US could be traced back to two bulls which were born in the 1960s (Xiang-Peng et al 2014). This level of genetic conformity is a challenge and it is necessary to maintain a gene pool from which new traits can be selected if necessary.

Genetic diversity is an important component of biological diversity. Rare and native breeds of farm animals are part of our cultural heritage, are often associated with traditional land management required to conserve important habitats, and may have genetic traits of value to future agriculture. Native or rare livestock breeds provide a resource from which to develop new breeds or improve existing breeds. Native breeds of farm animals are often associated with traditional land management required to conserve important habitats and could be vital in the future restoration of biodiversity and habitat.

The genetic diversity in UK breeds can be assessed by the effective population size, which accounts for the total number of animals in a population and the relative numbers of sires and dams (male and female parents). A low effective population size signifies a greater likelihood of inbreeding and risk of loss of genetic diversity.

Global recognition of the need to conserve animal genetic resources comes at a time when the livestock sector faces significant challenges in meeting the growing demand for livestock products and the mitigation of negative environmental impacts caused by livestock. In developing regions it would seem that portions of the growing demand for livestock products are being met by increasing animal numbers instead of achieving increases in production efficiency.

As a result of changes in livestock product demand and environmental pressures, there is a need to better assess breed performance and explore altering breed performance levels within and across production systems to meet climate change challenges. Kolmodin *et al.,* (2002) showed how selection in the presence of genetic-environmental interaction may increase animals' environmental sensitivity, highlighting the need to have genotypes that match the production environment in the event of a potential change in climate. Indigenous genotypes will already have a comparative advantage in the context of climate change, emphasising the need for breed conservation.

Livestock Management

This management bundle considers the implementation of different management systems to deliver environmental and productivity benefits. Genetic diversity may hold the key to fast-track future adaptation to climate change and ensure food security.

Livestock Management to reduce greenhouse gases

This bundle focuses on the effectiveness of optimised livestock management as a tool for reducing GHG emissions. It considers GHG mitigation approaches within livestock production and the potential for encouraging farmers to modify production processes to deliver GHG reduction.

Maintain genetic diversity by rearing rare breed livestock

This section is focused on determining the impact on GHG of maintaining genetic diversity by rearing rare breed livestock. A key component of interest is whether livestock can be bred to mitigate GHG emissions.

3.8.4.1. Causality

- **Amber (maintaining genetic diversity is vitally important, but the effect on GHG emissions is only known under certain conditions)**
    - The need to conserve animal genetic resources comes at a time when the livestock sector faces significant challenges in meeting the growing demand for livestock products and the mitigation of negative environmental impacts caused by livestock.
    - The link between animal breeding and GHG emissions is established, particularly in ruminants (Basarab *et al.,* 2013).
    - Wall *et al.,* (2009) indicated the importance of animal genetics in improving productivity and efficiency (both good indicators of reduced impact per unit of output, and on reduced wastage. In particular they indicated the potential to breed for reduced emissions.
    - Wall *et al.,* (2009) also indicated that new direct and indirect measurement techniques for emissions will improve the potential to reduce emissions by genetic selection.

- **Red (Impact of diversity/impact of lack of diversity)**
    - The level of impact of rare breed genetics on GHG emissions in a commercial population is essentially unknown.
    - The impact is dependent on the population into which the genetics are being introduced and the production levels of the animal.
    - The impact of a lack of diversity is also essentially unknown.
    - The use of rare breeds to aid climate change adaptation is also unknown

3.8.4.2. Co-Benefits and Trade-offs

There are a range of trade-offs for those farmers who are farming rare breed livestock. In general, rare breeds fell by the wayside because their genotype and hence phenotype is not appropriate to the requirements of the current marketplace as performance is lower than 'improved' livestock. As a consequence, unless a farmer can obtain a premium price through the sale of breeding stock or high provenance meat, there will be an economic cost to keeping rare breeds.

However, there is a significant upside to the use of rare breeds, with some animals displaying phenotypes which are well suited to specific environmental applications, especially in the uplands.

In general, rare breeds will grow more slowly than genetically improved stock and this has the effect of increasing the GHG cost of the animal per unit of output. As such this will be a trade-off between the environmental benefits (in terms of habitat management, soil improvements etc.) against the increased financial and GHG cost of keeping the rare breed animal.

3.8.4.3. Magnitude

Magnitude of impact of genetic diversity is very difficult to calculate because it is dependent on multiple factors. It is accepted that today's high performance livestock populations are relatively genetically homogenous, with breeding for high performance focus on a narrow range of traits to the exclusion of many others. Although the future need for many of the removed traits or genes is unknown, the need to maintain them is acknowledged. Genetic diversity is a key tool to help future generations guarantee food security for growing populations, deal with the effects of climate change, and safeguard against emerging diseases.

In general, at a given level of production, the GHG per unit of output of genetically improved livestock is likely to be lower than for rare breeds. This is less likely to be the case for specific grazing systems where more traditional breeds may perform equally well or better than improved breeds. Most (but not all) improved breeds have been improved to perform well on concentrate-based diets, whereas this has not been the case for traditional breeds. Genetic differences enable animals to perform differently under different conditions (Hoffmann, 2010). Hoffmann (2010) also states that *"Given the potential for significant future changes in* *production conditions and in the objectives of livestock production, it is essential that the value provided by animal genetic diversity is secured".*

3.8.4.4. Timescale

These interventions represent significant changes within current farm practices, but are very achievable with the correct incentive for a farmer to implement each mitigation. The table below shows the expected timescales for response:

Component	Expected timescale	Reason
Maintain genetic diversity by rearing rare breed livestock	Year 5-10	This is an ongoing priority and one that requires a proactive approach and support. Any genetics strategy is generally longer term.

3.8.4.5. Spatial Issues

There are limited spatial issues as this mitigation is well established. However, within this process descriptions of the production environments (e.g. uplands vs lowlands) of individual breeds and associated genetic description are important in identifying future traits for GHG emission mitigation. Specific genetics will be suited to certain specific locations.

3.8.4.6. Displacement

There will be minimal displacement with this mitigation strategy. Primarily, rare breeds are being farmed because a farm manager has an interest in the breed. This has the specific benefit of acting as a genetic resource which can be used as part of a hybrid breeding programme to insert beneficial traits into the wider genetic pool. However, in almost every case, the purebred rare breed is unlikely to become mainstream in the near future.

3.8.4.7. Maintenance and Longevity

Effective management of farm animal genetic resources requires comprehensive knowledge of the breeds` characteristics, including data on population size and structure, geographical distribution, the production environment, and within- and between-breed genetic diversity. Maintaining this knowledge and enhancing diversity requires significant maintenance and investment.

3.8.4.8. Climate Adaptation or Mitigation

The proposed strategies contribute to both adaptation and mitigation. These strategies are not affected by climate change, but could potentially have a positive impact on reducing emissions from agriculture systems, although this is not yet proven.

3.8.4.9. Climate Factors / Constraints

The main constraint is uptake, farmers are required to rear and maintain rare breed animals and usually these are less productive than modern breeds. Ensuring farmers who commit to maintaining genetic diversity are achieve economic viability within their business is essential to maintaining this genetic base.

3.8.4.10. Benefits and Trade-offs to Farmer/L-and manager

The main benefit is the conservation of genetic diversity, which could prove invaluable to food security in the future. Other smaller benefits also exist, being focused around the production of livestock which is suited to specific areas or habitats. The main trade off is around the usually higher cost of maintaining livestock which is less commercially viable. However, products from rare breeds can attract higher prices compensating in part for lower production levels.

3.8.4.11. Uptake

Conversion to genetic diversity will reduce the potential income for farming businesses due to lower levels of production. This will act as a significant disincentive to the keeping of rare breed livestock. Rare breed stock are held in herds across the country, but in general there is limited understanding of the range of genetic stock which is held (although some breed societies do maintain genetic records). There is a need for a coordinated approach to the maintenance of genetic stocks.

3.8.4.12. Other Notes

None

3.8.5. ETPW-156 Replace Grazing of Sheep with Cattle Grazing Particularly on Limestone Habitats

Introduction
Cattle and sheep graze differently. This has different effects on the grassland on which the animals graze. Sheep tend to graze forage to a very low level and this can have the effect of preventing the growth of some species and changing the species mix in the grassland. In some cases this means that sheep prevent the growth of rare or desirable plant life. The replacement of sheep with cattle raises the lowest height to which grass is grazed, enabling some species to regenerate. As a consequence, sheep are sometimes replaced with cattle to enable regeneration of habitats.

However, there are potentially trade-offs between habitat restoration and impact on GHG emissions. The replacement of sheep with cattle can impact GHG emissions as a result of the differences between the metabolism of the two species.

Restoration, Management and enhancement
This report examines some of the published literature and findings around the effect of grazing mixes and strategies on GHG emissions.

Grazing to reduce greenhouse gases
This bundle is focused on grazing management strategies and their effects on greenhouse gas production at macro and micro level. There are known effects on biodiversity, but less evidence around GHG production.

Replace grazing of sheep with cattle grazing, particularly on limestone habitats
This study seeks to clarify understanding around the effect on GHG emissions when sheep are replaced by cattle under strategies to improve species diversity when the animals are grazing on specific soil types. This report investigates the impact of overall animal load/stocking density when cattle replace sheep over a given area, and the comparative GHG emissions which result. There is little available evidence which is specific to limestone pasture on the GHG effect of the replacement of sheep with cattle.

Limestone pastures are a unique habitat and are rich in wildflowers. They support a wide range of bird species as well as reptiles and invertebrates. Limestone pastures contain many important habitats including woodland and scrub, heaths and bogs, wet flushers, limestone pavements and scree (Farmwildlife.info). Different grazing strategies impact the survivability of different plant species. Cattle enable the establishment of a more varied range of plant species and this in turn benefits a range of different insect and bird species, as well as enabling more wildflowers to reach the seed stage. In addition, cattle are able to graze rougher pasture than sheep and this enables management of the spread of this type of species. Farmwildlife.info report that sheep tend to preferentially graze the wildflower rich areas and leave other areas relatively untouched *"More intensive grazing, along with a move to predominantly sheep grazing has led to many grasslands being harder grazed, creating shorter swards and preventing many plants from flowering. As a result, many wildflowers have been lost or decreased in number".*

Farmwildlife.info go on to state that *"Conversely in other areas, steep-sided limestone pastures have fallen out of agricultural management, resulting in encroachment of scrub and coarse grasses. Grazing of cattle on these areas can change the grazing pattern and address the species loss."*

3.8.5.1. Causality

The effects of replacing sheep with cattle on GHG emissions at grazing can be calculated from the literature. This enables a direct comparison of the overall effect on GHG production for a given area of land. However, the figures in the literature vary wildly, meaning that the true effect is not certain.

Compounding this, there is very little evidence of the effect of the land or soil type on GHG emissions. Thus while we can say that the replacement of sheep with cattle on a given area may reduce/increase GHG emission, we don't know whether this is different for limestone soils versus any other soils. The evidence around this is very limited and merits a grey rating.

The following New Zealand publication shows the impact of beef and sheep grazing on GHG emissions for systems which are typically found in the UK.

Fritsch and Silva (2020) have created a fictional scenario based on actual measured figures which highlight differences between cattle and sheep GHG emissions per Hectare. Ruminants can produce 250 to 500 L per day of methane from their intestines through enteric fermentation or from animal manure (Pulido *et al.,* 2018). Animals also release nitrous oxide (N_2O) through nitrification and denitrification processes in urine and faeces.

Table 1: Estimates the stocking rate and methane emissions for a 60-hectare farm scenario when stocked with sheep versus beef (based on Fritsch and Silva (2020).

Systems	Pasture Production (kg/ha)	Intake/year	Stocking rate (hd/ha)	Total Animals	Total Emissions	Total Liveweight
Sheep	14000	650	21	1292	0.006-0.01	65000
Beef	14000	5800	2.4	145	0.087	30130

It can be seen that the land in this scenario is capable of supporting a level of cattle production which is less than half of which would be provided by a sheep enterprise. Additionally, the total emissions of cattle are up to 13 times as great as for sheep. However, using evidence from Edward-Jones (2009) paper, it can be seen that cattle emissions vary much more widely that those of sheep, suggesting that control of cattle emissions is highly system dependent. It does appear though, that they are very rarely below those of sheep.

Edwards-Jones *et al.,* (2009) stated that within a system boundary that considers the embodied greenhouse gases (GHGs) in inputs and on-farm emissions, producing 1 kg of lamb releases 1·3–4·4 kg CO_2 eq/kg live weight (case study farm 1) and 1·5–4·7 kg CO_2 eq/kg live weight (case study farm 2). The production of beef releases 1·5–5·3 and 1·4–4·4 kg CO_2 eq/kg live weight.

They went on to state that: Within a wider system boundary that also includes GHG emissions from animals and farm soils, lamb released 8·1–31·7 and 20·3–143·5 kg CO_2 eq/kg live weight on the two case study farms, and beef released 9·7–38·1 and 18·8–132·6 kg CO_2 eq/kg live weight.

They stated that these values overlap with nearly all other studies of GHG emissions from lamb and beef production.

Using ADAS figures for recommended stocking rates, emissions can be calculated and compared for beef and lamb. We have calculated the following emissions using the 31.7 figure for lamb and 38.1 for beef. We have used store lambs and store cattle figures to do this calculation, using average liveweights of 30kg and 400kg respectively.

- On a low stocking rate of 1.5 Livestock Units per hectare, there will be approximately 2.3 cattle (12-14 months of age) versus 37.5 lambs (younger than 1 year old). From a carcass perspective, output of lamb meat at an average carcass weight of 21kg gives a total output of 787.5kg of lamb versus 713kg beef at an average carcass weight of 310kg.

- At a high stocking rate of 2.5 Livestock Units per hectare, there will be approximately 3.8 cattle (12-14 months of age) versus 62.5 lambs (younger than 1 year old).

With an assumed liveweight average of 400kg for cattle and 30kg for lamb, this means that from an emissions perspective the following applies:

- Cattle emit a maximum of 35,052 CO_2 eq/kg per hectare at the lower stocking rate and 57,912 eq/kg at the higher rate.

- Lambs emit a maximum of 35,662 CO_2 eq/kg per hectare at the lower stocking rate and 59,438 eq/kg at the higher rate.

From the above calculation it can be seen that there is little difference between beef and lamb systems (in contrast to the figures used by Fritsch and Silva. However, if the upper estimates from the Edwards-Jones *et al.,* paper are used, cattle can emit up to 217,360 CO_2 eq/kg at the higher stocking rate, massively higher than the figures for lamb.

> From a carcass perspective, output of lamb meat at an average carcass weight of 21kg gives a total output of 787.5kg of lamb versus 713kg beef at an average carcass weight of 310kg. Output of lamb meat at the high stocking rate at an average carcass weight of 21kg gives a total output of 1312.5kg of lamb versus 1178kg beef at an average carcass weight of 310kg. This means that the emissions intensity per kg of finished products is higher for beef than for lamb.

The UK Government Agri Climate Report 2021 showed the emissions intensity of beef and sheep production relative to a base year in 1990. It can be seen that little progress in emissions intensity has been made for either species since 1990, suggesting that genetic progress is not being made.

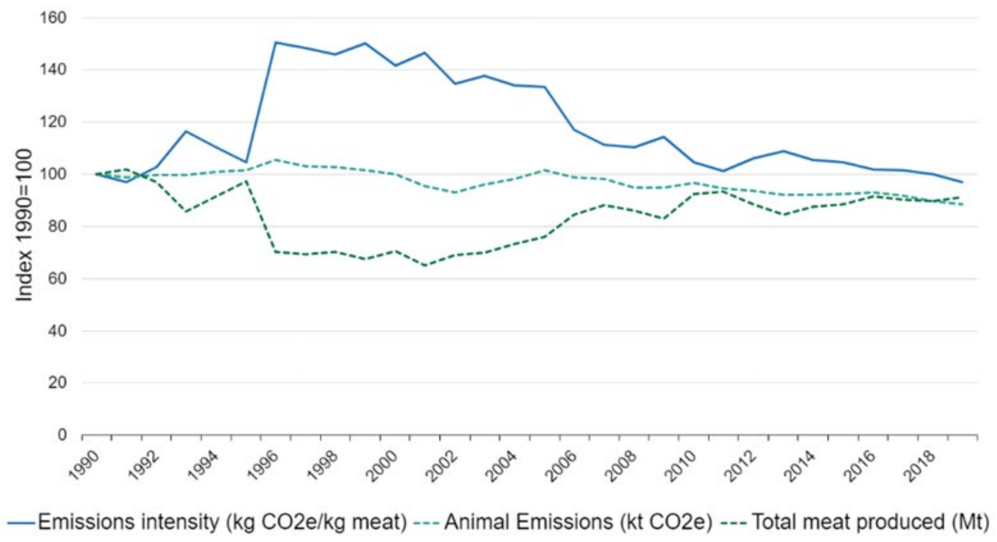

Figure 6: Beef Emission Intensity

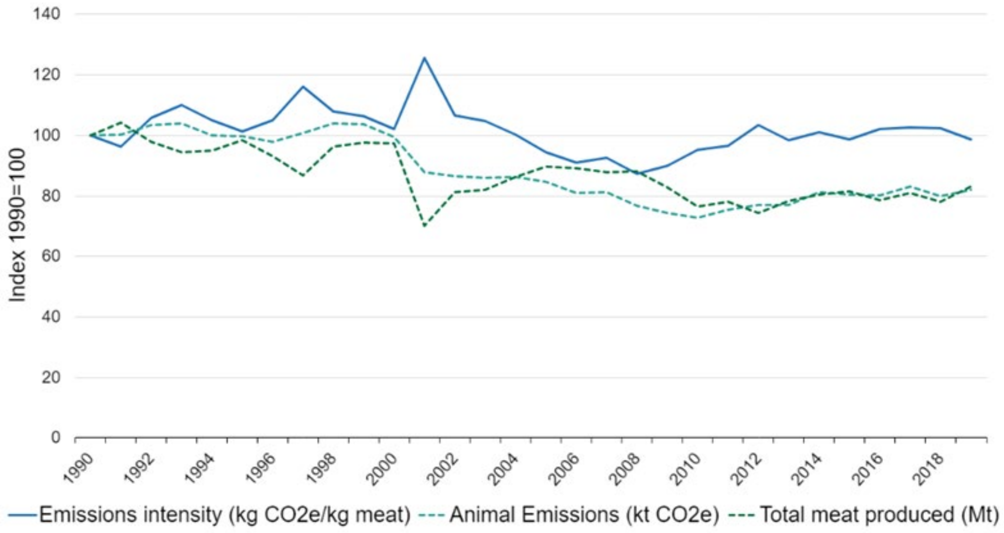

Figure 7: Sheep Emission Intensity

3.8.5.2. Co-Benefits and Trade-offs

The main impact of the replacement of sheep with cattle is the increased biodiversity of plant species resulting in higher numbers of invertebrates, reptiles and bird species.

There are also some very strong trade-offs. The replacement of sheep with cattle means that a much lower level of livestock production can take place on a given area of land, negatively impacting farm economic output. In addition, cattle require a much higher level of management than sheep do, raising farm management costs. Cattle also require heavier, more expensive equipment in addition to housing requirements during winter. The cattle will also result in increased GHG emissions than if the land was stocked with sheep.

The specific impact of soil type on GHG emissions from cattle or sheep is not well documented, and again using the information cited above, there is almost certainly a system/soil type/stock type/management approach interaction which heavily impacts emissions.

[TOCB Report-3-5B Grasslands **ETPW-156** and other grazing actions] Where stocking rates and intensity are reduced as a result of matching grazing to the requirements of the habitat there may be a reduced burden on fresh waters from nutrient run-off. Decreased grazing by livestock can sometimes lead to increased grazing by wild animals such as deer that can lead to unexpected biodiversity outcomes at the landscape level (DeGabriel et al, 2011). Increased soil erosion by grazing can lead to off-site impacts on fresh-water habitats by increased surface run-off risk. There may also be trade-offs between different biodiversity objectives for the grassland e.g. between floristic diversity and habitats for breeding waders.

3.8.5.3. Magnitude

There is insufficient evidence to demonstrate the overall impact of replacement of sheep with cattle on limestone pastures will have on GHG emissions specifically on limestone pastures. The available information relates to general grazing ground.

It appears likely that in most cases GHG emissions will rise as a result of sheep being replaced by cattle, although there is some evidence to suggest that this is also closely related to animal genetics. According to Fritsch and Silva, the replacement of cattle with sheep is associated with approximately 8 to 13 times the output of GHG for a specific area of land. This paper quotes an emissions factor for sheep of 0.006-0.01 and 0.087 for cattle which can be carried on the same area of land.

3.8.5.4. Timescales

Biodiversity improvement is likely to result from the change within 1 year of the change being made and the improvement will accelerate over the following years. Animal species change will start to change in year 1, but additional improvements will be seen for multiple years following the initial change.

GHG impacts are likely to be seen much more quickly, within year 1, delivered by the changes in livestock on the land.

3.8.5.5. Spatial Issues

The replacement of sheep with cattle on grazing is broad-scale in nature and can be applied across England. The overall impact on GHG production is dependent on a number of factors, but broadly, it is likely to increase GHG emission (Edwards-Jones *et al.,* 2009).

Obviously any measures to be implemented on limestone pasture are spatially targeted at those areas with limestone soils.

3.8.5.6. Displacement

The replacement of sheep with cattle will have an overall effect on economic output of the farm. Table 1 (section 3.8.5.1) from a New Zealand publication (Fritsch and Silva) details the potential carrying capacity for land for both sheep and cattle, and this is similar to what is quoted by AHDB. It can be seen from the table that the replacement of sheep with cattle on upland pastures means that the weight of livestock per hectare almost halves the output of meat whilst increasing the emissions factors from the land.

This is primarily because cattle graze land less closely, reducing the amount of forage which is actually consumed, with the result that a specific area of land supports less production. This has a direct impact on farm profitability and will generally mean that a farmer has to manage more land to maintain a specific level of income.

In 2019 the UK was 109% self-sufficient in lamb production (AHDB), but this is highly seasonal. Much lamb produced at peak season is exported and lamb has to be brought into the UK, particularly from New Zealand at times of low supply. Any reduced production from the change in land use from sheep to beef will mean that additional imported lamb product will be brought in to replace what cannot be supplied from within the UK.

3.8.5.7. Maintenance and Longevity

Replacement of sheep with cattle requires farm policy change and ongoing management of cattle. In general, there will be a reduction in the total weight of livestock and an increase in the level of management which is required. Cattle require much more management than sheep and the farmer must be prepared to undertake this if the strategy is to be successful.

In addition, cattle require housing for a much longer period of time over winter than sheep do, and cattle housing tends to be more expensive than that for sheep.

3.8.5.8. Climate Adaptation or Mitigation

Climate change can impact the species richness and growth performance of pasture, including limestone pasture, but this is unlikely to feature significantly in any management decisions being made around the replacement of sheep with cattle.

3.8.5.9. Climate Factors / Constraints

There are relatively few climate factors which impact on the decision to replace sheep with cattle. The main constraints are the requirement for heavier machinery to manage cattle and the need for housing (for most farms) for the winter period, which significantly increases costs.

The replacement of sheep with cattle on limestone soils is less subject to weather conditions than on clay or mineral soils. This is due to the free draining characteristics of the limestone soil meaning that the land is dry enough to carry cattle for longer than on heavier soil types. However, the grazing period for cattle will still be reduced in comparison to that for sheep.

3.8.5.10. Benefits and Trade-offs to Farmer/Land manager

Few, if any, benefits will result to the farmer/land manager. Increased management time will be required, reduced output will result, and the overall economic impact on the farm will be significantly negative.

Usually, cattle require supplementary feeding over the winter period, whereas upland sheep generally do not, or only require small amounts of supplementation. The requirement for increased volumes of feed means that machinery has to be used feed animals throughout winter (if they are outwintered), or that housing has to be built and maintained to house the animals over the winter.

3.8.5.11. Uptake

The main barrier to uptake is, as already noted, the increased management time and reduced profitability which will result from the action. Housing costs are also higher for cattle, as are machinery and winter feeding costs.

3.8.5.12. Other Notes

Verification of the implementation of this policy would have to be carried out through inspection of cattle and sheep numbers and through checking of farm records by scheme auditors.

3.8.6. GHG-01: Farm Animal Genetic Improvement

Introduction

In general, the majority of current breeding goals are either directly or indirectly selecting for traits associated with improved production, reproduction and health which will positively impact emission intensity and GHG emissions. For example, the reduction in dairy cattle numbers in the past two decades in the UK, which was accompanied by an increase in milk production, has resulted in a significant decrease in enteric CH_4 emissions from the dairy sector (Brown *et al.,* 2016, Brown *et al.,* 2018). Similarly, increased growth rate enables beef animals to reach slaughter age quicker, reducing their lifetime emissions. Furthermore, Garnsworthy (2004) estimated, using modelling, that if cow fertility was restored to 1995 levels (from the 2003 level) that methane emissions from the dairy industry could be reduced by 10-15%.

Genetic improvement in the national herd can, and is being, enhanced by using genomic tools. This entails establishing a significant database of phenotypic information from farms to allow robust association analysis with genomic data. Within the Holstein breed, this approach has been extremely effective in reducing the generation interval and speeding the rate of genetic improvement.

The extent to which genetics can influence GHG emissions now goes further than just production trait improvement. Literature suggests that the genetic improvement extends to the micro-organisms present in the gut (Hegarty and McEwan, 2010); selection for low CH_4 emissions is possible and incorporating this into selection indexes could have a massive impact of animal production systems of the future (Pinares-Patiño *et al.,* 2013, de Haas *et al.,* 2011, Roehe *et al.,* 2016). Using genetics/genomics to identify cattle genetic effects that produce lower emissions intensity (e.g. improved performance or rumen microbiomes with lower rates of methanogenesis) enables emission intensity to be included in cattle breeding goals and subsequent selection indexes. These emerging technologies present great promise in reducing greenhouse gas emissions even further.

Livestock Management

This area is focused on the impact of livestock management on a wide range of farm and environmental factors.

Livestock Management to reduce greenhouse gases

This bundle focuses on the effectiveness of optimised livestock management as a tool for reducing GHG emissions. It considers GHG mitigation approaches within livestock production and the potential for encouraging farmers to modify production processes to deliver GHG reduction.

Farm Animal Genetic Improvement

This action considers the impact of improved animal genetics on the GHG emissions. It includes a consideration of genetic improvement's impact on production parameters and direct GHG production.

3.8.6.1. Causality

Causality is rated green. The use of genetics to improve production, reproduction and health traits will positively impact emissions intensity and will reduce carbon footprint per unit of product.

Genetic improvement represents a multifaceted approach to improving animal performance, particularly in terms of emissions intensity. *'If the goal is to increase profitability, flock management interventions are most beneficial; if the goal is to reduce emissions intensity, superior breeds containing improvements in several genetic traits have the greatest potential.' Can animal genetics and flock management be used to reduce greenhouse gas emissions but also maintain productivity of wool-producing enterprises? (*Alcock *et al.,* 2015)

Genetic improvement is an important tool to accumulate response to selection and it can be used to reduce emissions, mainly through three approaches:

1) **Improving animal production efficiency:** Breeding for improved efficiency leads to a reduction of inputs at a given production level (Wall et al 2010). Developing breeding schemes to assist mitigation of greenhouse gas emissions can significantly reduce impact per unit of output, mainly through reducing the energy input for animals to reach finish when compared to an unimproved animal.

2) **Improving animal systems efficiency:** this is mainly based on the improvement of functional traits that can reduce wastage from the system and therefore GHG emissions. Improving production efficiency is a strategy to mitigate greenhouse gas emissions on pastoral dairy farms in New Zealand (Beukes et al 2010). This approach matches the production system to the animal and requires animals which are genetically optimised for that system.

3) **Direct reduction of GHG emissions through breeding:** Specific breeding systems can be established to reduce GHG emissions from animals. This type of system does not take production into account and, for that reason can rapidly reduce GHG emissions per animal. Essentially this type of programme achieves the reduction of GHG emissions using selection to identify animals that are low GHG emitters.

3.8.6.2. Co-Benefits and Trade-offs

There are a number of areas where co-benefits are likely to result from work in this area. Reduced emissions intensity from selection for improved animal performance and direct selection for lower emissions will lead to reductions in emissions by reducing the amount of feed consumed and the amount of unutilised energy and nitrogen excreted per unit of output, which will in turn reduce the environmental impacts associated with feed production and manure management. Both improved air and water quality will benefit from this mitigation.

3.8.6.3. Magnitude

The magnitude of impact is difficult to estimate accurately as most models have limited data on actual emissions associated with genetic improvement. However, based on current scientific data, the following estimates are as accurate as they can currently be:

Farm Animal Genetic Improvement

- Animal production efficiency
    - In beef, genetic selection for improved production performance will reduce the age at slaughter and achieving this will result in a lower total GHG emission per unit of product relative to a higher age at slaughter. Impacts can be substantial, for example, feedlot finishing of cattle in northern Australia for 2- 5 months calculated to reduce lifetime methane production of slaughter cattle by 34–54%, largely through reduced time to slaughter (McCrabb *et al.,* 1998).

    - Residual feed intake is a feed efficiency trait used for genetic improvement of feed efficiency. It has the unique characteristic that low RFI cattle consume less feed than high RFI cattle for the same level of productivity (Arthur *et al.,* 2001). Theoretical calculations based on the reduction in feed intake showed that low RFI cattle have 15% - 21% reduction in methane emissions, 15% reduction in methane from manure and 17% reduction in nitrous oxide from manure, relative to high RFI cattle (Okine *et al.,* 2001; Herd *et al.,* 2002).

- Animal systems efficiency
    - In Ireland, the use of the Economic Breeding Index (EBI) system allows for improved systems efficiency through multi-trait selection system based on production, fertility, calving, maintenance, Health, beef value etc. Higher EBI cows have better fertility, which reduced emissions from non-milk producing animals and improved herd lifetime milk performance

relative to lower EBI cows. Increasing EBI reduces emissions through increases in the efficiency of production, with the carbon footprint of milk production being reduced by over 20%, a GHG reduction of 0.43 Mt CO_2e/yr (Lanigan & Donnellan, 2019).

- Direct reduction of GHG emissions through breeding
    - Host genetics has been demonstrated to play a role in determining the microflora composition in the gut of model organisms (Benson *et al.,* 2010) and in the rumen of dairy cows (Garnsworthy *et al.,* 2012), opening the possibility of using an integrated approach to reduce carbon footprint in dairy farms. The potential of this approach is relatively unquantified, limiting impact prediction at this stage.

Typically, selective breeding can achieve annual rates of response of between 1% and 3% of the mean in the trait (or index) under selection (Simm *et al.,* 2004). Recent modelling studies in the UK by Genesis-Faraday (Jones *et al.,* 2008) have indicated that past selection for production traits such as growth rate, milk production, fertility and efficiency of feed conversion has resulted in decreases in GHG production per unit of livestock product of about 1% per annum. These decreases have been greatest in those species in which the greatest genetic gains have been achieved – poultry, dairy cows and pigs. However, the reductions were much smaller in beef cattle and sheep. This was due to poorer rates of genetic improvement across the population in these sectors and poor dissemination of information from elite breeders to the commercial populations (Gill *et al.,* 2010). Knapp *et al.,* (2014) concluded that for intensive dairy herds, genetic selection for feed efficiency, heat tolerance, disease resistance, and fertility can augment selection for milk yield in reducing enteric CH4 /milk product with the potential of 9 to 19% reductions. To achieve enteric reductions through genetic selection requires appropriate supporting management, including feeding and nutrition, health, reproduction, and housing facility design.

3.8.6.4. Timescale

These interventions represent significant changes within current farm practices, but are very achievable with the correct incentive for a farmer to implement each mitigation

The table below shows the expected timescales for response:

Component	Expected timescale	Reason	Size of benefit
Farm Animal Genetic Improvement	Year 5	Whilst genetic programmes within the UK are well established, developing selection indexes that incorporate more environmentally important traits will prolong the impact of this mitigation. However, this approach will have a long-term and permanent impact.	Large

3.8.6.5. Spatial Issues

This mitigation is wide-reaching and can be applied to any geographical region.

3.8.6.6. Displacement

In general, the practices associated with improved animal genetics and performance will not result in displacement, and in actual fact may free up land for alternative use due to improved resource utilisation due to less animals needed for the same level of output.

3.8.6.7. Maintenance and Longevity

Genetic improvement of farm animals through breeding programmes is additive and permanent. Improved farm animal genetics will improve resource use efficiency, business sustainability and result in significant GHG emission mitigation and reduction in emission intensity.

3.8.6.8. Climate Adaptation or Mitigation

The proposed strategies contribute to both adaptation and mitigation. These strategies are not affected by climate change but have a positive impact on reducing emissions from agriculture systems.

3.8.6.9. Climate Factors / Constraints

The main constraining factor limiting implementation of improved genetics is the strong lack of phenotypic data to allow accurate genomic models to be established. Whilst this is not as severe in some sectors (such as pig or poultry), it remains the biggest constraint to effective progress. Until this can be addressed, particularly in the beef and sheep sectors, progress is likely to be slow.

It is also worth noting the relatively low uptake of artificial insemination of sheep (primarily because it is invasive) and in suckler herds, where AI tends not to be used because heat detection is difficult in grazing animals, meaning that oestrous synchronisation of the herd is usually required. A range of other factors also reduce the uptake of effective breeding technologies, including supply chain integration, antagonism towards Estimated Breeding Values (EBVs), policy failure and the lack of data capture at farm level (Islam *et al.,* 2013),

3.8.6.10. Benefits and Trade-offs to Farmer/Land manager

Implementing genetic improvement will improve efficiency (lower food conversion ratios), resulting in less feed / unit of product. This will indirectly reduce water usage, reduce nitrate usage, and improve land use efficiency. Delivering efficiency gains will assist in achieving Intergovernmental Policy for Climate Change (IPCC) targets to reduce emissions by 80% by 2050; www.theccc.org.uk; 2014).

3.8.6.11. Uptake

So far, improvement in cattle production and efficiency using the current breeding goals has been happening. However, the uptake of use of better genetic material is only around 20-25% in the dairy herd, and still lower in the beef herd (Defra 2018). An increased uptake will lead to further improvements in efficiency.

The sheep sector remains the single biggest challenge. The lack of non-invasive AI means that the use of advanced genetics is more constrained than for other sectors and a different approach is needed to enable the uptake of the best genetics.

3.8.6.12. Other Notes

An improved data infrastructure in combination with farm management systems could be used as a tool to improve the gathering of phenotypic data at farm level. Creation of incentives to measure farm performance could increase the focus on use of genetics to deliver improvement and hence improvements in GHG intensity of livestock production.

3.8.7. GHG-02: Improved Productivity

Introduction

Emissions of GHGs in livestock systems imply losses of nitrogen, organic matter and energy, decreasing the overall efficiency of the sector. Increasing overall productivity and efficiency of farm systems, and recovering energy and nutrients are key strategies to reduce the emissions intensity of livestock systems. Historically, the main drivers for this increased efficiency were generally economic and improved resource utilisation; however, reduced GHG emissions intensity, which was usually an indirect benefit, is now demanding equivalent weighting. Production efficiency improvement directed towards meeting GHG targets can be accelerated by the increased adoption of current ‘best practice’ across a wider number of farms which elevates ‘average’ productivity and efficiency of the sector.

Improvements in livestock productivity have been shown to reduce (direct) emission intensity, whilst meeting increasing demand (Capper *et al.,* 2009). In dairy, such productivity gains were achieved through the introduction of a combination of production and management practices that increase yields, notably through increased and improved use of inputs such as feed and related fertiliser use, genetic advances, animal health inputs and energy (Gerber *et al.,* 2011). With increasing yields, an increasing proportion of the energy and protein consumed is directed towards production. Furthermore, nitrogen use efficiency generally improves with intensification, resulting in lower amounts of nitrogen excreted in faeces and urine, reducing N_2O emission per kg of milk (FAO, 2010).

Improving animal productivity requires a multifaceted approach to reducing on-farm livestock GHG emissions intensity. These include improving feed quality/digestibility, use of precision farming techniques, improved animal health and improved reproduction. However, in this paper, production will be considered in terms of output per animal and how this impacts GHG production. Particularly, this relates to parameters such as whole farm feed efficiency which relates to the output per unit of feed produced or purchased for animal within a given system. Generally improving overall energy efficiency improved farm productivity and profitability as well as assisting in the reduction of total on-farm emissions (or emissions per unit of production).

Livestock Management
This management bundle considers the effectiveness of optimised livestock management on a range of different parameters.

Livestock Management to reduce greenhouse gases
This management bundle considers the effectiveness of optimised livestock management as a tool for reducing GHG emissions. It will consider GHG mitigation approaches within livestock production provoking farmers to modify production processes to deliver GHG reduction. Factors considered within this include (but are not limited to)

- *Active diet and feed planning management to match animal requirements*
- *Using more high starch and reduced crude protein in diet*
- *Using ad lib feeding system*
- *Using phase feeding of livestock*
- *Maintaining genetic diversity by rearing rare breed livestock*
- *Enabling farm animal genetic improvement*
- *Improving animal health*
- *Improving productivity*

Improved Productivity
This action considers the impact of improved animal productivity on the GHG production of that animal.

3.8.7.1. Causality

Improved Productivity is strongly linked to reduced emissions per unit of output and is rated green.

- Dairy
  - Within the dairy sector productivity is key to reducing the emission intensity. Higher yielding cows spread maintenance costs over more litres of milk produced, resulting in a higher proportion of energy consumed being directed towards milk output.
  - Improved productivity also results in fewer cows being required to produce a given total milk supply, reducing the economic and environmental cost of rearing replacements and therefore reducing emissions. Replacement rate dictates the proportion of unproductive stock that are contributing to reduced resource use efficiency and higher emissions.

    - Productivity is also expressed as lifetime output and this is particularly relevant in the dairy sector where the economic and environmental cost of replacements is high. Grandl *et al.,* (2018) stated that both emission intensity and profitability were most favourable in cows with long productive life, whereas cows that had not finished their first lactation performed particularly unfavourably with regard to their emissions per unit of product and rearing costs were mostly not repaid. Weiske *et al.,* (2006) showed that optimising the lifetime efficiency of dairy cows, by reducing the replacement rate and exporting surplus heifers from the system as newborns, would reduce GHG emissions by up to 13%.
- Beef
    - Within the beef sector, fragmentation of the supply chain is a huge limitation to improving productivity, having significant implications for animal health as well as productivity.
    - Key mitigations would include:
        - Improving the fertility and performance of breeding cows and heifers (reduced calving interval)
        - Improving store and finishing cattle performance by monitoring their ability to efficiently utilise given inputs.
        - Improving the overall herd productivity, health, and welfare of rearer and finisher units (dairy origin beef).
    - Murphy *et al.,* (2017) showed decreased emission intensity when reducing age at slaughter, which has other wide reaching benefits also.
- Impact on total GHG production
    - To realise overall GHG reduction through increased productivity, animal numbers need to decrease so that the overall production volume is the same. This means that there are fewer animals to maintain, reducing overall feed quantity needed to meet a certain level of production.

3.8.7.2. Co-Benefits and Trade-offs

There are a number of areas where co-benefits are likely to result from work in this area. Reduced emissions intensity as a result of improved animal productivity will lead to reduced amounts of feed consumed and the amount of unutilised energy and nitrogen excreted per unit of output, which will in turn reduce the environmental impacts associated with feed production and manure management. Improved animal productivity and subsequent reduction in emissions intensity will have significant positive implications for air and water quality.

Reducing the number of replacement dairy stock needed can also have a co-benefit in diverting more dairy-bred cattle into beef production, thereby reducing the numbers of suckler cattle required to produce the same level of beef, leading to an overall improvement in resource use across the whole cattle sector.

3.8.7.3. Magnitude

Based on current scientific data, the following estimates are as accurate as they can currently be:

Farm Animal Genetic Improvement

- Dairy
    - Select genetic line animals managed under Low Forage regime was estimated to hold potential to reduce emissions intensity by 24% compared to Control genetic merit cows managed under a High Forage regime. Individually, improving genetic merit of the herd and implementing Low Forage regime hold potential to reduce emissions intensity by 9% and 16%, respectively (Ross *et al.,* 2014).
    - Lower GHG emissions intensity is associated with increasing milk yield per cow. Total GHG emissions remained approximately constant with increasing milk yield from 6000 to 8000 kg/cow per year, dramatically decreasing the emissions intensity.

  - While improving animal productivity results in increased GHG emissions per animal, the high milk response rate results in a trend of decreasing net emissions per kilogram of milk (Gerber *et al.,* 2011).
- Beef
  - In beef, emissions per kg of beef increased from 10.75 kg CO_2eq to 16.24 kg CO_2eq due to the inclusion of suckler cows, when compared to dairy origin beef (Zehetmeier *et al.,* 2012).
  - According to emissions modelling data provided by J. Bell *et al.,* (2020), reducing the age at first calving for heifers on a rearer-finisher unit from 36 months down to 24 months can reduce the emissions intensity of the cattle enterprise by up to 6.9%.
  - According to emissions modelling data provided by J. Bell *et al.,* (2020), increasing the rearing percentage on a rearer-finishing unit by 4% can reduce the emissions intensity of the cattle enterprise by 1.4%.
  - Increased carcass weight (BPH) and reduced age at slaughter reduced the emission intensities by 2.0% for British and 6.6% for Continental breeds (Veysset *et al.,* 2014).

3.8.7.4. Timescale

These interventions represent significant changes within current farm practices, but are very achievable with the correct incentive for a farmer to implement each mitigation. The table below shows the expected timescales for response:

Component	Expected timescale	Reason	Size of benefit
Improving Productivity	Year 1	This mitigation can be implemented immediately, with huge impacts. Productivity increases have a significant management influence and implementing knowledge exchange and policy incentives will aid uptake greatly	Large

3.8.7.5. Spatial Issues

This mitigation is wide-reaching and can be applied to any geographical region.

3.8.7.6. Displacement

In general, the practices associated with improved productivity will not result in displacement, and in actual fact may free up land for alternative use due to improved resource utilisation.

3.8.7.7. Maintenance and Longevity

Improved productivity will enhance resource use efficiency, business sustainability and result in significant GHG emission mitigation and reduction in emission intensity. In terms of longevity, altering management practices to improve productivity is a continuous process.

If animal productivity is increased and total number of animals decreases (whilst maintaining the same level of production), overall management of the system may, in many circumstances, actually become slightly easier, making a farm easier to manage. This does not necessarily apply which the productivity is a result of significant management changes which require increased effort (such as 3x daily milking, or longer housing of animals).

3.8.7.8. Climate Adaptation or Mitigation

The proposed strategies contribute to both adaptation and mitigation. These strategies are not affected by climate change, but have a positive impact on reducing emissions from agriculture systems.

3.8.7.9. Climate Factors / Constraints

The main constraint is the knowledge transfer relating to approaches to improve productivity. Furthermore, validation of changes, especially within the beef sector, is a major suppressant of improved practice.

3.8.7.10. Benefits and Trade-offs to Farmer/Land manager

Implementing strategies to improve production will improve efficiency (lower food conversion ratios), resulting in less feed / unit of product. This will indirectly reduce water usage, reduce nitrate usage, and improve land use efficiency.

As stated before, if animal productivity is increased and total number of animals decreases (whilst maintaining the same level of production), overall management of the system may actually become slightly easier, making a farm easier to manage. For example, genetic improvement in the fertility of the sucker herd or sheep flock will result in the production of increased numbers of calves or lambs, reducing the number of cows or ewes required and the management associated with feeding, calving or lambing, health management etc.

3.8.7.11. Uptake

On many farms, true productivity figures are unknown because data collection is inadequate. Consideration of incentives for correct record keeping, production of business KPIs and appropriate management in response to this will encourage uptake.

Practically, the uptake of management practices to improve productivity is low and incentives need to be put in place to drive change at farm level, especially within the beef sector. One example of this would be incentives for under 16 month steer and heifer systems within the beef supply chain.

Ongoing, effective knowledge exchange is also key in raising measures which encourage uptake of practices which raise productivity.

New technology may be necessary to realise productivity gains, and the use of this often requires increased skills. This can be a disincentive for some farmers, unless appropriate skills training is made available.

3.8.7.12. Other Notes

An improved data infrastructure in combination with farm management or handling systems could be used as a tool to improve the gathering of data to validate management changes. As an example, investment by beef farmers in weighing facilities which strongly increase their ability to lift useful management data which leads to overall farm improvement.

Support for data readers, weighing facilities, monitors, farm software could impact the uptake of management against data which, in turn, will improve productivity.

3.8.8. GHG-03: Improved Animal Health

Introduction
The occurrence of disease within livestock production systems is a major constraint on efficient production and will negatively impact the emissions intensity of livestock farming (Gerber *et al.,* 2013). Reducing the emissions intensity (i.e. the amount of GHG emitted per unit of meat or milk produced) of ruminants is key to reducing agricultural emissions, and so, improving health status would be expected to significantly improve the carbon footprint of livestock production.

Endemic diseases are production-limiting and can impact on the biological efficiency and productivity of livestock in a number of ways. Disease challenge reduces productivity, arising from a combination of reduced intake and reduced efficiency of resource use for production purposes (Sykes, 1994; Coop and Kyriazakis, 1999), and challenged animals would be expected to take longer and require more resource input to achieve the same productive output. GHG production associated with this extra required resource input would effectively be the consequence of pathogen challenge on resource efficiency, and thus increase GHG intensity.

Some diseases have a short but significant impact during their acute phase, others become chronic with long-term impacts on production, fertility, and feed-conversion. Examples of losses include:

- Animals taking longer to reach their target market weight
- Animals being less productive (lower yield)
- Reduced reproductive performance
- Lost production (abortion)
- Animal condemned, and lower carcass weights at abattoir
- Premature culling
- Premature death of animals.

To reduce disease-related GHG emissions effectively, an integrated assessment of health impacts on emissions is essential and can be achieved using whole farm system models (Özkan *et al.,* 2018). This report aims to deliver a summary of potential mitigations and the impact on reducing the GHG emissions, as well as limitations to achieving a whole farm systems approach.

Livestock Management
This management bundle considers the effectiveness of optimised livestock management.

Livestock Management to reduce greenhouse gases
This management bundle considers the effectiveness of optimised livestock management as a tool for reducing GHG emissions. It will consider GHG mitigation approaches within livestock production provoking farmers to modify production processes to deliver GHG reduction. Factors considered within this include (but are not limited to)

- *Active diet and feed planning management to match animal requirements*
- *Using more high starch and reduced crude protein in diet*
- *Using ad lib feeding system*
- *Using phase feeding of livestock*
- *Maintaining genetic diversity by rearing rare breed livestock*
- *Enabling farm animal genetic improvement*
- *Improving animal health*
- *Improving productivity*

Improved Animal Health
This action considers the impact of improved animal health on the GHG production of that animal.

3.8.8.1. Causality

Improved Animal Health is green rated as there is a strong evidence base supporting the link between improved health, improved animal performance and reduced GHG emissions per unit of output. Total GHG emissions can also be reduced if, due to increased animal performance, total output can remain the same whilst animal numbers are reduced.

- Evidence indicates that improving livestock health represents a significant opportunity to reduce GHG emissions. For example, IBR in cattle is a disease of the upper respiratory tract that leads to pneumonia and death. Furthermore, the disease results in poor fertility and decreased milk yields. This disease can be controlled with a vaccination programme and good management and eradication has been demonstrated in other countries (Skuce *et al.,* 2015. Özkan *et al.,* 2018)
- Treating and preventing diseases increases productivity and leads to reductions in the total amount of feed consumed and the amount energy and nitrogen excreted per unit of output, which will in turn reduce the environmental impacts associated with feed production and manure management (Houdijk *et al.,* 2017).
- Health can be improved through preventative controls such as changing housing and management to reduce stress and exposure to pathogens, vaccination, improved screening and biosecurity, and curative treatments such as antiparasitics and antibiotics.
- Overall, the available evidence suggests that reductions in emissions intensity could be achieved through the implementation of cost-effective control measures that positively impact parameters that have a significant effect on emissions intensity such as milk yield, fertility rates, abortion rates, mortality rates, growth rates etc.
- As noted previously, total GHG emissions can also be reduced if, due to increased animal performance, total output can remain the same whilst animal numbers are reduced.

It is essential not to breed animals which lead to poor health and less fertility, since these factors are also responsible for higher emissions per unit of product (Garnsworthy, 2004). Poor fertility requires a large number of animals in herd size to meet demand and hence more GHG emissions. While breeding has resulted in increases in milk yield per cow year-on-year, fertility has decreased. Garnsworthy (2004) estimated the impact of fertility on GHG emissions, through the construction of a model, which linked changes in fertility to herd structure, number of replacements, milk yield and nutrient requirements to GHG emissions. Replacements of followers contributed up to 27% of the methane and 15% of the ammonia attributed to dairy cows in the UK. Improving fertility would lead to decreased numbers of replacements required, with a consequent significant decrease in GHG emissions from the dairy herd.

3.8.8.2. Co-Benefits and Trade-offs

There are a number of areas where co-benefits are likely to result from work in this area. Reduced GHG emissions from improved animal health will lead to reductions in emissions by reducing the amount of total feed consumed and the amount of unutilised energy and nitrogen excreted per unit of output, which will in turn reduce the environmental impacts associated with feed production and manure management. The mitigation will have significant benefits for air and water quality.

Improved animal health also meets the ‘One Health’ agenda, with reduced medicinal application to animals, reducing the risk of accelerating antibiotic resistance.

3.8.8.3. Magnitude

The magnitude of impact is very difficult to estimate accurately as most models have limited data on actual emissions associated with disease driven production changes. However, based on current scientific data, the following estimates are as accurate as they can currently be:

Improved Animal Health

- ADAS (2014) attempted to quantify the impact of the top cattle health ‘conditions’ on the carbon footprint of a litre of milk, and the reductions that could be made via veterinary and/or farm management interventions. The study concluded that a 50% movement from current health status to a healthy cattle population (assumed to be the maximum improvement achievable) would reduce emissions by 1436ktCO_2e, or 6%.

- In Sheep, Houdijk *et al.,* (2017) stated that periparturient parasitism reduced feed intake (-9%) and litter weight gain (-7%) and doubled maternal body weight loss. Indirectly, parasitism did not affect the daily calculated manure methane and nitrous oxide production but increased the manure methane and nitrous oxide yields per unit of dry matter intake by 16% and 4%, respectively, and per unit of digestible organic matter intake by 46% and 31%, respectively. Parasitism increased the calculated greenhouse gas intensity per kg of lamb weight gain for enteric methane (+11%), manure methane (+32%) and nitrous oxide (+30%).
- Eory *et al.,* (2015) used a similar approach to quantify the effect of improving sheep health, and estimated that a 50% movement from current health status to a healthy sheep population would reduce emissions by 484ktCO_2e/year by 2035.
- Other approaches have tried to quantify the cost benefit associated with improving animal health and have identified a mean marginal costs across production measure with a saving of -€46/t CO_2e abated. The measure reduces GHG per kg product by reducing the need for replacements and an increase in overall production (Lanigan & Donnellan, 2019).

3.8.8.4. Timescale

These interventions represent significant changes within current farm practices, but are very achievable with the correct incentive for a farmer to implement each mitigation. The table below shows the expected timescales for response:

Component	Expected timescale	Reason
Improved Animal Health	Year 2	Improved Animal Health strategies are in place currently and concerted effort would improve uptake and improved performance within the national herd.

Some immediate improvements may be observed, resulting from improved hygiene and biosecurity, but in general the main improvements will be observed from year two onwards when good practice has become established and when preventative regimes have been implemented with new batches of stock.

3.8.8.5. Spatial Issues

This mitigation is wide-reaching and can be applied to any geographical region.

3.8.8.6. Displacement

In general, the practices associated with improved animal health will not result in displacement, and in actual fact may free up land for alternative use due to improved resource utilisation due to fewer animals being required to maintain the same level of performance.

3.8.8.7. Maintenance and Longevity

Improved animal health through animal health plans, vaccination programmes, changes in management are sustainable and relatively easy to maintain. Improved animal health will improve resource use efficiency, business sustainability and result in significant GHG emission mitigation and reduction in emission intensity.

3.8.8.8. Climate Adaptation or Mitigation

The proposed strategies contribute to both adaptation and mitigation. These strategies are not affected by climate change, but have a positive impact on reducing emissions from agriculture systems.

3.8.8.9. Climate Factors / Constraints

There are a number of important limitations in quantifying the aforementioned benefits. For example, there is a complete lack of active surveillance, with limited passive surveillance and inconsistent reporting. Without knowing the prevalence and incidence of individual diseases, the likely impact of control on GHG emissions cannot be predicted accurately.

Recent literature highlights barriers to improving modelling relating to the impact of animal health on GHG emissions to include data availability, data quality, and challenges of interdisciplinary communication (Kipling *et al.,* 2016, Özkan *et al.,* 2016).

3.8.8.10. Benefits and Trade-offs to Farmer/Land manager

The most obvious benefit of improving animal health is the improved nutrient use efficiency, improved environmental footprint, and improved profit margins. Treating and preventing diseases increases productivity and leads to reductions in the amount of feed consumed and the amount of energy and nitrogen excreted per unit of output, which will in turn reduce the environmental impacts associated with feed production and manure management.

3.8.8.11. Uptake

There are a number of factors which are likely to reduce the effectiveness of implementation and validation. In general, most farms do not record data or implement change that can be quantified quickly, especially in terms of carbon footprint. In addition to uncertainties about occurrence and production impacts, there is still a lack of information relating to the effects of animal health status on GHG emissions from livestock.

3.8.8.12. Other Notes

Farm assurance in combination with farm management systems could be used as a tool to verify animal health status, interventions, and improvements in emissions intensity. Currently an animal health plan is required, but the individual actions under this plan are not always followed through.

There is an importance to ensuring that vets focus on the delivery of good animal health at farm level and not just on delivering the wishes of clients. It is important that, when vets help a farmer design an animal health plan, they also follow this through to ensure that their clients are actually implementing the plan. This is challenging as vets are not there to police the industry and have a commercial business to run.

4. KEY ACTION GAPS

4.1. ECCM-014: USE LOW-INTENSITY GRAZING SYSTEMS USING BIODIVERSE SWARD MIXTURES

Substantial evidence is still required as outlined in the section. This evidence will assist in promoting this farm management practice to farmers

1) True operational costs of MSS vs PRG
2) Defined benefits/negatives of MSS vs PRG on economic performance and GHG emissions.
3) Defined benefits/negatives of MSS vs PRG on meat quality
4) Clearly defined environmental benefits

The benefits of using biodiverse sward mixtures still requires ongoing communication with farmers, along with methods of monitoring sward performance, as well as appropriate management strategies to encourage sward persistence and high performance.
Lowe *et al.,* (2021) state that *"A change in mind-set is required on how to manage MSS compared to a traditional PRG sward. In particular, ideal pre- and post- grazing covers need to be set for different physiological stages of beef and sheep production. Furthermore accurate equations need to be developed for using rising plate meters in MSS to estimate sward covers in kg DM/ha".*

4.2. ECAR-004: INCREASE THE CAPACITY OF FARM SLURRY AND MANURE STORES TO IMPROVE TIMING OF SLURRY APPLICATIONS

Key action gaps include:

1) The effective transfer of knowledge around nutrient use efficiency and the potential cost savings associated with reduced use of artificial N fertiliser.
2) Knowledge transfer around the impact of timing on the nutrient use efficiency
3) Increased knowledge around the impact of timing of application of manures and slurry on GHG release.
4) Modelling to understand the match between the volume of slurry and the number of 'correct' days to spread, and the interaction between existing soil nutrient content and the crop requirement.

4.3. ECAR-001 COVER SLURRY, SLUDGE, AND DIGESTATE STORES WHERE BUSINESS IS NOT REGULATED UNDER IED

There are no obvious action gaps.

4.4. ECAR-006 DILUTE SLURRY TO IMPROVE SOIL INFILTRATION, COUPLED WITH IRRIGATION

Practical evidence from farm advisors and consultants indicates that many farm or land managers currently do not understand the potential benefits of slurry dilution and consequently knowledge transfer to communicate these benefits is important.

A validation process is required to ensure this mitigation matches the farming system and soil type. Clear guidance to farmers about appropriate and inappropriate use of the technique is important.

4.5. ECAR-015 REPLACE NITROGEN FERTILISER APPLICATION BY USING CLOVER IN PASTURE OR ARABLE CROPPING SYSTEMS

There are well established knowledge initiatives around the reduction in fertiliser use and the environmental benefits and economic savings; however, support in management and establishment of clover / legume swards is required as various climatic factors can affect successful implementation.

4.6. MANAGE/ENHANCE COASTAL HABITATS TO COMPENSATE FOR LOSSES TO CLIMATE CHANGE AS PART OF A COASTAL MANAGEMENT PLAN

The main action gaps for this section are the same as for ECCA 033C. The below actions have been taken directly from the Ulster Wildlife Blue Carbon Habitat Restoration In Northern Ireland Feasibility Study

- Raise public and policy-makers' awareness of blue carbon as a nature-based solution to climate Change.
- Develop a cross-cutting blue carbon strategy that would underpin action to protect, restore, recreate and monitor blue carbon habitats, with priority given to protection and restoration of existing habitats
- Investigate application of enforcement and incentives to encourage coastal landowners to facilitate the natural development of coastal wetlands (may involve the removal of defences, drains and the infilling of ditches).

4.7. ECCA-033C: CREATE COASTAL HABITATS TO COMPENSATE FOR LOSSES TO CLIMATE CHANGE AS PART OF A COASTAL MANAGEMENT PLAN

The main action gaps for this section are the same as for ECCA 033C. The below actions have been taken directly from the Ulster Wildlife Blue Carbon Habitat Restoration In Northern Ireland Feasibility Study by Strong et al (2021).

- Raise public and policy-makers' awareness of blue carbon as a nature-based solution to climate Change.
- Develop a cross-cutting blue carbon strategy that would underpin action to protect, restore, recreate and monitor blue carbon habitats, with priority given to protection and restoration of existing habitats
- Investigate application of enforcement and incentives to encourage coastal landowners to facilitate the natural development of coastal wetlands (may involve the removal of defences, drains and the infilling of ditches).

4.8. ECCM-013 ACTIVE DIET AND FEED PLANNING MANAGEMENT TO MATCH ANIMAL REQUIREMENTS:

There are limited requirements at present for farmers to collect data which subsequently limits the data-based decision making at farm level. Future support must include elements that require the collection of data and allow the Agri-food industry to be much more quantifiable in terms of GHG emissions.

4.9. ECCM-061 CREATE AND USE AN ENERGY CONSUMPTION OPTIMISATION PLAN

At present there are no regulations which require the creation of a farm energy optimisation plan, and as a result the majority of farms will not produce one – primarily because it is another piece of paperwork which the majority of managers prefer to avoid.

The design and application of incentives or conditionality will be required to drive widespread implementation.
There are significant Knowledge Exchange delivery gaps around the usefulness of energy optimisation plans and the potential savings.
There is potential to include the creation of energy plans within the requirement to obtain future support payments. The requirement for this would, at worst, raise awareness of the need for a plan and would accelerate the uptake in agriculture.

4.10. ECCM-062 REUSE OF CAPTURED CO2 IN GREENHOUSES

At present, carbon removal or capture practices are not specifically incentivised in the UK except for afforestation, and most methods are at an early stage of development, currently moving into demonstrator or pilot stages.

- CO_2 capture facilities are an important component of the delivery of this programme. Determination of the number of facilities and production potential within the UK should be undertaken.

- A study should be undertaken of the volume of CO_2 used within UK agriculture now and potentially in the future. This will allow the potential volume of captured CO_2 which could replace non-captured CO_2.

4.11. CCM-063: MONITOR ENERGY CONSUMPTION AND IMPLEMENT TARGETS

At present there are no regulations which require the creation of a farm energy optimisation plan, and as a result many farms will not produce one – primarily because it is another piece of paperwork which many managers prefer to avoid. Even if an optimisation plan is produced by the farm, implementation is likely to be non-existent or slow unless the implementation steps within the plan are monitored and verified.
There is potential to include the creation of energy plans as a requirement to obtain future support payments. The requirement for this would, at worst, raise awareness of the need for a plan and would accelerate the uptake in agriculture.

4.12. ECCM-069: USE MORE HIGH STARCH AND REDUCED CRUDE PROTEIN IN DIETS

At present there is limited literature and farm information on implementing these types of strategies to reduce GHG emissions at farm level. As a result, the majority of farms don't provoke change from advisors limiting uptake at farm level.

4.13. ECPW-115: SWITCH TO EFFICIENT / PRECISION FERTILISER APPLICATION MACHINERY (E.G. TRAILING HOSE, TRAILING SHOE OR INJECTION, GPS)

There are well established knowledge initiatives around the usefulness of LESSE and the potential environmental benefits and economic savings.
The main action gaps are around widespread dissemination of the benefits from an economic and environmental perspective. The likely demand for public good from the new farm support packages are likely to incentivise the uptake of precision technology, and extensive communication of available technologies and their efficacy is required.

4.14. ECPW-131 SEPARATE SLURRY AND DIGESTATE (LIQUID AND SOLID) AND STORE SEPARATELY:

At present, awareness of the key management approaches needed to minimise GHG emissions whilst conducting separation is lacking.

4.15. ECPW-137: EXPORT MANURE AND SLURRY

Key action gaps include:

- Management of nutrient export – identifying the appropriate ground, soil types and crops which can make best use of exported slurry
- Regulation of export via the Animal By-product Regulations
- Ensuring adequate levels of record keeping to prevent nutrient overloading.
    - Type and amount of livestock manure exported
    - Date for export from holding

    - Nitrogen content
    - Name and address of recipient
    - Details of any contingency plan if export refused
- Creation of a system which can manage the export and distribution of slurries and manures at a national level.

4.16. ECPW-141 USE OF AD LIB FEEDING SYSTEMS

At present there is limited literature and farm information on implementing these types of strategies to reduce GHG emissions at farm level and the lack of easily discoverable case studies will slow uptake.

4.17. ECPW-145: OPTIMISE LIVESTOCK FEEDING STRATEGY TO MATCH ANIMAL REQUIREMENTS, (E.G. PROTEIN, LIPIDS) EXCEPT WHERE FARMS ARE SUBJECT TO THE PROVISIONS OF THE INDUSTRIAL EMISSIONS DIRECTIVE

At present there is limited tailoring of diets to meet the needs of individual animals. This is compounded by the fact that there is limited effective processing of data and allocation of feed plans at farm level with the support of feed suppliers and/or advisors.

Not all farmers are aware of the potential benefits of highly tailored individualised diets and the provision of case studies to demonstrate benefit to farmers is important.

4.18. ECPW-146 USE PHASE FEEDING OF LIVESTOCK

Phase feeding should already be implemented on all farming systems within England and the UK. The general principles are well known and the key action is the identification of farms or businesses where this type of system is not being used and its subsequent implementation. Very few farms have the ability to precision feed, but almost all have the ability to phase feed.

4.19. ECPW-171: USE VERY LOW INPUTS ON PERMANENT GRASSLAND

Key action gaps include:

1) The knowledge transfer of optimal management strategies to achieve this mitigation and ensure economic sustainability.

2) The creation of case studies to allow farm managers to identify the benefits, challenges and overall economic and environmental case for conversion to low input systems.

4.20. ECPW-173: USE NO FERTILISER

There are well established knowledge initiatives around the reduction in fertiliser use and the environmental benefits and economic savings; however, support in management and establishment of clover / legume swards is required as various climatic factors can effect successful implementation.

4.21. EBHE-227 MAINTAIN GENETIC DIVERSITY BY REARING RARE BREED LIVESTOCK

Knowledge exchange on the importance of maintaining genetic diversity is lacking and the true impact on GHG emissions is very unclear as is their possible contribution to climate change adaptation. There is limited understanding of the range of genetic diversity which is currently held in England or the UK as a whole. There is also very limited coordination around the maintenance of genetically diverse stock.

4.22. ETPW-156 REPLACE GRAZING OF SHEEP WITH CATTLE GRAZING PARTICULARLY ON LIMESTONE HABITATS

The main action gaps for this action are associated with the negative economic impact, and the lack of financial incentive for farmers to replace sheep with cattle. This action is unlikely to take place unless required by legislation or financially incentivised.

4.23. GHG-01: FARM ANIMAL GENETIC IMPROVEMENT

A stronger link between research and knowledge transfer is required to encourage uptake and the prompt development of policy measures and incentives to encourage this uptake. While many efficiency measures associated with genetic improvement are incremental in nature, the uptake of these is a key action gap.

4.24. GHG-02: IMPROVED PRODUCTIVITY

A stronger link between research and knowledge transfer is required to encourage uptake and the prompt development of policy measures and incentives to encourage this uptake. Much research has been conducted describing the benefits of improved productivity; however, the uptake of these is a key action gap.

4.25. GHG-03: IMPROVED ANIMAL HEALTH

The ability to quantify the effects of improved animal health is a major limitation in terms of emissions intensity but also in terms of driven evidence-based decision making at farm level. Improved data collection would allow quantification of all benefits associated with improved animal health.

Many farms do not realise the true impact of disease on their herd and as a consequence tend to treat acute disease but not underlying challenges which have a long-term impact. Currently, farm assurance requires the creation of a veterinary health plan, but many farmers treat this as a ‘tick box’ exercise and do not take the steps it recommends. Nonetheless, the fact that it is required means that awareness is raised, and over time, the uptake of practices within the plan become more prevalent (Inman et al 2018).

Rewarding close study of disease prevalent on each holding and the demonstration of appropriate steps to minimise health challenges will encourage uptake and will impact the GHG emissions of the farm unit. Kenyon et al (2013) showed that when lamb treatment was based on when clinical signs first appeared, this regime meant the lambs took significantly longer to reach target weight and there was an extra 10% of CO_2 emissions per kg of weight gain when compared with targeted, strategic, or monthly treatment strategies all of which the results were similar.

There is a wide range in performance between the best and worst farms, making it important to lift the performance of the worst farms.

5. EVIDENCE GAPS

5.1. ECCM-014: USE LOW-INTENSITY GRAZING SYSTEMS USING BIODIVERSE SWARD MIXTURES

There is potential for MSS to build resilience into beef and sheep systems. There is, however, a lack of evidence for establishment and management of MSS under varying soil and climactic conditions (Lowe *et al.,* 2021). Lowe *et al.,* (2021) also state that the following evidence gaps need to be addressed:

- Accurate equations need to be developed for using rising plate meters in MSS to estimate sward covers in kg DM/ha.
- Further research is required on optimising species persistency, especially under a cutting regime or when multi species are under-sown in other cover crops.
- Large, long-term studies are required to assess the impact of eating beef and lamb which has been grazed on MSS on human health, particularly mineral status.
- Further research is required to determine the beneficial or negative impacts of MSS vs PRG on economic performance and GHG emissions.
- A full cost benefit analysis is required from establishment to end of the sward life to take into account sward persistency and the effects of MSS on animal production, use of antimicrobial resistance and carbon footprint.

5.2. ECAR-004: INCREASE THE CAPACITY OF FARM SLURRY AND MANURE STORES TO IMPROVE TIMING OF SLURRY APPLICATIONS

There are relatively few evidence gaps around slurry and manure storage and application. However, detail around interactions between timing of spreading and spreading technique could further improve nutrient utilisation efficiency.

5.3. ECAR-001 COVER SLURRY, SLUDGE, AND DIGESTATE STORES WHERE BUSINESS IS NOT REGULATED UNDER IED

There is a good body of evidence on the positives and negatives of slurry covers and associated environmental benefits. There are no obvious evidence gaps.

5.4. ECAR-006 DILUTE SLURRY TO IMPROVE SOIL INFILTRATION, COUPLED WITH IRRIGATION

Additional evidence is required to validate reductions in emissions through implementing this mitigation on a range of soil types, application rates, climatic conditions and application rates.

5.5. ECAR-015 REPLACE NITROGEN FERTILISER APPLICATION BY USING CLOVER IN PASTURE OR ARABLE CROPPING SYSTEMS

There is a good body of evidence on the reduction of fertiliser use and associated environmental benefits. There is no obvious evidence gap.

5.6. MANAGE/ENHANCE COASTAL HABITATS TO COMPENSATE FOR LOSSES TO CLIMATE CHANGE AS PART OF A COASTAL MANAGEMENT PLAN

The main evidence gaps for this section are the same as for ECCA 033M. The below actions have been taken directly from the Ulster Wildlife Blue Carbon Habitat Restoration In Northern Ireland Feasibility Study as they are highly appropriate:

- A baseline inventory is required of all blue carbon habitats their extent, with local measurement of carbon sequestration rates (CSRs) and estimated total carbon storage by habitat, including understanding how the condition of habitat affects CSR.
- Action is needed to review coastal blue carbon habitat current extent and predicted suitability via additional surveys/ground-truthing, where possible identifying habitat condition at each site (which may affect carbon sequestration potential) and any notable local pressures – make use of existing monitoring programmes to gather such data and develop specific surveys for this purpose.
- An examination is required of historical records (pre-1980) of coastal blue carbon species and habitat extent (e.g. native oyster reefs) and examine how these relate to current habitat suitability models for potentially suitable conditions for these habitats.
- Undertake action to understand the role of other blue carbon pools, such as intertidal and subtidal sedimentary habitats,
- Identify pilot projects for coastal blue carbon restoration though further development of the blue carbon restoration feasibility GIS, crucially identifying habitat condition and local carbon sequestration rates then prioritising habitats based on their carbon sequestration and storage potential and practicality of restoration actions, exploring the options of co-restoration of habitats, developing partnerships and securing funding. Through this, build capacity locally for blue carbon restoration with flagship local projects to inspire further habitat restoration efforts and demonstrate viability, while also monitoring the co-benefits of habitat restoration such as biodiversity value and erosion protection.
- Investigate/research the likely response of blue carbon habitats to climate change, especially those coastal habitats that are the current focus for practical restoration.
- Undertake action to ensure a strong understanding (and valuation where possible) of the co-benefits of restoration, such as biodiversity gains, enhancement of other ecosystem services such as flood protection, water quality improvement, and community buy-in/ownership.

5.7. ECCA-033C: CREATE COASTAL HABITATS TO COMPENSATE FOR LOSSES TO CLIMATE CHANGE AS PART OF A COASTAL MANAGEMENT PLAN

The main evidence gaps for this section are broadly the same as for ECCA 033M. The below actions have been taken directly from the Ulster Wildlife Blue Carbon Habitat Restoration in Northern Ireland Feasibility Study by Strong et al (2021).

- A baseline inventory is required of all blue carbon habitats their extent, with local measurement of carbon sequestration rates (CSRs) and estimated total carbon storage by habitat, including understanding how the condition of habitat affects CSR.
- Action is needed to review coastal blue carbon habitat current extent and predicted suitability via additional surveys/ground-truthing, where possible identifying habitat condition at each site (which may affect carbon sequestration potential) and any notable local pressures – make use of existing monitoring programmes to gather such data and develop specific surveys for this purpose.
- An examination is required of historical records (pre-1980) of coastal blue carbon species and habitat extent (e.g. native oyster reefs) and examine how these relate to current habitat suitability models for potentially suitable conditions for these habitats.
- Undertake action to understand the role of other blue carbon pools, such as intertidal and subtidal sedimentary habitats.
- Identify pilot projects for coastal blue carbon restoration though further development of the blue carbon restoration feasibility GIS, crucially identifying habitat condition and local carbon sequestration rates then prioritising habitats based on their carbon sequestration and storage potential and practicality of restoration actions, exploring the options of co-restoration of habitats, developing partnerships and securing funding. Through this, build capacity locally for blue carbon restoration with flagship local projects to inspire further habitat restoration efforts and demonstrate

viability, while also monitoring the co-benefits of habitat restoration such as biodiversity value and erosion protection.
- Investigate/research the likely response of blue carbon habitats to climate change, especially those coastal habitats that are the current focus for practical restoration.
- Undertake action to ensure a strong understanding (and valuation where possible) of the co-benefits of restoration, such as biodiversity gains, enhancement of other ecosystem services such as flood protection, water quality improvement, and community buy-in/ownership.
- Create a better understanding of regulatory instruments to enforce protection of these ANNEX I habitats needs to be developed.

Investment in blue carbon projects in the UK is limited by a lack of verifiable standards and scientific evidence, although development of codes is ongoing. (Furness & Wentworth 2021)

5.8. ECCM-013 ACTIVE DIET AND FEED PLANNING MANAGEMENT TO MATCH ANIMAL REQUIREMENTS:

To date, there is limited data on the effect of improved nutrient allocation on individual animal performance. More scientific research is required to establish real-time alterations in feed allocation on performance and environmental impact. Furthermore, future development of feed additives to reduce methane emissions is essential. These must have robust data and validation behind their claims which would facilitate more accurate mitigation.

5.9. ECCM-061 CREATE AND USE AN ENERGY CONSUMPTION OPTIMISATION PLAN

This particular area does not suffer from significant knowledge gaps regarding the generation of a plan. The implementation of energy optimisation plans is a known quantity with demonstrable benefits. The monitoring of energy use and the design of a plans around it is normally followed by a reduction in energy usage. Many farm managers will be unaware of the potential advantages of energy optimisation planning and as a result may resist or act apathetically to its introduction. Behavioural science is important in this regard.

There is a need to the best methods of communicating the value of potential energy and carbon savings due to target setting and monitoring, to ensure that energy optimisation plans and activity are not treated as a tick-box exercise and instead become part of everyday farm practice.

5.10. ECCM-062 REUSE OF CAPTURED CO2 IN GREENHOUSES

A range of evidence gaps exist around this subject:

1) The number of greenhouses in England which are capable of implementing CO_2 enrichment is unknown and requires research.

2) The level of CO_2 enrichment which currently takes place in greenhouses in England and the rest of the UK is not understood and requires research.

3) The UK capacity to capture CO_2 is not fully documented and requires research.

4) Energy and carbon costs of transport vs carbon saved by recapture is unclear in the literature and the overall balance needs to be determined.

5) Horizon scanning for potential future use in Vertical Farming.

5.11. CCM-063: MONITOR ENERGY CONSUMPTION AND IMPLEMENT TARGETS

This particular area does not suffer from significant knowledge gaps regarding the generation of a plan. The implementation of energy optimisation plans is a known quantity with demonstrable benefits. The monitoring of energy use and the design of a plan around it is normally followed by a reduction in energy usage. Many farm managers will be unaware of the potential advantages of energy optimisation planning and as a result may resist or act apathetically to its introduction. Behavioural science is important in this regard.

There is a need to the best methods of communicating the value of potential energy and carbon savings due to target setting and monitoring, to ensure that energy optimisation plans and activity are not treated as a tick-box exercise and instead become part of everyday farm practice.

5.12. ECCM-069: USE MORE HIGH STARCH AND REDUCED CRUDE PROTEIN IN DIETS

This particular area does not suffer from significant knowledge gaps as rumen dynamics has been well studied and reported at a scientific level. The implementation of these strategies is limited by the translation of science into practice and the routes of dissemination. Legislative incentives could greatly encourage uptake.

5.13. ECPW-115: SWITCH TO EFFICIENT / PRECISION FERTILISER APPLICATION MACHINERY (E.G. TRAILING HOSE, TRAILING SHOE OR INJECTION, GPS)

There is a good body of evidence on the positives of LESSE and associated environmental benefits.

The main gaps are around the presentation of clear case studies which land managers can use to make decisions around investment.

5.14. ECPW-131 SEPARATE SLURRY AND DIGESTATE (LIQUID AND SOLID) AND STORE SEPARATELY:

There are few evidence gaps around the implementation of this technology, but there is a need to identify new techniques to allow separation that also mitigate GHG emissions. Current practices are not effective and require modification.

5.15. ECPW-137: EXPORT MANURE AND SLURRY

There are some evidence gaps around practice and management. There is a need to identify storage and transportation methods which enable best control of GHG emissions within a commercial context. There are very few other knowledge or evidence gaps.

5.16. ECPW-141 USE OF AD LIB FEEDING SYSTEMS

Rumen dynamics are well studied and reported at a scientific level, but there are still knowledge gaps around practical translation and management at a farm level. The implementation of these strategies is limited by the translation of science into practice and effective dissemination. Legislative incentives could greatly encourage uptake.

5.17. ECPW-145: OPTIMISE LIVESTOCK FEEDING STRATEGY TO MATCH ANIMAL REQUIREMENTS (E.G. PROTEIN, LIPIDS) EXCEPT WHERE FARMS ARE SUBJECT TO THE PROVISIONS OF THE INDUSTRIAL EMISSIONS DIRECTIVE

There is some knowledge of deficiencies relating to the effect of improved feed efficiency on methane production. The relationship between methane emissions and feed efficiency is not consistent and appears to be affected by factors such as forage digestibility etc. This is backed-up by the fact that diets rich in starch tend to observe a lower methane emission per day for the most efficient cows (Jones *et al.,* 2011). Furthermore, these studies may have had differences in experimental conditions, such method used to measure methane emission, feeding level, or level of grains in the diet.

5.18. ECPW-146 USE PHASE FEEDING OF LIVESTOCK

Ample evidence exists regarding the implementation of phase feeding. There are no evidence gaps.

5.19. ECPW-171: USE VERY LOW INPUTS ON PERMANENT GRASSLAND

Evidence gaps include

1) A lack of recent papers outlining current findings. Much of the literature is around 20 years old, and updating is required.
2) The exact economic benefit or penalty associated with the use of low input grazing systems under a range of different conditions is not definitively known, and an in-depth review of all available data is recommended. There are a very wide range of influencing factors, and it is clear from this basic review that the literature is contradictory.
3) The interaction between low inputs and management practices that optimise production (such as clover inclusion, rotational grazing etc) is not fully understood and needs further study.
4) Optimised species mixes for low-input grassland under a range of different conditions are also unclear.
5) The true overall systems impact on GHG of low input farming on grassland is unknown. There does not seem to be any obvious literature which takes a high-level view of the reduced inputs, reduced or changed production or changed practice.

5.20. ECPW-173: USE NO FERTILISER

There is a good body of evidence on the reduction of fertiliser use and associated environmental benefits. There is no obvious evidence gap.

5.21. EBHE-227 MAINTAIN GENETIC DIVERSITY BY REARING RARE BREED LIVESTOCK

There are multiple evidence gaps around the maintenance of genetic diversity and its impact on GHG emissions. The level of knowledge is currently low in almost all areas. Key areas where knowledge is lacking include;

1) Interactions and performance impact of genetics when used on existing commercial livestock.
2) Potential genetic advances which are contained within rare breed populations
3) Characterisation of potential environmental and financial value of advances

In particular the knowledge gap around livestock breed-environment relationships may prevent the design of successful conservation measures and it is essential that this is addressed.

5.22. ETPW-156 REPLACE GRAZING OF SHEEP WITH CATTLE GRAZING PARTICULARLY ON LIMESTONE HABITATS

The main evidence gaps are:

1) Identification of the main area of limestone pasture grazed by sheep versus cattle in England and the UK as a whole.
2) Identification of the true economic impact of the replacement of sheep with cattle in Upland Regions of England
3) Identification of the true rate of change of GHG emissions under different climactic conditions and management processes.
4) Identification of the specific effects of soil type on GHG emissions of cattle and sheep.

5.23. GHG-01: FARM ANIMAL GENETIC IMPROVEMENT

The exact impact of advanced genetics on GHG production under a range of different production systems has not been determined. Impacts are multi-factorial and the creation of advanced models is probably the most effective method of indicating potential impact.

The impact of the rumen microbiome and its interaction with animal genetics is not yet understood and it is possible that the control of the microbiome may be more significant in terms of GHG reduction than the genetics of the animal itself (Difford *et al.,* 2018).

5.24. GHG-02: IMPROVED PRODUCTIVITY

More research into whole farm efficiency and associated systems is required to establish best practice and quantify the impact of variables currently not measured.

The provision of evidence around the financial and environmental impact of productivity improvement measures, in case study format, with clear input and output information would encourage the uptake of better practice. Wide scale information distribution via a clear communication plan would be helpful. The information provided must be heavily science based, with a clear commercial output.

It needs to be recognised that significant emission reductions could be obtained by reducing the variability of farm performance within farm type (lowland, upland, mountain). For example, the number of lambs reared per ewe varied between 0.7 and 1.8; and lamb growth rate between 57 g/day and 356 g/day, demonstrating considerable potential for improvement on the poorest performing farms. This can be achieved by improving the number of lambs reared per ewe and lamb growth rate by 30% (Jones *et al.,* 2014) to the performance levels of higher performing farms. Genetic improvement would also facilitate this reduction.

5.25. GHG-03: IMPROVED ANIMAL HEALTH

The exact prevalence of disease incidence and type at farm level is a major evidence gap in UK systems. This is largely due to a lack of recording at farm level and future policy should incorporate an element of data recording to enable effective preventative strategies to be implemented.

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