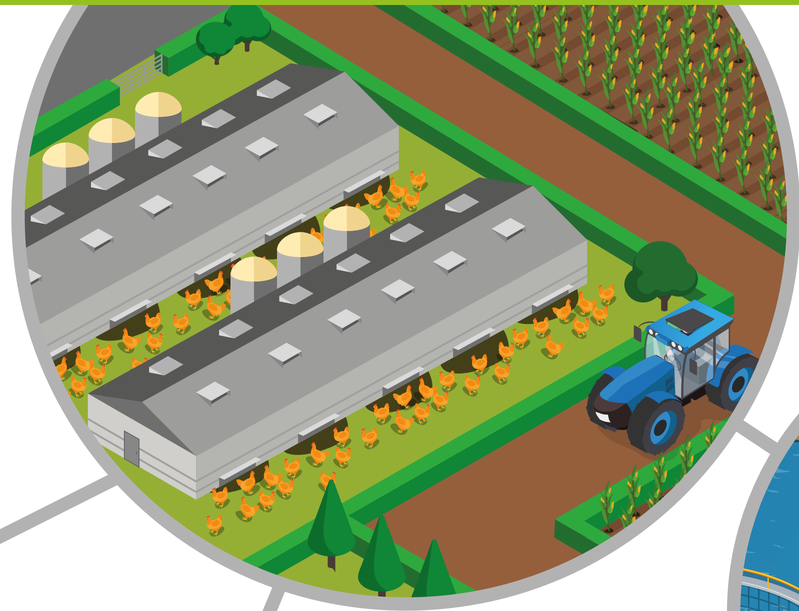
CIEL

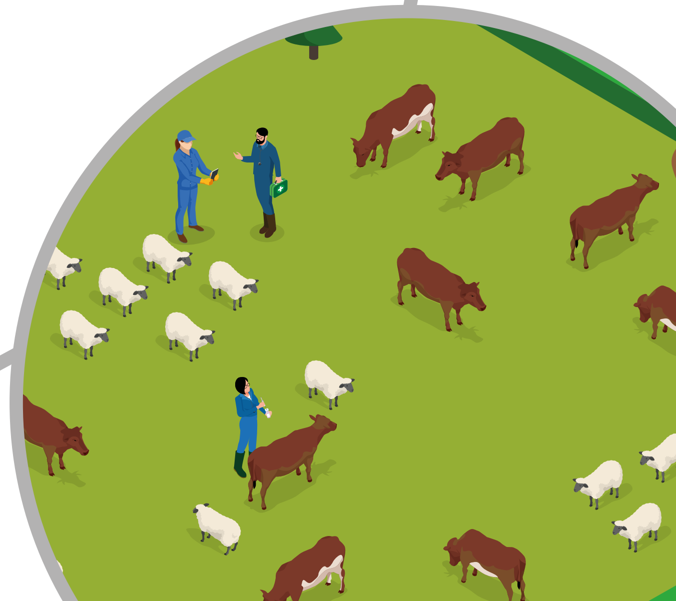
NET ZERO & LIVESTOCK

NET ZERO & LIVESTOCK:
BRIDGING THE GAP

July 2023







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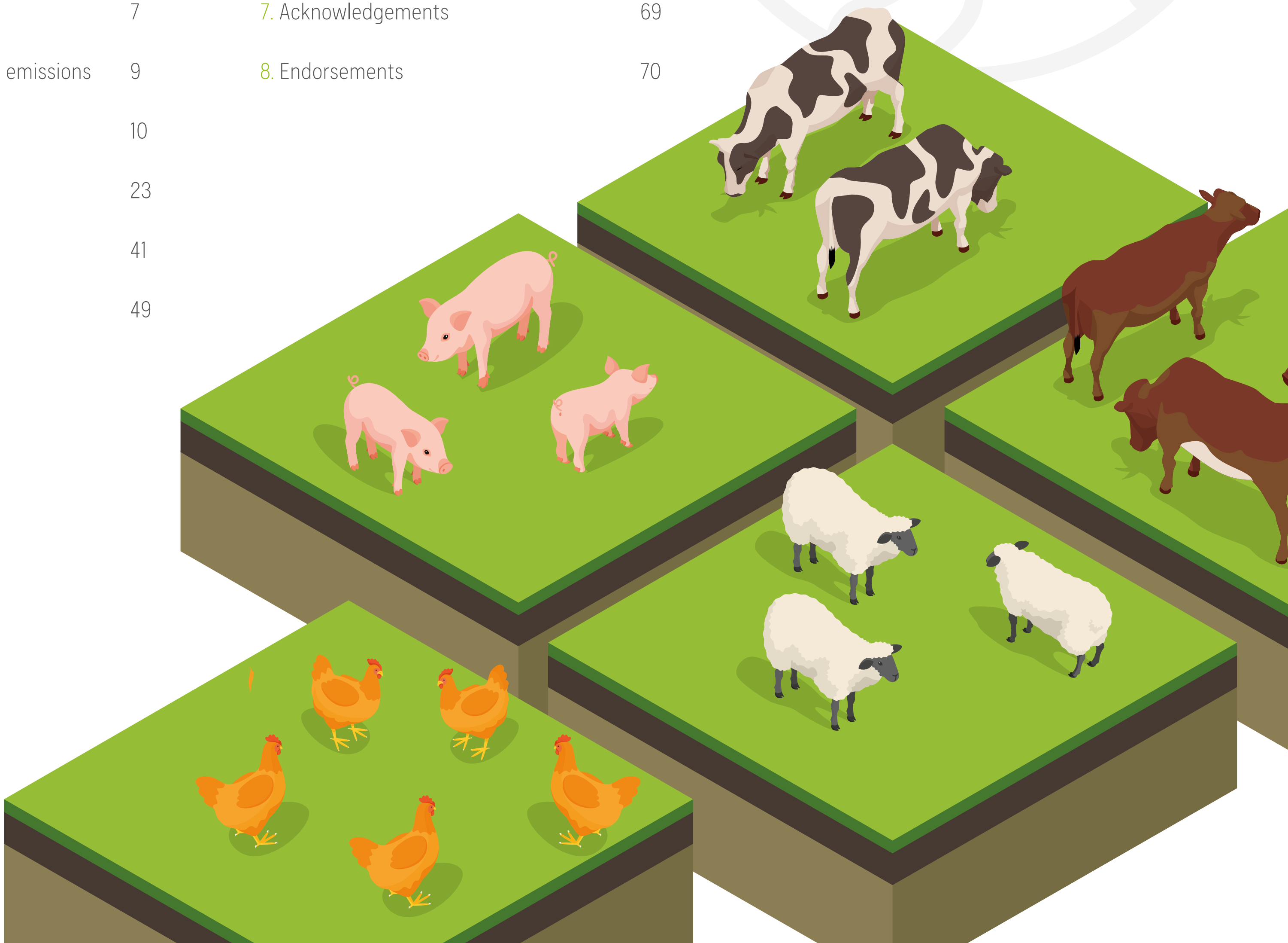
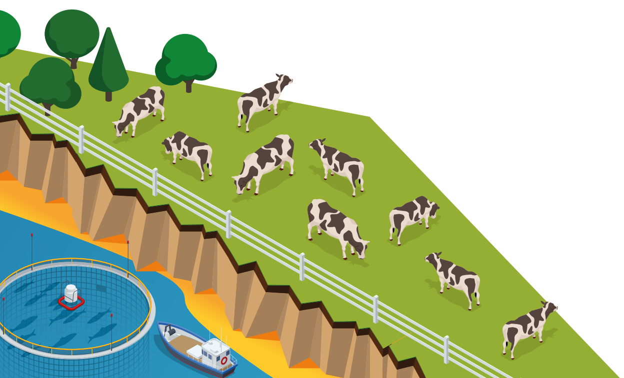
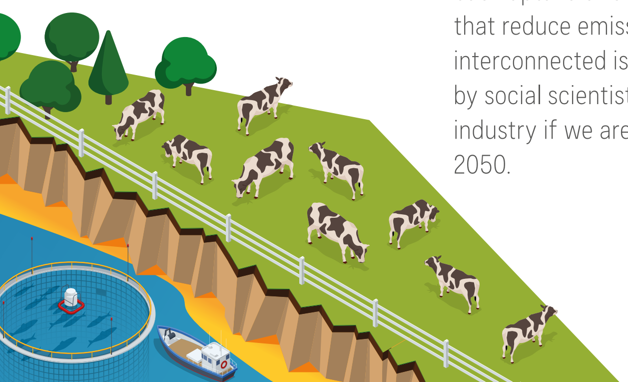




1. Preface



In recent years, CIEL has produced two key reports relating to achieving net zero ambitions for the UK livestock sector. A sobering conclusion from the expert authors of these reports was that for the ambitious goal of a 64% reduction in carbon dioxide equivalent emissions, current technology and practices could only deliver a 24% reduction* at high rates of uptake. The remaining 'emissions reduction gap', requires new innovations in technology, services and management approaches.

This latest report puts this emissions gap under the spotlight, exploring the existing technology gaps and identifying key areas for innovation. To inform report findings, CIEL has commissioned collective scientific knowledge and insight to highlight potential impact-based innovations in livestock agriculture and aquaculture that could accelerate progress towards widespread emissions reductions. Whilst we recognise that further innovation is required throughout these sectors, this report considers 11 areas of innovation that, if widely adopted, provide a platform for achieving the UK's wider net zero targets.

The focus of the report is ultimately asking the question of where to look for new innovations capable of making significant reductions in emissions in this decade of action. The report does not, however, address the issue of what is holding back uptake of existing technologies or services that reduce emissions. Uptake is a separate, yet interconnected issue that requires urgent attention by social scientists, government, regulators and industry if we are to deliver the changes needed by 2050.

Delivering net zero for the UK is critical in our collective efforts to prevent runaway global warming this century, and there is enormous potential to unlock emissions reductions in agriculture; a sector that contributed 11% of national greenhouse gas (GHG) emissions in 2020. Within agriculture, livestock, particularly ruminants through enteric fermentation, are seen as contributing a high proportion of the sector's emissions, directly and indirectly. The technological advancement of modern agriculture has accelerated growth of the sector, maximising efficiencies and productivity. However, while this has boosted crop yields and global food production, its wider impact on the environment is proving significant. Perhaps notably, the linear nature of existing practices within the industry and subsequent impacts are being felt throughout the supply chain, fueling interest in a more circular food system for all nutrients.

*Authors of the 2020 CIEL report on **Net Zero Carbon & UK Livestock** assumed UK livestock have the same goal as UK agriculture and land use, set by the UK Committee for Climate Change, of achieving a 64% reduction in emissions by 2050. In the 2020 report, the authors estimated current technology could only deliver 19% of that goal by 2035. 19% of 64% is a 12% reduction, hence maintaining this rate of reduction would only reduce emissions by 24% by 2050. The gap that needs to be bridged urgently is a further 40% emission reduction which requires an intense focus to deliver further innovations that industry will pick up quickly and widely. **Bridging this gap is the challenge we face.**

We have the tools to manage efficiency; the shift needed is to look at whole-system efficiency ahead of maximising efficiency of individual components of the system. We are all in this together when it comes to the results of an inefficient UK food system, as emissions and other nutrient losses not captured or diverted to reuse will impact the health and sustainability of our whole food system, particularly when that system relies on a nurturing and healthy environment.

This report is the third in a series directly targeting **Net Zero & Livestock**, and we have more in development with a targeted focus. As with previous work, we welcome the opportunity to share this insight with the livestock industry, both domestically and globally. CIEL believes that adopting new innovations will help the livestock sector deliver a lower carbon footprint, whilst continuing to be a key part of the food system that delivers highly nutritious food for society in more sustainable ways. If you would like to discuss any of the topics and issues relating to **Net Zero & Livestock**, please contact enquiries@cielivestock.co.uk.

Phil Bicknell

Director, CIEL

Uptake is a separate, yet interconnected issue that requires urgent attention by social scientists, government, regulators and industry if we are to deliver the changes needed by 2050.

2. Executive Summary

The way forward to bridge the emissions gap in the livestock sector and deliver net zero goals by 2050 is through innovation. Impact-based technologies with significant potential to contribute to this target are highlighted in this report. Research has repeatedly demonstrated that greenhouse gas (GHG) emissions can be considerably reduced through better livestock management. Innovation across health and genetics, nutrition, waste, and land management provide further opportunities for sector-wide emissions reductions and sustainable food systems.

Health and Genetics

Innovations focusing on improving animal health by boosting immunity through **vaccination against endemic disease** or **prophylactic health products** (PHPs) can increase productivity while reducing resource use, cost and, ultimately, GHG emissions. PHPs and rapid on-farm diagnostics can improve feed efficiency in aquaculture systems while conferring environmental benefits besides emission reductions through improved water quality, lower ammonia (NH_3) emissions and reduced water usage. Challenges such as lack of accurate, standardised disease and performance data and health metrics in carbon calculators can be overcome through a measurement, reporting and verification (MRV) process.

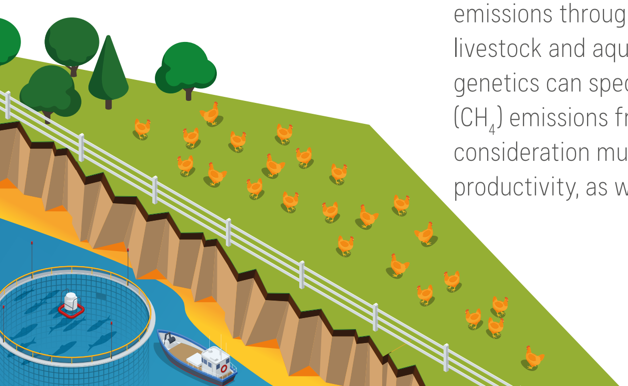
Genetic improvement can contribute to reducing emissions through general gains in efficiency for all livestock and aquaculture systems. For ruminants, genetics can specifically focus on lowering methane (CH_4) emissions from enteric fermentation, but consideration must be given to how this impacts on productivity, as well as efficiency.

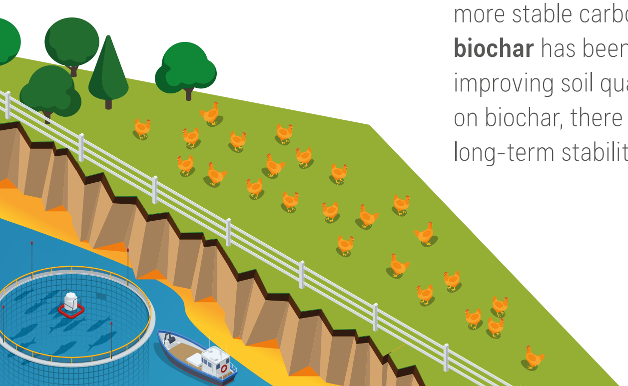
To deliver innovations in this area requires further research and funding targeted at increasing the collection of CH_4 emission performance data (phenotypes), use of restricted selection indices, and development of genetic tools to manage the rumen microbiome.

Nutrition

Methane emissions from the ruminant microbiome can also be targeted using **CH_4 inhibitors** or **CH_4 vaccines**. Currently several CH_4 suppressing products are at various stages of market readiness, with potential emissions reductions of 12% – 37%. Although the UK Government is anticipating entry of safe and high efficacy products to the UK market from 2025, no CH_4 inhibitor is currently available in a form that ensures consistent supply of effective and safe dosage to grazing animals. On the other hand, CH_4 vaccines remain at early development stages but have shown promising results in New Zealand. Best case scenario models have estimated that annual CH_4 emissions of UK livestock could be reduced by 30% (6.8 $MtCO_2$-eq).

Nutrition, through both enteric fermentation and feed production, is the dominant source of emissions for livestock and aquaculture. It is critically important for production and health but can also help mitigate GHG emissions associated with feed production, including costs due to recent land use change. Replacing soya or fishmeal with low carbon, less resource-intensive **novel protein feeds** can significantly reduce emissions. Further research is needed to assess production impacts at scale. Legislation in this area that is fit-for-purpose needs to align with, and facilitate, feed innovations, right through to implementation if we are to address the urgent need for improvements in this major area to deliver 2050 net zero targets.





Waste

Improving manure management using innovative processing methods such as **plasma treatment of slurry** can bring about significant emissions reduction, e.g., NH_3 and CH_4 emissions from pig slurry storage can largely be eliminated, but there is a need for innovation to provide green energy to drive on-farm plasma units to minimise the carbon footprint. Other manure additives and novel data approaches underpinning best management practices can further contribute to mitigating emissions. The focus must be placed on nutrient circularity, so a systems approach is needed to exploit potential synergies and balance trade-offs while closing the nutrient loop.

Land

Manure management can further mitigate emissions by returning carbon to the soil. Innovative approaches to **optimise soil carbon sequestration** include multispecies swards and forage crops, new technologies for measuring and monitoring soil carbon, and increased focus on subsoil for long-term, more stable carbon storage. As a soil amendment, **biochar** has been shown to boost soil carbon while improving soil quality. Despite extensive research on biochar, there are still key knowledge gaps on its long-term stability in soil.

Good nutrient management balances inputs and outputs while reducing losses and optimising circularity. Complexities of farming systems, practices and conditions make this difficult to standardise methods for supporting farmers. To this end, data at farm level is needed and, consequently, technological innovations and **improved data capture systems** are required if we are to improve nutrient management using a precision agriculture approach.

Accelerating Innovation

To meet UK net zero emissions targets in livestock production in the required timescale, innovative technologies already in early stages of development are urgently needed. Obstacles must be removed, and a systematic approach implemented to create an enabling environment that will **accelerate innovation.**

CIEL proposes a four-point plan to help accelerate innovation and maximise uptake:

1. **Farmer engagement and capacity building**
2. **Enabling regulation and policy**
3. **Effective financial flows**
4. **Supply chain and cross-sector collaboration**

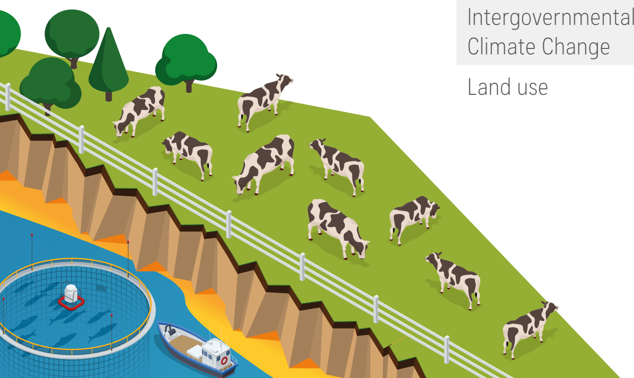
Collectively, the areas highlighted in this report are where a major proportion of resources should be focused to deliver the emission reductions needed from the livestock sector. We expect these reductions will come from lower emission feed production systems, increased feed efficiency, improved animal health and greater nutrient circularity.

We recommend this report to policy and decision makers in government, on-farm, in-farm support and across the food industry to guide efforts in innovation for bridging the gap.

Mark J Young

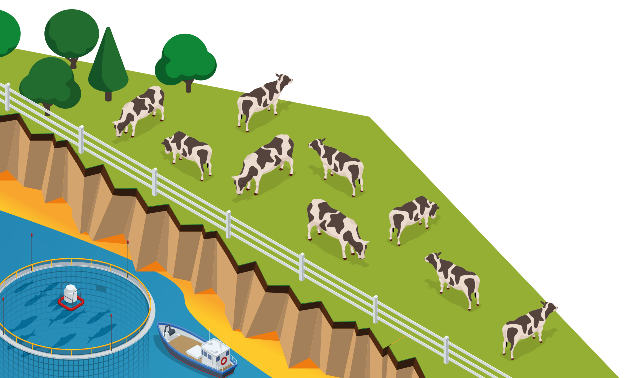
Dr Mark Young
Innovation Specialist, CIEL

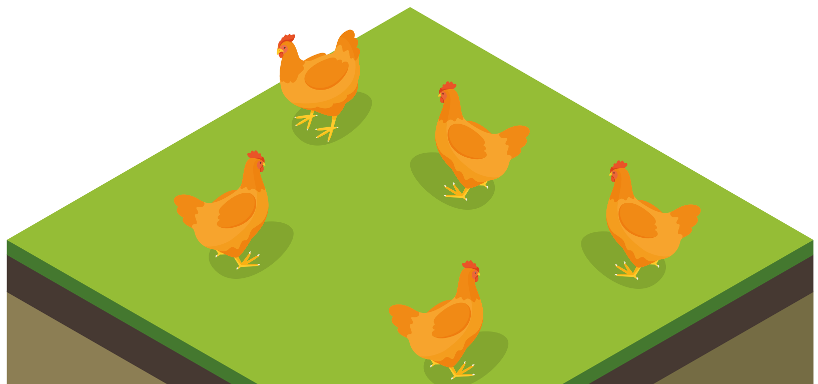
3. Glossary



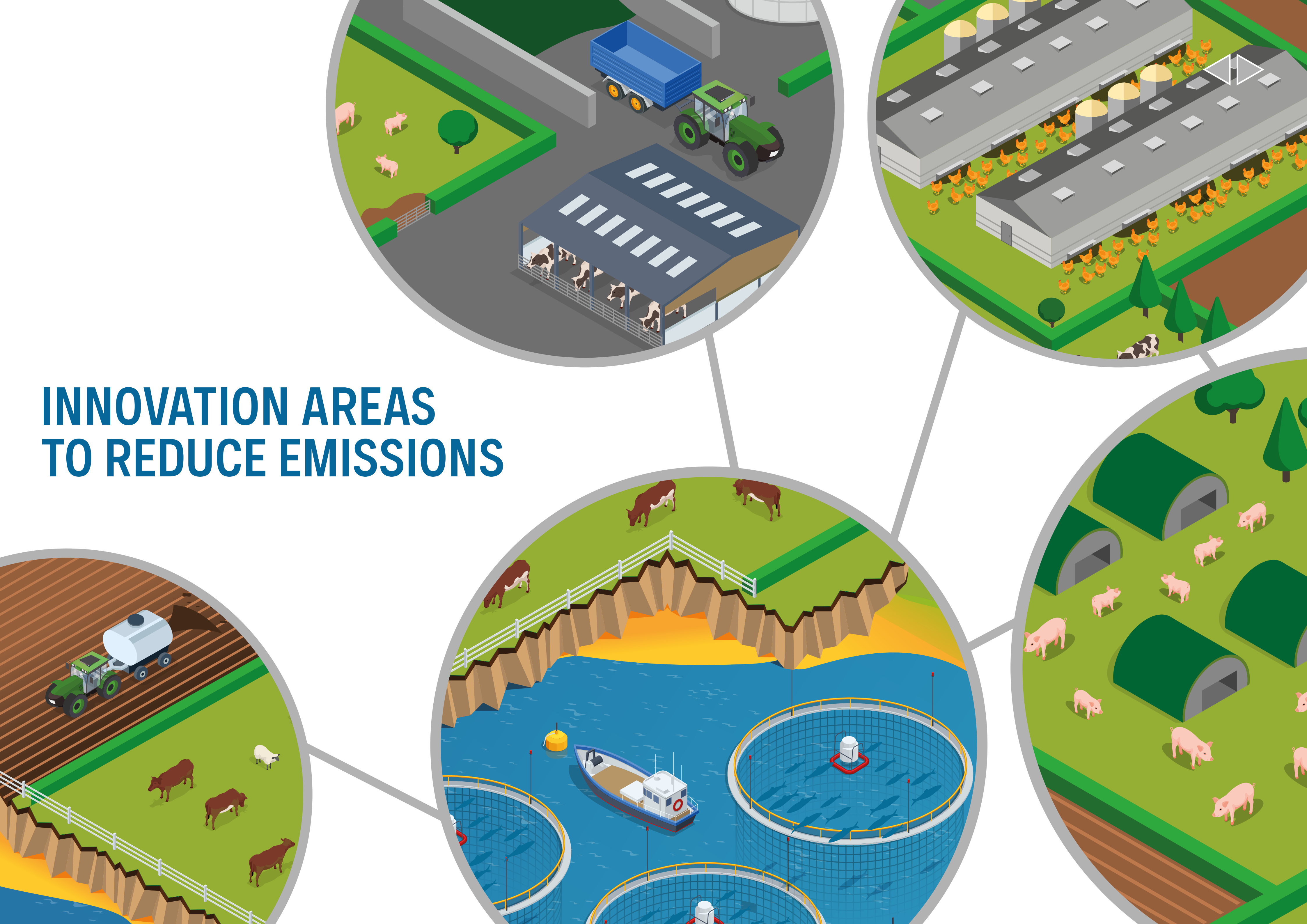
Terms	Abbreviation	Definition
Ammonia	NH_3	A colourless gas released mainly during naturally occurring processes created when faeces and urine mix i.e., during breakdown of urea excreted by farm livestock or of uric acid excreted by birds.
Antimicrobial resistance	AMR	The ability of a bacterium/micro-organism to grow or survive in the presence of an antibiotic at a concentration that is usually sufficient to inhibit or kill bacteria/micro-organisms of the same species.
Anthropogenic		Resulting from or produced by human activities.
Carbon	C	A natural element that forms the backbone of molecules used for energy transactions in biology. It has become shorthand for the unit of 'emissions efficiency' and is the standard unit for emissions related to global warming potential (GWP).
Carbon dioxide	CO_2	A naturally occurring gas, CO_2 is a by-product of burning fossil fuels such as oil, gas and coal, burning biomass, land use changes (LUC) and industrial processes (e.g., cement production).
Carbon emissions avoided		Avoided emissions are emission reductions that occur outside of a product's lifecycle or value chain, but as a result of the use of that product.
Carbon dioxide equivalent	CO_2-eq	A unit of greenhouse gas (GHG) expressed as a CO_2 equivalent and used to compare GWP of different GHGs on a common scale.
Carbon sequestration		The removal and storage of carbon from the atmosphere by natural processes. If the CO_2 sequestered is more than the CO_2 emitted, the carbon store is increasing and known as a carbon sink.
Carbon unit		Carbon units represent measurable amounts of CO_2 removed from the atmosphere, typically used for carbon trading. One carbon unit is one tonne of CO_2 removed from the atmosphere. Emissions of other GHGs are represented as carbon equivalents (see definition above).
Gigatonne carbon dioxide equivalent	$GtCO_2$-eq	The standardised abbreviation for one billion (10^9) tonnes of CO_2 equivalent.
Global warming potential	GWP	A measure of the warming potential of a GHG relative to that of CO_2.
Greenhouse gas	GHG	Greenhouse gases (GHG) are gases in the atmosphere such as water vapour, carbon dioxide, methane and nitrous oxide that can absorb infrared radiation, trapping heat in the atmosphere. This greenhouse effect means that additional emissions of GHGs due to human activity cause global warming.
Intergovernmental Panel on Climate Change	IPCC	An intergovernmental body of the United Nations, responsible for advancing scientific knowledge and consensus on climate change caused by human activities.
Land use	LU	In national GHG inventories, land use is classified according to the IPCC land use categories of forest land, cropland, grassland, wetland, settlements, and other lands. Some land use change (LUC) is considered to release carbon into the atmosphere e.g., conversion of natural forest to farmland.

Terms	Abbreviation	Definition
Lifecycle assessment	LCA	A methodology or process to assess and evaluate the environmental impacts of a product across all stages of its lifecycle.
Methane	CH_4	A GHG produced by ruminant livestock from enteric fermentation in the digestion process or during storage of livestock manure. It has 28 times the GWP of CO_2.
Mitigation		In relation to GHG, to reduce emissions created by human activities or enhance the sinks of carbon and nitrogen that would otherwise become GHGs.
Megatonnes carbon dioxide equivalent	$MtCO_2$-eq	The standardised abbreviation for one million (10^6) tonnes of CO_2 equivalent.
Net zero		Often referred to as net zero carbon or net zero emissions. A situation where anthropogenic emissions of GHGs to the atmosphere are balanced by removals over a specified period.
Nitrogen	N	Nitrogen, a constituent of all living matter, is the most abundant element in Earth's atmosphere and is an essential part of biological life. In the atmosphere it is largely present as a gas, N_2. N is required to make protein molecules from carbohydrate molecules. Plants absorb N in the form of nitrate (NO_3^-) or ammonium (NH_4^+) ions from the soil, and artificial and organic fertilisers release one or both of these ions. Some microbes can "fix" nitrogen from the air, converting N_2 and oxygen (O_2) to create NO_3^-. Decaying biological material and fertiliser can release nitrous oxide (N_2O), a potent GHG, to the atmosphere.
Nitrous oxide	N_2O	A GHG produced largely as a result of the use of nitrogen fertilisers and manures. It has a GWP 298 times that of CO_2.
One Health		One Health is an integrated, unifying approach to balance and optimise the health of people, animals, and the environment, mobilising multiple sectors, disciplines, and communities at varying levels of society to work together.
Soil carbon		Carbon stored in organic matter in the soil. It comes from decomposing plant and animal material and is important for soil health. About 58% of soil organic matter is carbon, some of which is 'active' i.e., present as living organisms. High levels of soil carbon are considered to be a mark of healthy soils.
Soil carbon sequestration	SCS	Land management changes which increase the soil organic carbon content, resulting in a net removal of CO_2 from the atmosphere.





INNOVATION AREAS TO REDUCE EMISSIONS



4.1 Health and Genetics
Vaccination Against Endemic Disease

HOW IT WORKS

Overview

Targeting endemic cattle disease has significant potential to reduce greenhouse gas (GHG) emissions given that there are currently 9.6 million cattle within the UK[1] and vaccination uptake is relatively low within the cattle sector compared to pigs and poultry. This potential depends on aetiology, productivity impacts and incidence for different diseases.

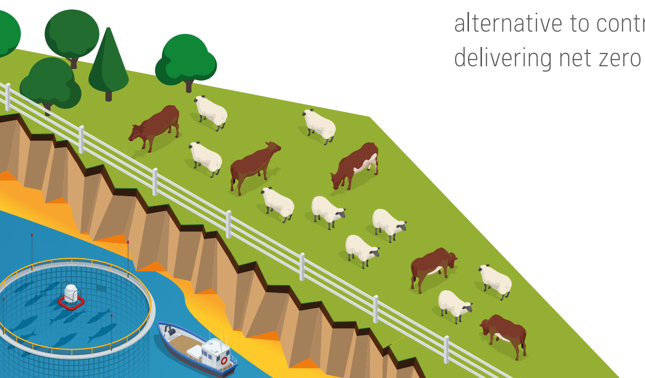
Endemic diseases result in milk or meat losses, reduced product quality, or failure to meet key performance indicators e.g., growth rate, fertility, feed efficiency and mortality. This means a greater number of animals, quantity of time, or combination of the two, are required to maintain milk and meat output. This increases resource use, GHG emissions and economic costs of production at the product, operation and sector levels[4,5]. Reducing disease severity decreases GHG emissions[1,6,7,8] with disease control or elimination reducing GHG emissions from 1 – 40% per unit of milk or meat[9]. Although antimicrobials can be used for disease treatment, increasing threat of antimicrobial resistance (AMR) means that vaccination provides a more sustainable alternative to controlling some diseases and delivering net zero carbon goals.

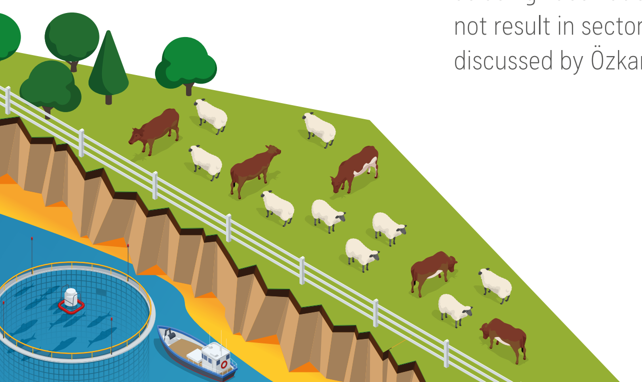
Implementing all mitigation measures for endemic disease within the UK cattle sector, such that 50% of cattle move from the prevalence and impact of diseases in the UK at the time of analysis (2015) towards good health, reduces GHG emissions by 1,436 ktCO_2-eq, a 6% reduction[2]. Higher vaccine adoption rates than is currently the case can deliver much of this reduction **(see Table 1).**

Table 1. Impacts of using vaccination against endemic disease in the UK beef and dairy sectors on total potential GHG emissions mitigation

Production system	Disease	Potential mitigation (ktCO_2-eq)*
Dairy production	Infectious bovine rhinotracheitis (IBR)	227.1
	Johne's disease	167.8
	Salmonella	83.5
	Bovine viral diarrhoea (BVD)	73.3
	Calf pneumonia	11.7
Suckler beef production	Infectious bovine rhinotracheitis (IBR)	101.6
	Bovine viral diarrhoea (BVD)	100.6
	Johne's disease	26.3
	Calf pneumonia	5.8
	Salmonella	4.6

* Note that this is a maximum potential mitigation as reported by ADAS[2].





POTENTIAL IMPACT

The impact of endemic disease is often overshadowed by exotic diseases, including Avian Influenza and African Swine Fever, that have sudden and catastrophic impacts on animal health, farm profit and food security. Nevertheless, reducing endemic disease would confer tri-fold sustainability benefits in reducing economic costs of production, resource use, and GHG emissions; whilst also increasing social acceptability through demonstrated improvements in cattle health and welfare.

ADAS[2] investigated the impacts of cattle vaccination on GHG emissions from UK dairy and beef production, with the greatest reductions conferred by preventing IBR and Johne's disease in dairy cattle (reducing total sector GHG emissions by 227.1 ktCO_2-eq and 167.8 ktCO_2-eq respectively), compared to IBR (101.6 ktCO_2-eq) and BVD (100.6 ktCO_2-eq) in beef cattle. In addition, Statham et al.[8] reported that eradicating BVD alone would cut emissions by ~4% in average UK herds and ~11% in the worst 10% of herds. The trade-off between improving health and increasing cattle numbers for the same inputs due to reduced morbidity and mortality must be considered however, as using vaccination to mitigate net emissions must not result in sector GHG emission increases, as discussed by Özkan et al.[10]

Co-benefits of vaccination in improving animal health would also exist for GHG emissions from associated agricultural sectors. For example, livestock in good health would require less feed and forage to maintain production, and therefore total fuel and cropping inputs would be reduced. Moreover, effective vaccine use would reduce the quantities of antibiotics, and the GHG emissions from their production, needed to treat disease. Reducing use of antibiotics also delivers on One Health goals to tackle AMR.

Eradicating BVD alone would cut emissions by ~4% in average UK herds and ~11% in the worst 10% of herds.

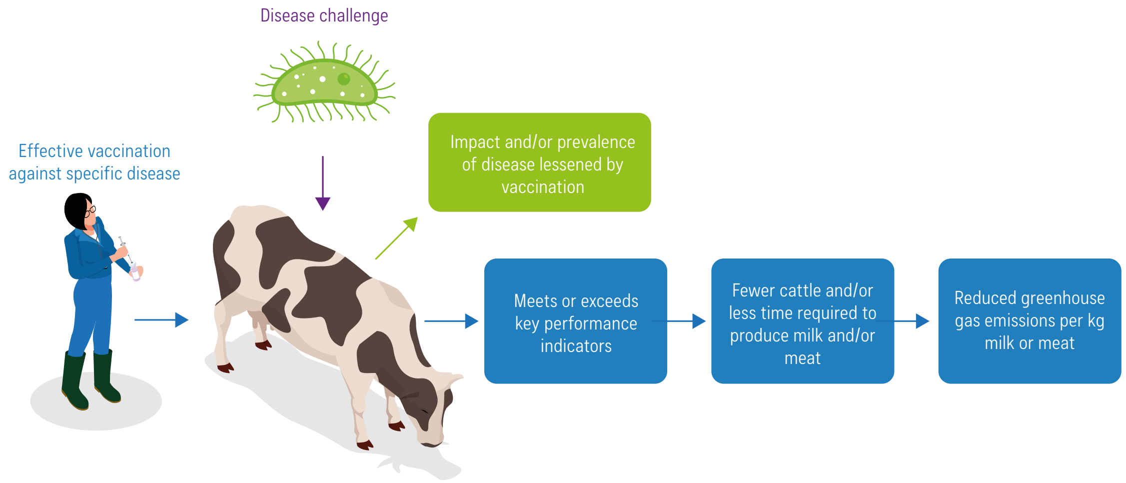
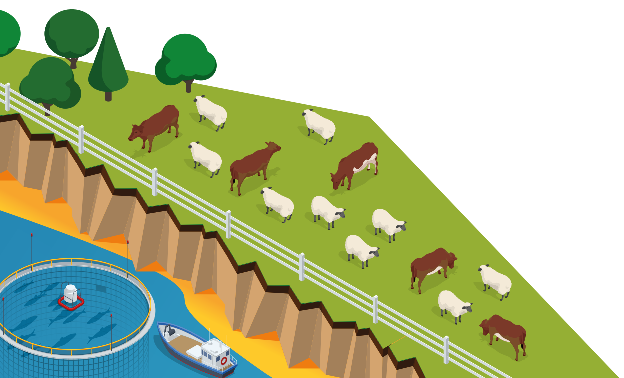


Figure 1 Effect of vaccinating cattle against endemic disease upon GHG emissions per kg of milk or meat



AMBITION

Total number of doses of cattle vaccines sold increased by 20.3% between 2011 and 2021[3], with 2021 sales data indicating vaccine adoption rates of 44% for calf pneumonia, 33% for IBR, 41% for BVD, 30% for leptospirosis, and 21% for calf enteritis. This indicates considerable potential to further increase adoption and reap greater GHG emission reduction rewards. However, vaccines are not 100% effective in every situation, therefore full adoption does not imply disease elimination; and as vaccines are not available for every endemic disease, this mitigation strategy cannot be applied to every health challenge.

Primary barriers to effective vaccine adoption and use are lack of understanding of associated economic benefits; inadequate training on vaccine storage or administration; and unwillingness to change farming practices[2]. Economic impacts of specific endemic diseases have been quantified – O' Doherty et al.[11] found that unvaccinated herds testing positive for Salmonella or Leptospirosis hardjo had lower milk sales compared with a vaccinated baseline. Vaccinated herds generated between £58 to £88 (Salmonella) or £8.32 to £8.42 more profit per cow lactation (L. hardjo) compared with unvaccinated herds positive for exposure.

Communicating these potential gains to producers could provide sound business cases for vaccine use which, in combination with vaccine usage training, could significantly improve adoption and efficacy. Changing producer behaviour is a greater challenge, yet may be partially achieved through improved peer-to-peer learning[12].

GAPS TO ADDRESS

Many diseases co-exist and interact on-farm, therefore it is difficult to quantify the effects of implementing a vaccination strategy for one specific disease[13], as evidenced by the paucity of data in peer-reviewed literature. Yet a greater issue is lack of accurate, standardised disease and performance data, in combination with incorporation of health metrics into GHG emission calculation tools. As Özkan et al.[10] concluded, this may be overcome by implementing a measurement, reporting and verification (MRV) process for assessing impacts of vaccine use on GHG emissions, with demonstrated dedication by all stakeholders to promoting and maintaining this resource.

Lack of current, accurate economic data for many diseases also limits opportunities to enhance vaccine uptake. Moreover, other significant benefits of vaccination such as improved animal welfare and reduced AMR have not been quantified in the literature, yet can provide further, significant benefits to society and environmental sustainability.

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4.1 Health and Genetics
Health Innovations In Aquaculture

HOW IT WORKS

Overview

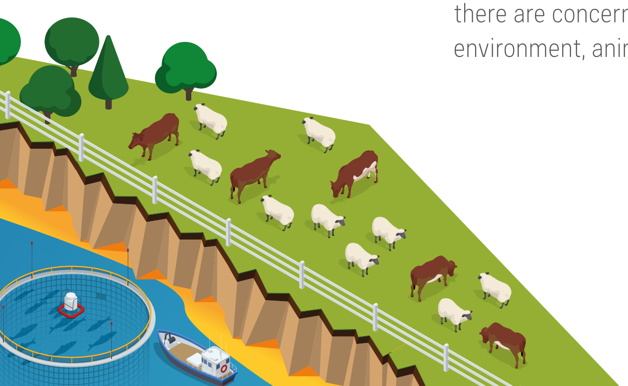
Aquaculture and greenhouse gas (GHG) emissions

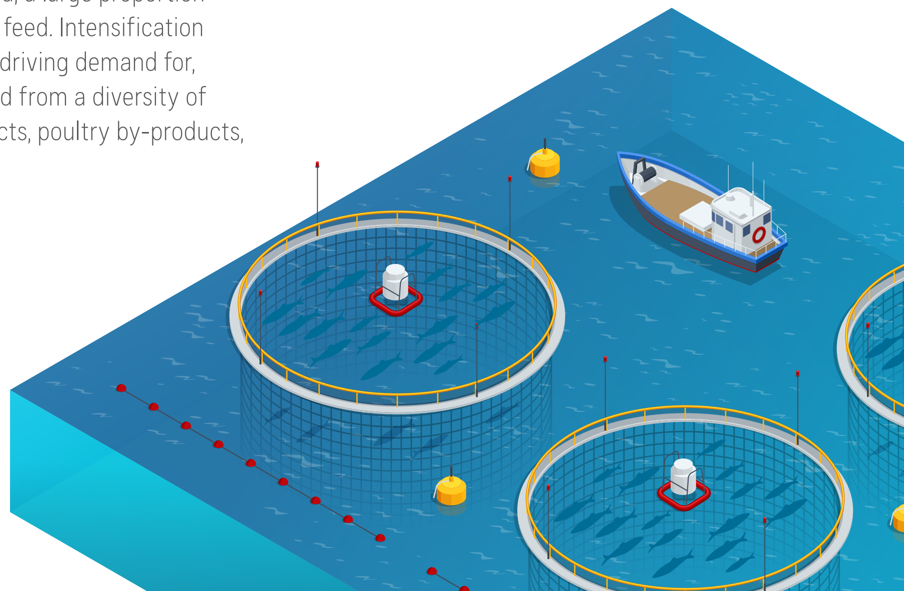
Declining capture from wild fisheries, in combination with a rapidly growing demand for aquaculture products, is driving intensification of the sector, with an average global annual growth rate of up to 8%[14]. The average greenhouse gas (GHG) emissions per kg of edible product (carcass weight) globally for finfish e.g., catfish, cyprinids, carps, salmonids and tilapias, is ~5 kgCO_2-eq/kg of product, with the largest proportion of these emissions coming from production, processing and transport of feed[15]. Globally, feed accounts for up to 57% of the sector's emissions[15], however this can increase up to 80% in certain highly industrial production systems[16,17]. In the UK, the main finfish species produced by aquaculture is Atlantic salmon and mussels are the main shellfish species. The current GHG footprint for Atlantic salmon has been estimated as 3 kgCO_2-eq/kg of liveweight at farm gate[18] and for mussels 0.25 kgCO_2-eq/kg of liveweight at the farm gate, or 0.6 kgCO_2-eq/kg of mussel meat[19]. Although growth of the sector can support food security and nutrition, there are concerns with regards to impacts on the environment, animal health and welfare.

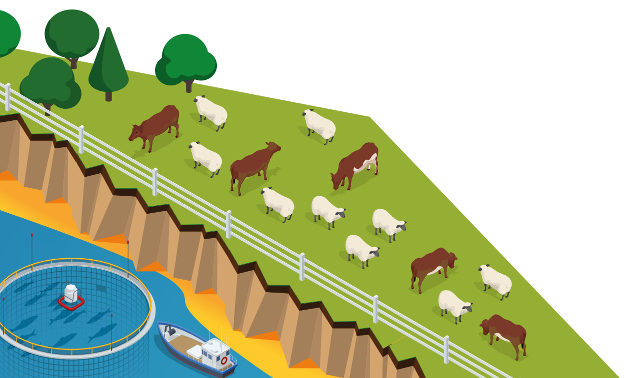
Health related innovations can improve feed efficiency and environmental outcomes

Global annual losses due to infectious disease in aquaculture are over £5 billion[20]. Therefore, the combination of health management and improved feed efficiency are vital areas of innovation for sustainable intensification and reduction in emissions. There are potential interventions to improve productivity of aquaculture and reduce emissions across the value chain. These include design of farm systems, fish processing, as well as by-product and waste management[21,22]. Given the significant emissions associated with feed, a large proportion of innovations are focused on feed. Intensification has been enhanced by, and is driving demand for, commercial fish feed produced from a diversity of sources (fishmeal, soya products, poultry by-products, insects and feed additives)[23].

Feed conversion ratio (FCR) is a simple measure used by industry based on weight of feed required to produce weight gain in an animal over a set period of time. FCR is influenced by many factors including growth rate, species, genetics, environment, husbandry practices, feed composition. Health-related innovations, including both rapid on-farm diagnostics and prophylactic health products (PHPs), can improve the FCR of aquaculture. Healthier fish use feed more efficiently (lower FCR) and reduction in mortality rate reduces waste of feed inputs so that, overall, less feed is required per unit of product output[23].







POTENTIAL IMPACT

1. Prophylactic health products (PHPs)

Published studies indicate that use of prophylactic health products (PHPs), such as probiotics (beneficial microorganisms), prebiotics (ingredients that promote growth of beneficial microorganisms in the gut), synbiotics (mixtures of probiotics and prebiotics) and immuno-stimulants, improve productivity by increasing resistance to disease and reducing mortality rates. An increase in fish growth rate of 17% has been observed, with an improvement in FCR of ~11%[24] (107kg less feed per tonne of fish produced). Other environmental benefits, such as improved water quality have also been observed[25] e.g., ammonia (NH_3) emissions were reduced by ~51%[24]. NH_3 emissions have been associated with algal blooms, adversely affecting the health of farmed aquatic species, and reducing FCR. Life cycle assessments (LCA) demonstrated that any potential negative environmental impacts associated with probiotic production (largely relating to high energy demands) were offset by other benefits such as improved water quality (which in turn reduces water usage) while reducing waste and GHG emissions[16].

For stakeholders to make informed decisions on which product(s) to use and how they should be applied, evidence-based assessments must be developed.

This would include inventories that would outline efficacy (from studies and trials), GHG mitigation potential and the cost-benefit of commercially available PHPs used for different aquaculture species in different production systems.

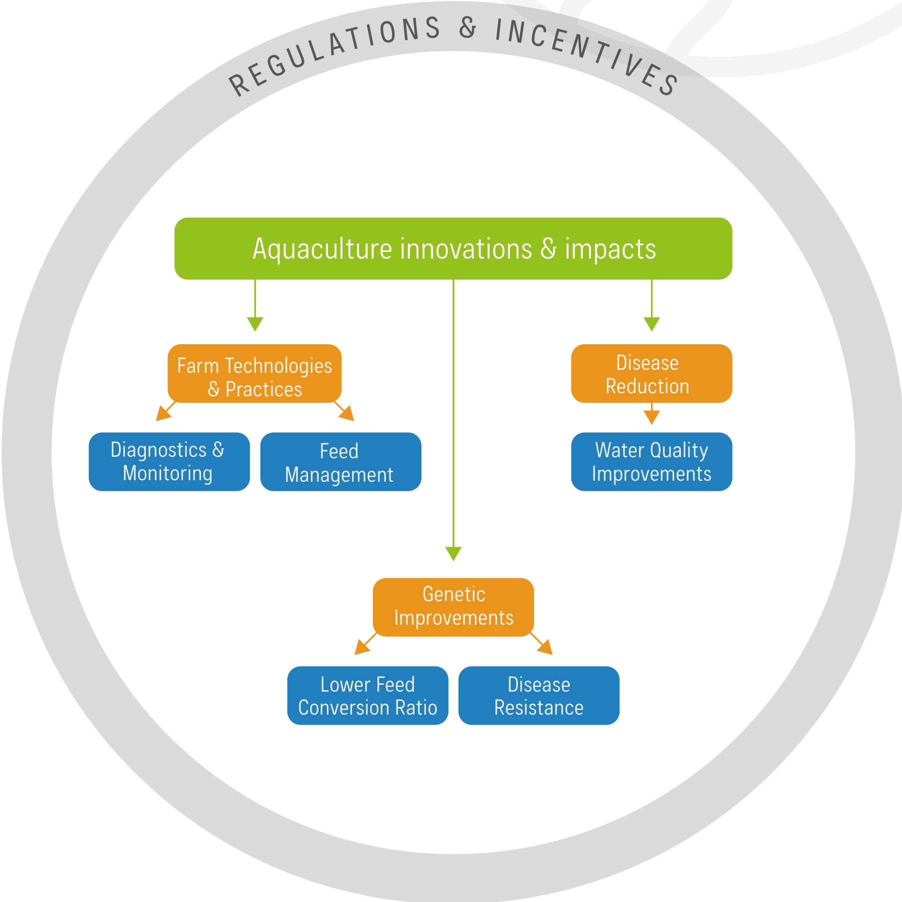
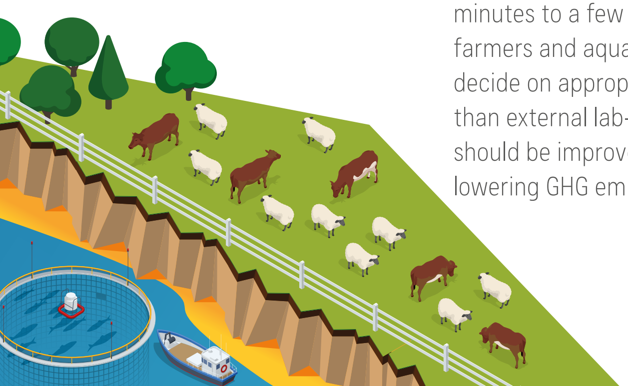


Figure 2 The landscape of potential interventions[21] to improve aquaculture



2. Rapid on-farm diagnostics

Disease diagnosis in aquaculture species usually depends on appearance of clinical signs, rather than use of diagnostics. This is less than ideal because of the time before results are available, even with well organised central services[26]. Relying on clinical signs can delay reporting of disease outbreaks, leading to faster or wider disease spread, with major negative economic impacts[27]. The expense and time required for diagnoses can result in increased use of antimicrobials to try and control disease and reduce losses, leading to increased antimicrobial resistance (AMR) of pathogens in farmed populations[28,29].

Recently, molecular techniques such as polymerase chain reaction (PCR), real-time quantitative PCR (qPCR), multiplex PCR, DNA probe-based *in situ* hybridisation and microarrays have been used for faster detection of viral and bacterial diseases in aquatic animals[28,29]. These molecular techniques are both more accurate and rapid than conventional methods, and so can reduce spread of disease.

Animal health and mortality rates influence production system FCR and farm performance. Effective and rapid on-farm disease diagnostics (from minutes to a few hours to detect disease), enable farmers and aquatic animal health professionals to decide on appropriate interventions much earlier than external lab-based tests. Feed use efficiency should be improved and animal losses reduced, both lowering GHG emissions intensity of product. This would also help effective management of, and reduce use of, antimicrobials[21].

Rapid on-farm diagnostics are also important for aquatic health surveillance, a key component of farm and industry biosecurity measures. Spread of infectious diseases within and between production systems can be reduced, while emerging diseases can be detected early. Detection of emerging diseases requires a surveillance system that can respond quickly with the ability to develop or apply existing tests where required.

More research is required to deliver new on-farm diagnostics for aquatic diseases. At the same time, an inventory is needed of diagnostics currently available to support stakeholder decisions on management options to deploy. To drive uptake, stakeholders must be informed about options that provide good efficacy, deliver economic benefits and mitigate GHG emissions – a win-win scenario.

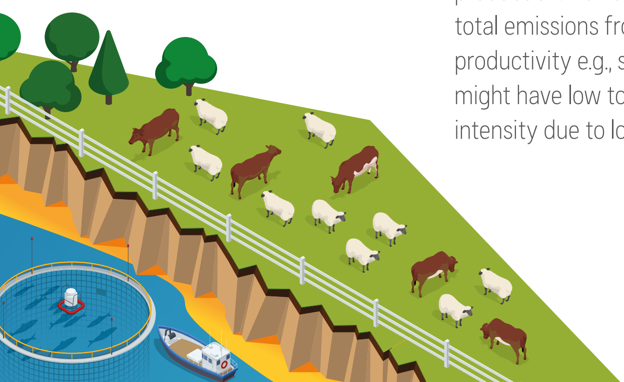
AMBITION

Both PHPs and rapid on-farm diagnostics are important areas for innovation to mitigate emissions associated with aquaculture. The positive impacts of PHPs on animal health and productivity have been extensively investigated[29]. However, the impact of PHPs and rapid on-farm diagnostics on GHG emissions has not been thoroughly investigated and warrants further research. Targeted PHPs and rapid on-farm diagnostics are promising solutions to improve production, health and welfare of aquatic species, reduce antimicrobial use, increase FCR and reduce GHG emissions.

GAPS TO ADDRESS

- Meta-analysis and databases for published data on PHPs in aquaculture (global, open-access resources) to aid decision making on industry and farm biosecurity
- Assessment of the impact PHPs and rapid on-farm diagnostics can have on GHG emissions
- Inventory of commercially available PHPs for different aquatic species worldwide that describe efficacy, economic benefits and GHG mitigation potential
- Inventory of available rapid on-farm diagnostic tools for aquatic animal diseases that describe efficacy, economic benefits and GHG mitigation potential
- Both innovation and translational research are required to produce new PHPs and new rapid on-farm diagnostics for aquatic diseases

NET ZERO & LIVESTOCK CIEL



4.1 Health and Genetics Genetic Improvement

HOW IT WORKS

Overview

Much research has shown how emissions can be reduced through better management and nutrition of livestock herds or flocks. Reducing emissions through genetic improvement is relatively less well researched but offers scope for significant reductions medium- to long-term. This is through exploitation of natural variation in greenhouse gas (GHG) emission intensity[30].

There are three routes for genetic improvement to reduce emissions per kg of livestock product (emissions intensity):

1. Improvements to individual animal productivity
2. Reduction of farm system waste
3. Direct selection for reduced emissions

Animal productivity

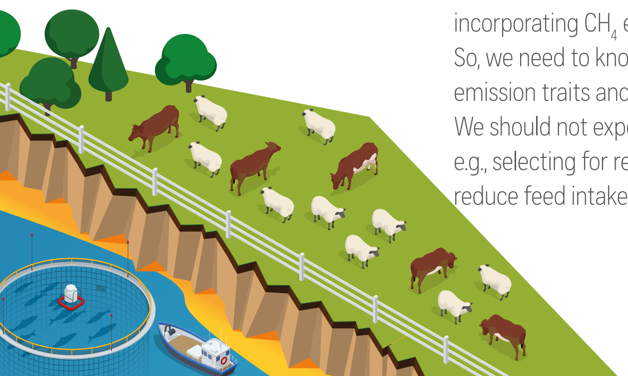
Increasing animal productivity while reducing waste will decrease inputs required per unit of output, reducing overall emissions intensity. Effectively, fewer inputs are lost or used for maintenance and more used for production. However, direct selection for reduced total emissions from individual animals could reduce productivity e.g., smaller animals with low productivity might have low total emissions but high emissions intensity due to low productivity. The challenge is to reduce emissions while maintaining or even improving animal productivity[31,32].

Existing research into breeding for reduced emissions has mostly focused on cattle, but researchers in New Zealand have made considerable progress in research with sheep. Traditionally, sheep and cattle have not been bred for lower GHG emissions, the focus being on productivity per head. As such, there are no significant differences in emissions between different breeds[33], but there is strong evidence to suggest that ample genetic variation (in both feed use efficiency and GHG production from enteric fermentation) exists within breeds[33] that can be exploited for genetic improvement.

Benefits

Genetic improvement is delivering cost-effective, permanent and cumulative gains routinely in most livestock species, types and breeds. Applying existing tools to reducing methane (CH_4) emissions can reasonably be expected to progressively reduce total emissions and emissions intensity from future generations[30,34]. However, concerns remain that ruminant animals (cattle and sheep) selected for reduced CH_4 emissions may have reduced productivity[33].

For pigs, the key breeding goal should be to reduce nitrous oxide (N_2O) emissions (CH_4 to a lesser extent) because N_2O is the main GHG for pigs. The focus should be on feed efficiency linked to digestion of protein which impacts on N_2O lost from manure[32].



POTENTIAL IMPACT

Making reduction of GHG emissions part of breeding objectives is a viable mitigation strategy for the livestock sector[30,35]. This should be implemented as soon as possible, given the need to exploit all known tools for doing so, if we are to meet net zero targets for UK agriculture. In the Netherlands, selectively breeding dairy cattle for low CH_4 production could reduce emissions by 24% by 2050[30]. Estimates for European livestock suggest that breeding could reduce emissions annually by 53.5 $MtCO_2$-eq by 2029, an 8% reduction in emissions intensity[32]. Scientists at AgResearch in New Zealand have predicted 20 – 30% reductions in CH_4 emissions intensity for sheep by 2050.

Several opportunities for innovation to capture this potential are discussed below:

1. Selection indices

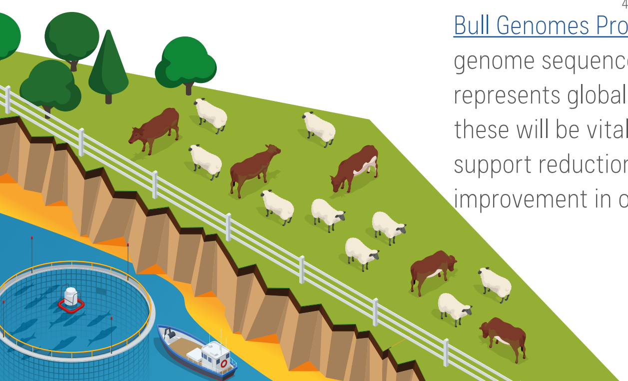
Selection indices are industry standard tools for selection of animals with superior merit across a range of traits. Composite value is based on economic weightings for each trait, and allowance is made for genetic correlations between traits. Currently there is considerable interest in incorporating CH_4 emission traits into selection indices. So, we need to know genetic correlations between CH_4 emission traits and other economically important traits[34]. We should not expect these to always be favourable e.g., selecting for reduced total CH_4 emissions is likely to reduce feed intake or body size[36]. This may mean there are intermediate optimums for some emission traits, rather than minimums, in order to minimise emissions intensity. Restricted selection indices may help for traits where no change is wanted to avoid economically costly losses[34].

2. Focus on phenotype data

Due to limited numbers of animals with actual CH_4 emissions records, genomic estimated breeding values offer scope to impact across a wider range of genetic improvement populations, where targeted measurement of emissions in key animals is complemented by genotyping of the same animals[34,37]. Limitations due to lower genetic variation within breeds, from intense selection for production traits, can be addressed through exploiting diversity between breeds and novel phenotypes.

There is increasing confidence in using phenotype data (measured performance of animals) to predict CH_4 emissions[36,38,39,40]. However, we must embark on wider collection of CH_4 emission performance data to better estimate key correlations and to calibrate genomic predictions of genetic merit. Innovative technologies, such as wearable sensors (e.g., ZELP), automated emissions measurement (e.g., GreenFeed by C-Lock Inc) and infrared spectrometry, are increasing our ability to collect emissions-related performance data[41,42]. These should be exploited right away to improve our ability to select for reduced emissions with little impact on other important characteristics.

There is a strong case for intensive measurement of many traits, including GHG emissions, in reference populations to roll out genomic estimates of genetic merit from just genotype tests used across the wider population.



3. Influencing the microbiome

Selection for animal performance can reduce emission intensity indirectly, but a more innovative area of research is 'microbiome breeding', based on evidence that some rumen or gut microbial population characteristics are heritable. This provides potential to directly select for a more desirable rumen microbiota that further improve feed efficiency and reduce CH_4 emissions[43]. To what extent this is independent of host animal genetics remains to be determined.

4. International genomic databases

Genomic analyses rely on sufficient bodies of performance (phenotype) and DNA (genotype) data to provide accurate predictions of genetic merit. Suitable datasets have until recently been lacking in the livestock sector. However, international efforts are being made to enhance and aggregate datasets into databases with the aim of increasing genomic analysis accuracy for emissions traits. The Efficient Dairy Genome Project is an example, where the focus is on dairy cattle feed efficiency with reduced CH_4 emissions[44]. Another is the 1,000 Bull Genomes Project, which has compiled whole-genome sequences for around 3,000 animals and represents global cattle diversity[45]. Efforts such as these will be vital for future genomic analysis to support reductions in emissions while continuing improvement in other important traits.

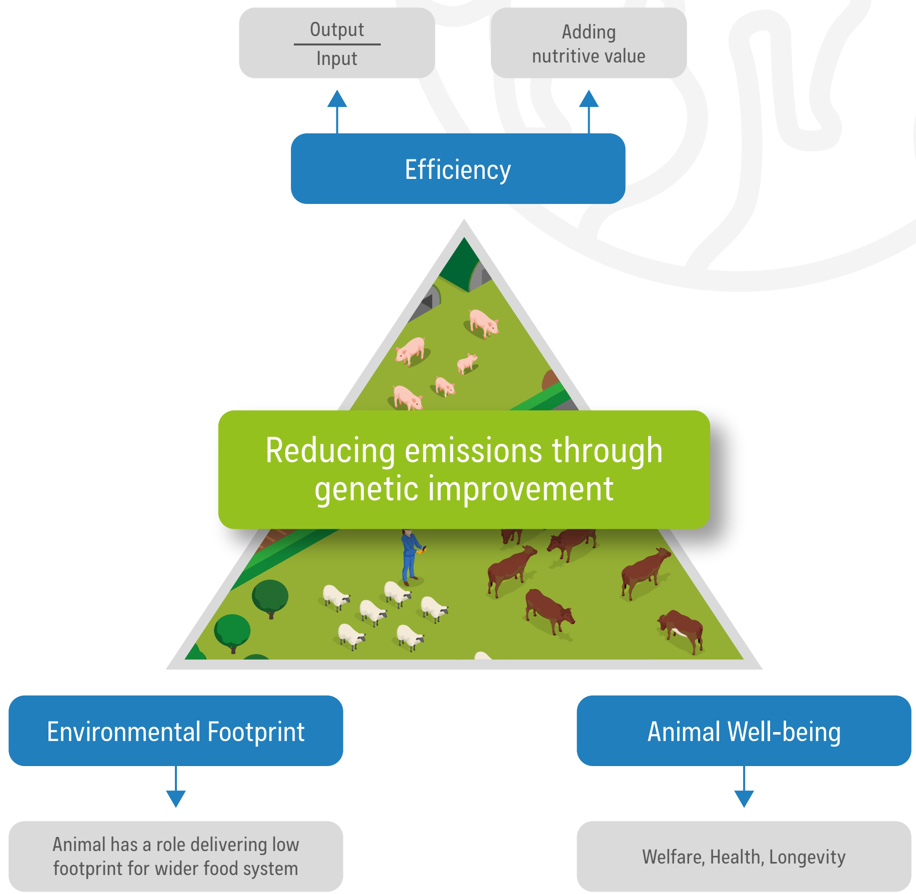
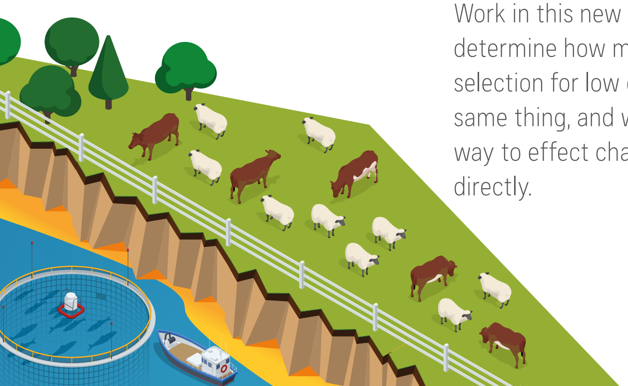


Figure 3 Transforming breeding programmes through a focus on bringing existing and novel traits into a sustainable breeding objective



AMBITION

Livestock breeding to reduce emissions has huge potential based on evidence so far. However, for this ambition to be realised widely, reduced emissions must be considered a fundamental part of the breeding objective alongside traditional traits. Ten years of selection for low emissions from sheep in New Zealand have shown it is possible to obtain significant emission reductions without adversely affecting productivity.

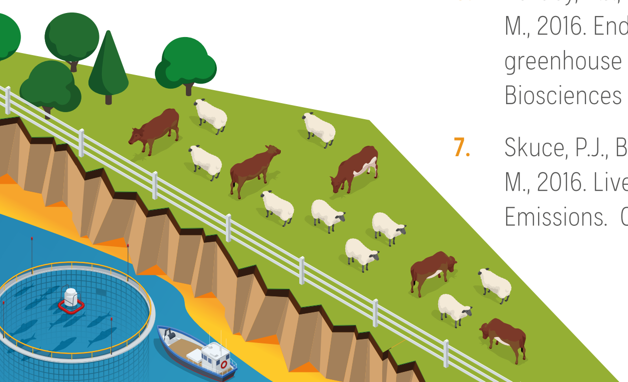
Technology improvements are making collection of performance data on farm more cost-effective, increasing adoption of new traits. However, current costs of collection for emissions traits, and associated traits such as feed efficiency, mean only some breeders can afford to collect these. To address this, we need well-structured and rich data sets from those populations collecting critical performance information, including emissions, to allow production of cost-effective, genomic predictions of genetic merit for reduced emissions that are accessible to all breeders through genotype tests.

There is potential for CH_4 emissions to be reduced by genetic selection of gut microbiome composition. Work in this new area should be continued to determine how much extra this can add over selection for low emissions, whether these are the same thing, and whether this is a more cost-effective way to effect change than by measuring emissions directly.

Given the magnitude of goals for emission reductions, and the short timescales for these goals, sharing of data will be essential for unlocking opportunities. Collaboration, sharing data and developing information rich datasets that include individual animal emissions can create the synergies needed to deliver the UK net zero ambition.

GAPS TO ADDRESS

- Livestock breeding for reduced emissions will benefit from increased expansion, integration and aggregation of datasets internationally. Such initiatives must be both encouraged and supported
- Sharing and aggregation of data should be a requirement for obtaining public money for research in this space. Barriers to data sharing should be identified and removed wherever possible
- Going forward, the volume and breadth of emissions phenotyping must be increased, initially in targeted populations that deliver most value to industry as a whole, using the leverage of genotypes closely linked to whole-genome sequence information
- Reducing costly and labour intensive measurement of CH_4 emissions from individual animals is vital and urgently needed to help accelerate uptake while keeping costs down. However, we should begin using existing technology right away while alternatives are sought



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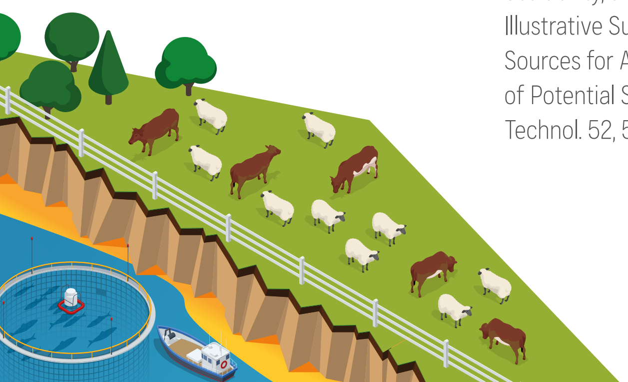

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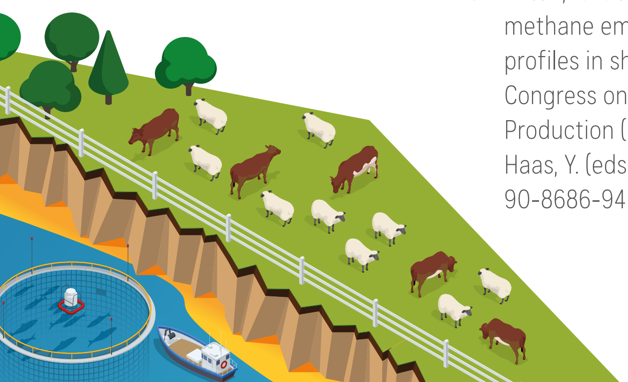

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4.2 Nutrition Novel Protein Feeds

HOW IT WORKS

Overview

Protein in feed is essential for livestock and aquaculture production. Inadequate protein intake can reduce growth rates and limit operation of vital organs, mammary gland activity, reproduction and immunity. In ruminants (cows and sheep), lack of protein can reduce activity of rumen microorganisms, further limiting productivity. At present, there is significant interest in replacing a proportion of protein in livestock or aquaculture rations with protein from novel sources. Depending on their source, proteins can reduce greenhouse gas (GHG) emissions by utilising 'waste' products or replacing protein that has a higher carbon footprint.

Where a novel protein is highly digestible, it can improve digestibility of the overall ration. This is important for ruminant species where improved digestibility reduces energy lost as methane (CH_4) from enteric fermentation[1].

In contrast, for monogastric species (pigs and poultry) it is protein quality, the proportions of different constituent amino acids, that is of primary importance and how available these are to the animal.

If amino acid content is less available, more protein will be wasted, and more nitrogen (N) excreted by the animal. If amino acid balance does not meet animal needs, excess amino acids will be broken down and more N excreted. So, maximising the efficiency of use of protein can help reduce emissions of nitrous oxide (N_2O) and ammonia (NH_3).

For aquaculture, novel protein feeds can reduce demand for soya or fishmeal in diets, improve efficiencies and, in addition, some may increase omega-3 levels in the finished product[2].

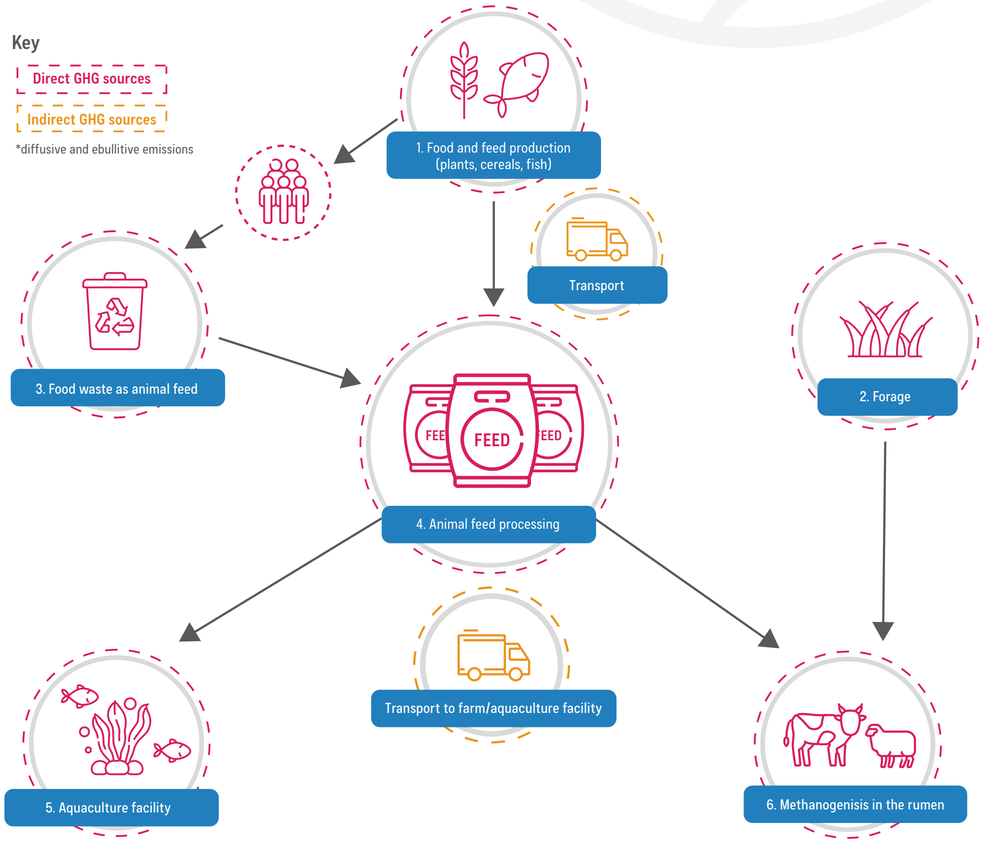
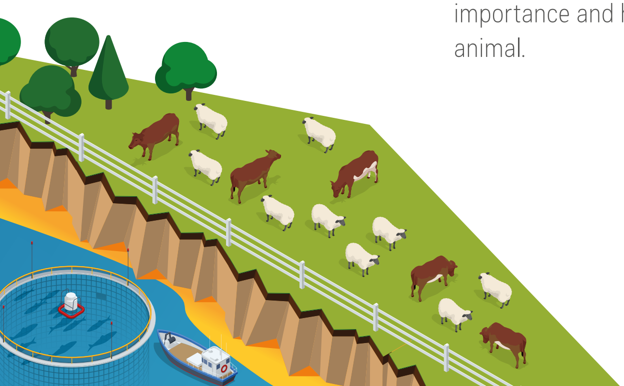


Figure 4 Sources of GHG emissions from the feed supply chain and on-farm opportunities for novel feeds to reduce GHGs



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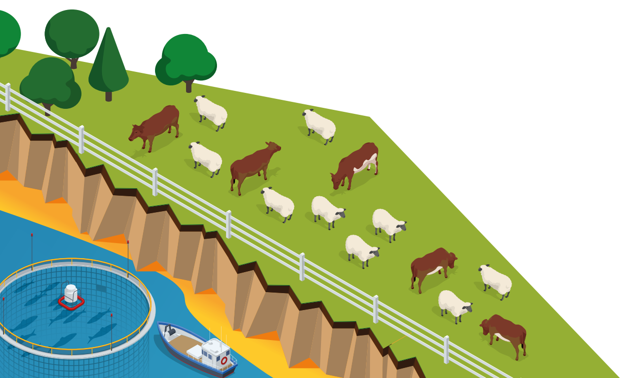


GHG emissions from feed production

Feed production contributes around 36% of GHG emissions from cattle and sheep production. Emission sources for feed production include land use change (LUC), manufacture and application of fertilisers, machinery, and transport, but the primary source of emissions from cattle and sheep production is enteric fermentation.

In contrast, for monogastrics, feed production is the largest cause of emissions, particularly when soya used is associated with LUC. Global figures suggest 48% of pig GHG emissions relate to feed production, rising to 61% if soya is associated with LUC. Feed production contributes 57% of chicken meat and egg emissions, rising to 78% for meat and 70% for eggs if soya is associated with LUC.

For aquaculture production, feed (commonly soya or soya-derived products) contributes up to 57% of total emissions[3,4].

For all livestock, any opportunity to reduce emissions associated with feed production can deliver significant reductions in GHG emissions.

POTENTIAL IMPACT

Replacing soya or fishmeal are the main reasons for interest in novel proteins. For soya, this is because of awareness of the impact of LUC caused by deforestation on emissions. For fishmeal, it is due to use of fish that could be used for human food and to reduce the risk of overfishing. There are schemes to certify that soya is produced without recent LUC.

Several novel feeds have been considered to replace conventional protein sources and reduce GHG emissions within livestock systems. Some are novel to the UK but familiar in other areas of the world (e.g., insects as feed). The impact of any novel intervention in a UK market relies on:

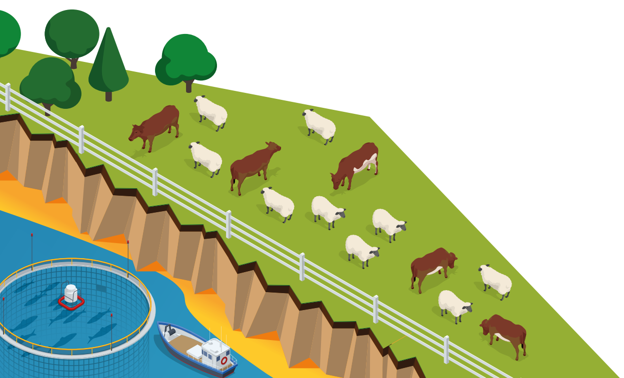
1. Technology readiness
2. Legislation that would enable the technology to be marketable
3. Commodification (ability for funding to lead to product as well as market confidence)

The following tables explore these three factors to support an assessment of readiness. However, it is recognised that a range of factors can influence viability of novel interventions[5].

Please note: These tables are not exhaustive, and inclusion does not indicate any endorsement by CIEL.

Table 2: Algal protein

Novel feed	Examples of impact	Readiness level		
		Development Has the feed been developed?	**Legalisation** Has the feed been legalised?	**Commodification** Is there evidence of the feed being used as a commodity (widely used)?
Phytoplankton (low trophic species) e.g., Microalgae, macroalgae and duckweed[6]	• **Dairy**: 0.5% diet inclusion = 26.4% CH_4 reduction; 1% diet inclusion = 67.2% CH_4 reduction but had negative impact on milk yield & feed intake[7] • **Poultry**: Positive impact on production[8] • **Aquaculture**: Can improve protein and omega-3 in product[2] 1 tonne algae-based oil saves ~ 30 tonnes of oil from wild fish	• Development continues	• **UK**: Yes, with approval. Harmonised with EU legislation at time of UK withdrawal from EU • **EU**: Yes[9]	• Suitable for ruminants and monogastrics • Viable for commercialisation as taste has been found to be comparable to other protein types[10] • Challenging as there is not likely to be enough algae in current production cycles to sustain at large scale[11]



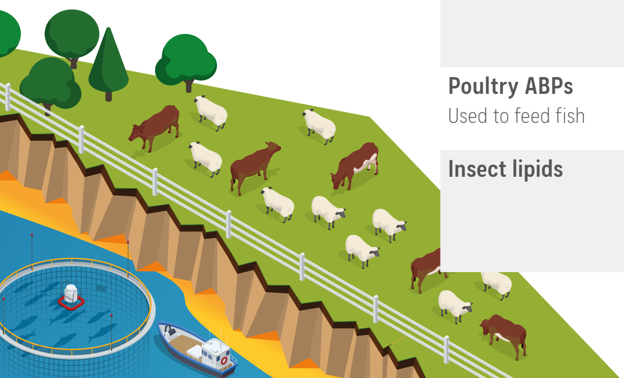


Table 3: Animal-derived protein feeds and animal by-products (ABPs)

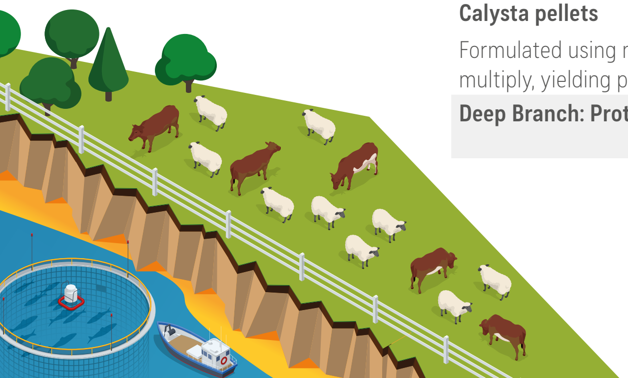
Recent changes in UK legislation make this more viable at a larger scale.

Novel feed	Examples of impact	Readiness level		
		Development Has the feed been developed?	**Legalisation** Has the feed been legalised?	**Commodification** Is there evidence of the feed being used as a commodity (widely used)?
Live insects e.g., black soldier fly (BSF), housefly, mealworm[12,13]	• 2.1 $kgCO_2$-eq to produce 1 kg of protein compared with 1.7 $kgCO_2$-eq for soya bean meal[14] due to high energy needed to produce insects • Feeding whole insects on food waste offers a greater GHG reduction potential (22 – 67%) due to energy savings[15]	• For Atlantic salmon, trials have replaced fish meal and production has not been impeded[2]	• **UK**: Yes • **EU**: Yes	• Aquaculture[12,13] • Pig • Poultry • The potential for insect-based diets depends on the necessary resources being available to harvest insects in respective countries[15]
Pig and poultry protein Processed Animal Protein (PAP)	• Inclusion typically 5 – 10% of diet • PAP at a 5% inclusion rate could reduce soya by 20% in a typical broiler diet or by 40% in a typical mid-lay ration • Smaller carbon footprint than soya	• Development established • Research and development continues	• **UK**: Not currently legal • **EU**: Legal for poultry protein fed to pigs and pig protein fed to poultry since 2021	• Not legal in the UK, preventing establishment of commercial sector
Insect meal Processed Animal Protein (PAP)	• A slight reduction of 0.14 $kgCO_2$-eq (kg protein) less compared with soya bean[16] • Emissions not reduced significantly on a kg basis but at scale this could help sector to reduce emissions	• Development continues	• **UK**: Only legal for aquaculture[17,18] • **EU**: Legal for pigs, poultry and aquaculture since 2021[13,17]	• Insect meal could reduce soya imports by one fifth if scaled up and used more commercially[17] • Only commercialised for UK aquaculture at present
Processed zooplankton (Low trophic) feed derived from *Calanus finmarchicus*[19,20]	• *Calanus finmarchicus* is combined with algal oil[19] • Diets fed a higher content of *Calanas finmarchicus* have increased N and energy retention efficiencies[20]	• Development continues	• **UK** and **EU**: Yes	• Commodification for use in aquaculture (salmon) in Norway • Most abundant zooplankton[21] • Climate change may impact the lifecycle of *Calanus finmarchicus*[22]
Biofloc meal[23] Recycles fish waste as food	• Likely to be able to contribute to GHG reductions in aquaculture[23] but more applicable for warm water species[24]	• Development continues	• **UK** and **EU**: Legislation feasbility being explored[24]	• Within aquaculture sector, not seen as commercially viable at present, and where possible more suited to warm water species[25]
Animal-based food waste	• Can create protein for livestock feed meaning that there is a reduced carbon footprint[2] • Can supply omega-3 to livestock[2]	• Development continues	• **UK** and **EU**: No	• Requires facilities to ensure that this remains commercaily viable
Poultry ABPs Used to feed fish		• Development continues	• **UK**: Legal[26] • **EU**: Legal[26]	• Limited uptake in the **UK**[21]
Insect lipids	• Insect lipids are not crude protein source for diets but are an alternative lipid source • Can reduce emissions from production of conventional feed lipid sources	• Development continues	• **UK** and **EU**: Insect lipids are legalised for use in aquaculture, pig, poultry and ruminant feed[17]	• Yes

Table 4: Single-cell protein

Single-cell proteins (SCPs) have received significant investment and a selection is listed here. Systems to produce these proteins need to be brought to scale for SCPs to be viable. If this can be achieved, SCPs look to be a promising replacement for conventional proteins.

Novel feed	Examples of impact	Readiness level		
		Development Has the feed been developed?	**Legalisation** Has the feed been legalised?	**Commodification** Is there evidence of the feed being used as a commodity (widely used)?
Yeast	· Yeast produced from trees and seaweeds[27] · Yeast can provide 50 – 60% more protein than soya on a per kg basis[27] · Reduces GHG emissions as it is likely to impede methanogens[28] · Contains amino acids unlike plant alternatives	· Development continues	· **UK** and **EU**: With application	· Cost effective feed[29] · As the sector develops this more as a direct human feed[29], this enables the technology to be present for animal feed too · Useful for both the livestock and aquaculture sectors
SCP using CH_4 Using CH_4 as a by-product	· It is possible that by 2050 CH_4 can be used to produce this protein, reducing emissions by ~7%[30] · Conventional protein estimated to produce 5,819 kgCO_2-eq per tonne of protein. CH_4 single-cell reduces this to 2,274 kgCO_2-eq per tonne[2]	· Development continues	· **UK** and **EU**: With application	· Easy to implement[30] · Costs are competitive[30] · Uses CH_4 which is a by-product · Useful for both the livestock and aquaculture sectors · Requires facilities to produce the SCP
SCP using CO_2 CO_2 sourced as by-product	· Single-cell product equivalent to fishmeal but has a 25% lower carbon footprint[2]	· Development continues	· **UK** and **EU**: With application	· Uses CO_2 which is a by-product · Useful for both the livestock and aquaculture sectors
Examples of commercially-registered products				
Uniprotein **Unibio International**[31]	· Could replace 10 – 19% of conventional crop-based animal feed protein by 2050, reducing global crop land area by ~6% & emissions by ~7%[31]	· Development continues	· **UK** and **EU**: Yes	· Yes. Substitution for fishmeal and soya bean meal[31]
Calysta pellets Formulated using methanotrophs that use CH_4 to multiply, yielding protein-rich biomass[32]	· FeedKind if produced by biogas is claimed to be "comparable or better to other feed sources"[33]	· Development continues	· **UK** and **EU**: Yes[34]	· Has recently been commercialised-investing in commercial plants[32]
Deep Branch: Proton™[35]	· Commercial Claim: Carbon footprint is up to 90% lower than conventional feed[35]	· Development continues	· **UK** and **EU**: No	· Commercialisation and scaling up underway



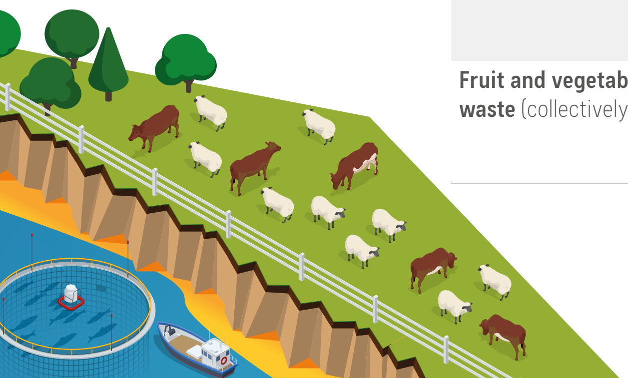


Table 5: Plant derived feeds Alternative feeds that could help to reduce GHG emissions when included in livestock diets.

Novel feed	Examples of impact	Readiness level		
		Development Has the feed been developed?	**Legalisation** Has the feed been legalised?	**Commodification** Is there evidence of the feed being used as a commodity (widely used)?
Alternative crop-based products e.g., lupin meal[36]	• Higher amino acid content than soya bean meal • 27% inclusion in lamb finisher diets, saved 19% in costs (Lupins in UK Agriculture and Aquaculture project (LUKAA)	• Processing of lupins is being explored after a hiatus • LUKAA Project has been pertinent • Development continues	• **UK** and **EU**: Yes	• Commercial products e.g Lupin meal with Synergen™ has enabled the feed to be used for aquaculture[37] • Explored for agriculture
Leaf protein concentrate[16,38]	• Reduction of 2.44 kgCO_2-eq; per kg of feed product compared with soya bean meal[16]	• Development continues	• **UK** and **EU**: Yes	• Ruminants • Monogastrics
Plant protein hydrolysate Formed by breaking plant proteins into amino acids	• Peptide and amino acid based • Improves digestibility of feed which can reduce emissions	• Development continues[39]	• **UK** and **EU**: ongoing	• Limited facilities to hydrolysate products • Suitable for pigs, chicken and aquaculture

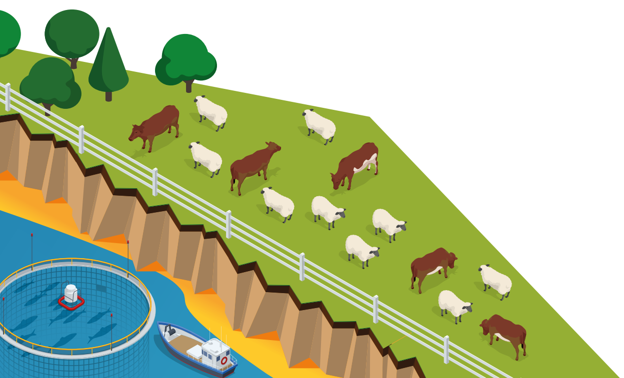
Table 6: Plant by-products Infrastructure and energy needed to be viable is a challenge.

Novel feed	Examples of impact	Readiness level		
		Development Has the feed been developed?	**Legalisation** Has the feed been legalised?	**Commodification** Is there evidence of the feed being used as a commodity (widely used)?
Grape pomace[40]	• Reduce dairy cattle CH_4 • Some studies found it reduced milk production[41] • Grape skins, seeds and stems show potential. Reduce CH_4 emissions from dairy cattle (up 15% reduction), but at expense of 10% reduction in milk production, due to reduced metabolisable energy intake[41]	• Development continues	• **UK** and **EU**: Yes	• Limited
Olive pomace[42]	• Likely to reduce GHG emissions[43]	• Development continues	• **UK** and **EU**: Yes	• Challenges in commodification due to safety, digestibility and palatability by livestock[42]
Fruit and vegetable waste (collectively)[44,45,46]	• Re-using waste so reduces emissions from producing the plant-based material • Effectiveness depends on the energy intensiveness of facilities	• Development continues	• **UK** and **EU**: Yes	• Energy intensive process to process waste may make this unviable as a commodity or as a way to reduce emissions

Table 7: Gene-edited and transgenic plants

For example, to fix N, improve digestibility, or cope with climate change. Legislation approved in UK, but regulations require care in application.

Novel feed	Examples of impact	Readiness level		
		Development Has the feed been developed?	**Legalisation** Has the feed been legalised?	**Commodification** Is there evidence of the feed being used as a commodity (widely used)?
Genetically improved legume crops (peas, beans and lupins) **Cereals, Oilseed crops**[47,48]	• Use of transgenics/gene-edited plants and specifically development of N fixing crops (peas, beans and lupins) can support reducing emissions in production • Lupins also provide high protein feed • Whole narrow-leafed lupin seeds = 32% protein[49] • Lupin Kernal = 40% protein[49]	• Development of peas continues for monogastric diets (PeaGen project) • Other crops in development	• **UK**: Some restrictions but gene editing legislation passed in 2023 makes this feasible (England)[50] • **EU**: Some restrictions	• Development being explored in the UK following UK withdrawal from the EU
Rapeseed	• Protein rich residue from rapeseed is high in protein and can be fed to animals • Would reduce need for transport of soya products and so reduce livestock emissions	• Development continues	• **UK**: Gene editing legislation passed in 2023 makes this feasible (England)[50]	• Commodification to be explored following legislation changes
Cereals	• Generally has a low crude protein but gene editing could improve digestibility	• Development continues	• **UK**: Gene editing legislation passed in 2023 makes this feasible (England)[50]	• Commodification to be explored following legislation changes
Gene editing to increase plant lipids	• Increase in lipids in plants that are fed to livestock provides an opportunity to reduce enteric CH_4[51]	• Development continues	• **UK**: Gene editing legislation passed in 2023 makes this feasible (England)[50]	• Not yet



AMBITION

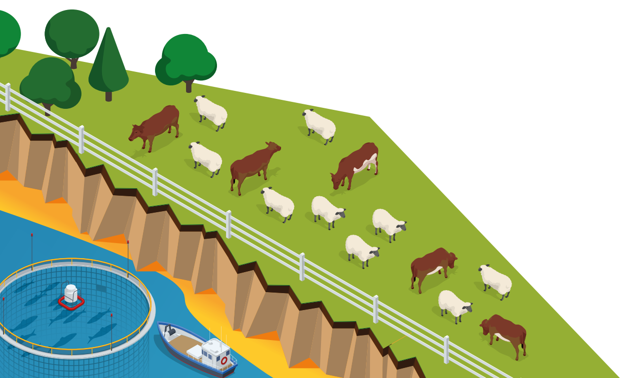
Feed and food production systems are complex. To reduce emissions from livestock we must minimise the carbon footprint of feed protein components by avoiding those produced after LUC, by minimising carbon costs (largely energy) for processing, manufacturing, transport and storage, and by exploiting opportunities to use waste from other processes or systems.

Novel protein feeds have significant potential to mitigate GHG emission intensities associated with livestock products by decreasing emissions associated with feed production or enteric fermentation. Lifecycle assessments (LCA) will be fundamental to assessing whether net emissions are reduced. We must also monitor other aspects of livestock production, health and welfare to avoid unintended consequences.

This is an area of increasing private interest and investment, with a growing number of patents registered for novel proteins (such as SCPs)[51]. Legislation must keep pace with such innovation to avoid becoming a barrier and negatively impacting investor confidence[52].

GAPS TO ADDRESS

- LCAs are needed to assess the net change in emissions for novel protein sources introduced at sector scale
- Both technical and economic viability at scale need to be proven to support private interests in novel protein feeds
- Effects of novel proteins on feed palatability and possible negative effects on health or welfare for livestock
- Lack of information on possible impacts on nutritional value of food products produced from livestock-fed novel proteins
- Appropriate legislation frameworks that foster innovation at pace in order to deliver UK 2050 emission targets



4.2 Nutrition
Methane Inhibitors In Feed

HOW IT WORKS

Overview

Enteric methane (CH_4) is produced by ruminants during digestion of feed in the rumen. This process involves a large and complex population of microbes producing hydrogen (H_2) and carbon dioxide (CO_2), with methanogenic microbes using these compounds to synthesise CH_4 which is released mainly from the animal's nose or mouth. There are various points during this process that can be targeted by CH_4 inhibitors to reduce the amount of CH_4 produced.

Depending on the inhibitor, mean reductions in CH_4 yield (gCH_4 per kg feed dry matter consumed) of 12 – 37% have been reported in meta-analyses. Actual reductions depend on specific farming conditions (e.g., species and diet type) and can range from 0 to >90%.

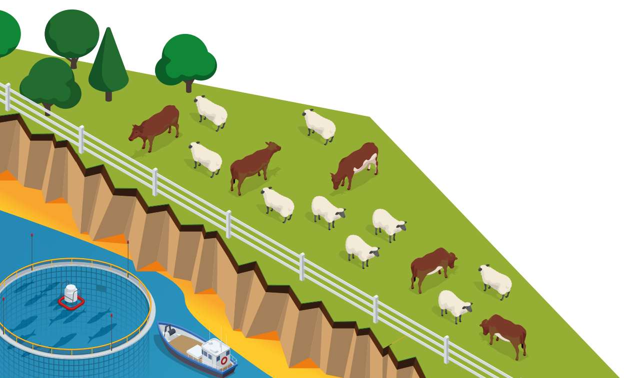
POTENTIAL IMPACT

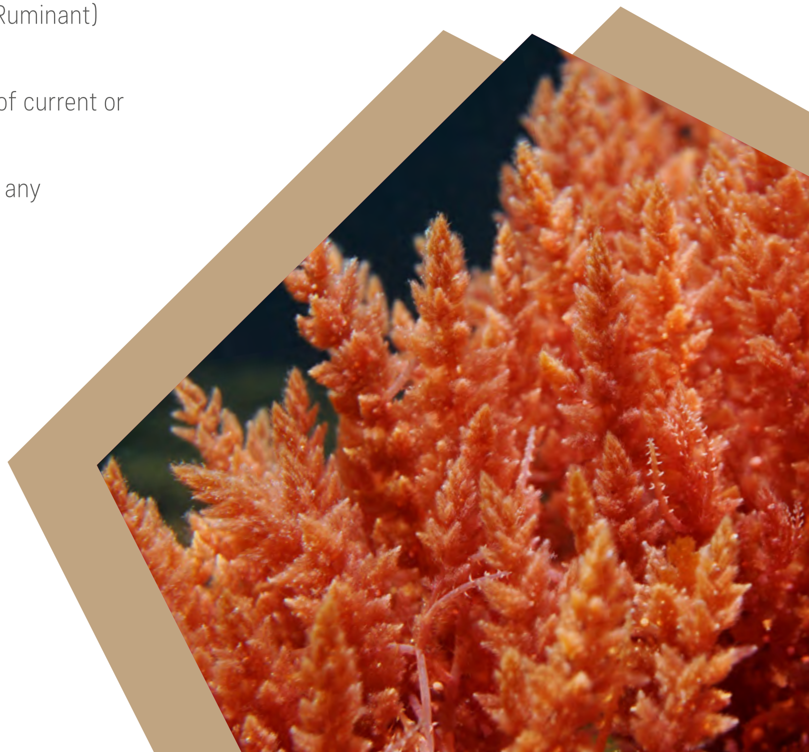
Focusing on near-to or on-the-market CH_4 inhibiting products, the modes of action of the CH_4 inhibitors considered here are:

- **Suppressing methane production** by manipulating activity or population size of methanogenic microbes (Products: Bovaer 10, Asparagopsis, Mootral Ruminant)
- **Mopping up H_2** by promoting chemical processes other than CH_4 production e.g., production of ammonia (NH_3) (Product: SilvAir) leaving less H_2 available for CH_4 production
- **Changing the activity or population size of microbes** involved in fermentation resulting in less H_2 production (Product: Agolin Ruminant)

Please refer to Table 8 for an overview of current or in-development CH_4 inhibitors.

Please note: Inclusion does not indicate any endorsement by CIEL.





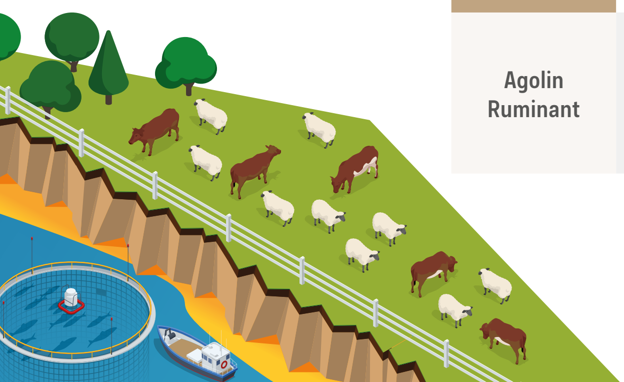


Table 8: Methane inhibitors

Product	Overview and potential impact
Bovaer 10	The active ingredient in Bovaer 10 is a synthetic compound (3-nitrooxypropanol or "3-NOP"). There is a broad evidence base for the efficacy of 3-NOP. A recent meta-analysis[53] showed a ~30% reduction in CH_4 yield in dairy cattle. Bovaer 10, developed by DSM, is authorised as a Zootechnical Feed Additive (a feed additive that favourably affects animal performance or the environment) for lactating ruminants in the EU and Northern Ireland, and DSM have applied to the Food Standards Agency (FSA) for the same authorisation in Great Britain. A new manufacturing line for Bovaer is being constructed in Scotland to increase production capacity.
Asparagopsis	There is some evidence to demonstrate the CH_4 reduction potential of *Asparagopsis*, a red seaweed, in live animals. A recent meta-analysis[54] (based on three studies), showed a reduction in CH_4 yield of ~37% (ranging from a 4% increase to a 97% reduction). *Asparagopsis*, as an enteric CH_4 inhibitor for ruminants, is patented by CSIRO and James Cook University, Australia and is licenced by FutureFeed Pty Ltd. Seaweed is a feed material and so can be administered with no additional approvals, but *Asparagopsis* may be regulated as a feed additive in the future. There is currently no supply chain to the UK agricultural market. There may be potential to grow *Asparagopsis* in tanks under controlled conditions (some work has recently started in this area) which would ensure a constant and consistent supply. However, agriculture may face competition for *Asparagopsis* from markets potentially willing to pay more (e.g., nutraceuticals and cosmetics).
Mootral Ruminant	Developed by Mootral, this natural feed supplement is presented in a pelleted form which can be administered with no additional approvals as garlic (fresh) is a feed material and citrus oil is a sensory feed additive. Availability is currently limited to a small number of dairy farms participating in carbon credit projects in the UK and USA. There are relatively few live animal studies (five), with results ranging from an increase in CH_4 yield of 12.8% to a reduction of 24.6%. No formal meta-analysis has been published.
SilvAir	The active ingredient in SilvAir, a new feed product from Cargill, is calcium nitrate ($Ca(NO_3)_2$). There is a broad evidence base for the efficacy of nitrate (NO_3) on enteric CH_4 emissions. A recent meta-analysis[55] found an 11.4% reduction in CH_4 yield. $Ca(NO_3)_2$ double salt (the specific form of NO_3 in SilvAir) is considered a feed material, having nutritional benefits (calcium and non-protein nitrogen), and so can be administered without further approvals. Cargill claim a modest 10% CH_4 reduction at 1% inclusion of SilvAir, a dosage level chosen to ensure that NO_3 toxicity does not occur in any animal, particularly those with high intake levels. The branded product is currently only available in the Netherlands and Belgium through specific feed compounders.
Agolin Ruminant	A combination of essential oils, Agolin Ruminant, is commercially available as a blend of authorised sensory feed additives. There is limited evidence to demonstrate its CH_4 reduction potential. A meta-analysis of the three published live animal studies[56] (all in dairy cows) found a reduction in CH_4 yield of 12.9%. Milk yield may be slightly increased (3.6%) after sustained supplementation (>4 weeks).

GAPS TO ADDRESS

The CH_4 inhibiting feed supplements discussed are at various stages of market readiness. There are common knowledge gaps across CH_4 inhibitors, and others that are product specific.

General gaps: There is a lack of publicly available lifecycle analyses (LCAs) assessing the net impact of CH_4 inhibitors, including crop growth (for plant-based inhibitors), manufacture, distribution, and down-stream effects on greenhouse gas (GHG) emissions from wastes (manures) and soils (e.g., after deposition of dung/urine or spreading of slurry/manure). No CH_4 inhibitor is currently available in a form which ensures consistent supply of an effective and safe dosage to grazing animals.

Table 9 below highlights the gaps to address for the CH_4 inhibitors featured.

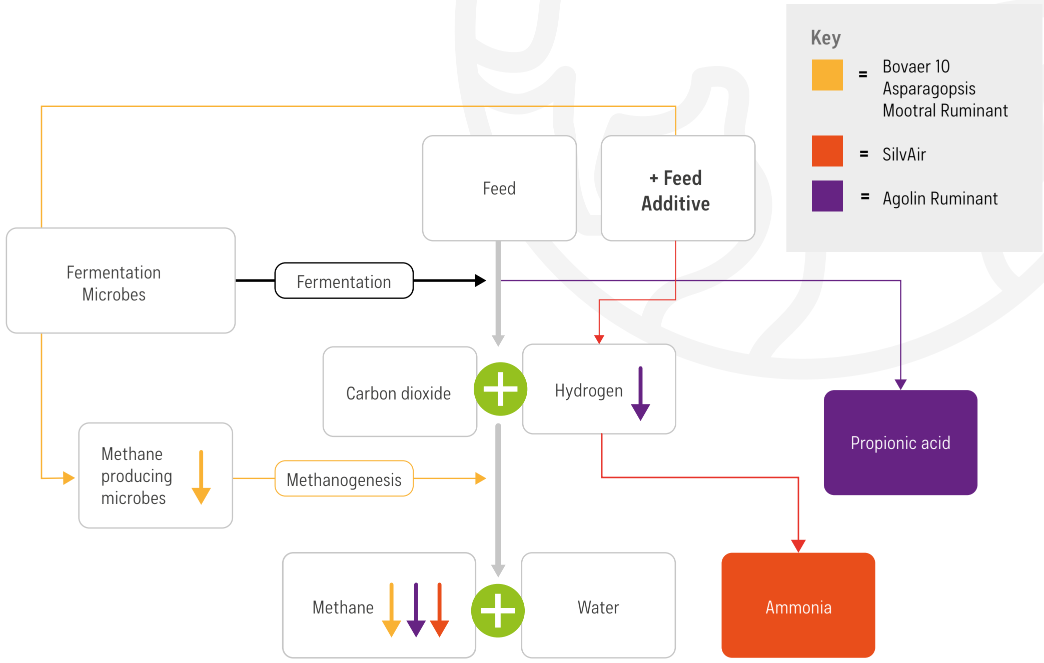
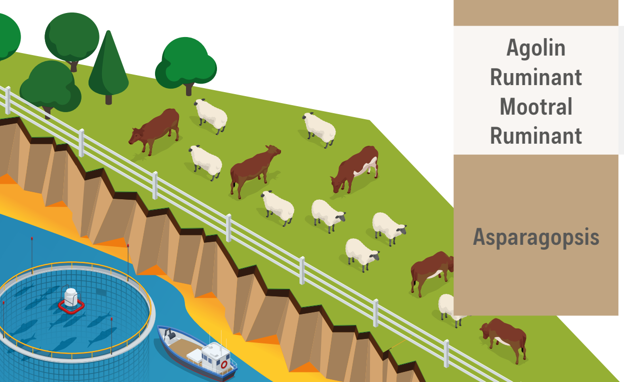
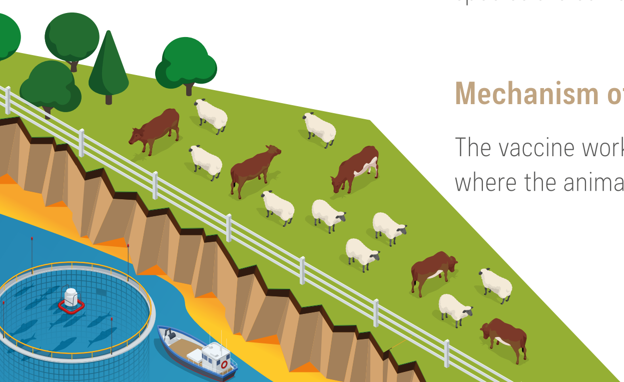


Figure 5 Schematic of normal rumen fermentation and how this is manipulated by the feed supplements discussed. Different colours = different modes of action

Table 9: Identified gaps to address for each product

Product	Gaps to address
Bovaer 10	There is uncertainty around the impact of Bovaer on nitrous oxide (N_2O) emissions.
SilvAir	Guidance on the adaptation of animals to NO_3 supplementation to avoid NO_3 toxicity. There is a risk that N_2O emissions will increase if the NO_3 in SilvAir is not accounted for in the diet formulation (i.e., providing excess rumen-available nitrogen).
Agolin Ruminant Mootral Ruminant	More evidence to demonstrate the CH_4 mitigation potential and impact on production in live animals is required, particularly longer-term studies to address the potential for rumen microbes to adapt to the product.
Asparagopsis	More evidence in live animals (including long-term studies) is required to understand the wide range of CH_4 reductions observed and possible side effects on productivity. Concerns around animal and human health relating to concentrations of bromoform (the active ingredient causing CH_4 reduction) must be addressed. When cultivated in the marine environment, seaweed can absorb heavy metals and trace elements (e.g., iodine, lead, copper) and these have the potential to be toxic for some livestock types. Methods of producing this seaweed that is safe to consume in quantities that produce significant reductions in enteric CH_4 need to be developed and validated.





4.2 Nutrition Methane Vaccines

HOW IT WORKS

Overview

Methane (CH_4) has a 100-year global warming potential (GWP) 28 – 34 times that of carbon dioxide (CO_2). Ruminants (predominantly cattle, sheep and goats) emit most of global livestock's CH_4[57]. They lose up to 12% of gross energy in what they eat as CH_4 due to fermentation of feed in the rumen[58].

Microbes naturally present in the forestomach digest plant fibre, something the ruminant as a mammal cannot do itself. The rumen is the largest part of a ruminant's forestomach. Methanogens (part of the Archaea domain) are one type of microbe which produce CH_4 as a by-product of fibre digestion. Methanogen species are diverse and past research exploring this diversity has been critical for development of vaccines to selectively reduce methanogens among rumen microbes. Crucially, the same methanogens exist in ruminants across the world[59]. Two methanogen species groups, clustered around the species *Methanobrevibacter gottschalkii* and *M. ruminantium*, account for ~ 70% of archaea in ruminants and produce most of the CH_4. These two species are current targets of vaccines.

Mechanism of a methane vaccine

The vaccine works by inducing an immune response where the animal produces antibodies in saliva. Saliva travels to the forestomach carrying these antibodies to the targeted methanogens[57,60]. For greater impact, future vaccines may be designed to target more than just these two rumen methanogen species. New vaccines could be delivered as part of routine animal vaccination programmes, limiting the need for additional labour[61,62]. Vaccines are used routinely in farm livestock and so should pose no risk to consumer safety, following existing regulation processes[61].

Vaccine development

Regular vaccine development is neither straightforward nor quick. Development stages include basic and translational research stages, followed by product development, registration, commercial production and marketing. The timeline can be several years before a commercial product is ready for registration and approval, depending largely on both technical hurdles and commercial viability. Funding to support all these stages is critical to successfully producing a vaccine with long-term benefits.

Hundreds of potential antigen components have been researched, but not yet formulated as possible vaccines[62,63,66,67]. Even when technical potential is identified, impact in a farm setting and cost-effectiveness are critical. It is expected that commercial vaccines require a decade of development after a suitable target antigen is identified.

POTENTIAL IMPACT

Vaccines to reduce CH_4 emissions are under development but remain several years away from commercial release, at earliest.

Early research in Australia in the early 2000s did not use a specific antigen approach in vaccine development and found equivocal results in terms of CH_4 reduction[63,64]. However, new methods for developing vaccines must be considered as past research using older techniques may not be a good guide to what can be achieved. Recent research in New Zealand has used vaccines that generate specific antibodies, but the impact of this on CH_4 emissions remains to be quantified. These researchers have an aspirational goal to reduce CH_4 by 30% with the vaccine targeting a range of methanogens.

While there are risks that vaccination may not deliver significant reductions in CH_4, a successful vaccine could deliver huge reductions. It could be a simple approach where a low frequency vaccination schedule or even just one treatment could reduce CH_4 production for long periods. Given modern developments in vaccine production, costs for vaccines need not be high where they are produced at scale for farmed ruminants. Given the ambition for CH_4 reductions, some would argue we must pursue high risk, high return options like this.

	Total CH_4 ($MtCO_2$-eq)*	Potential 30 % CH_4 reduction ($MtCO_2$-eq)
Dairy cattle	6.4	1.9
Beef cattle	11.6	3.5
Sheep	4.7	1.4
Total	**22.7**	**6.8**

* UK inventory data from IPCC AR5 Fifth Assessment Report 5th Edition[65]

Table 10: Illustrative example of impact for a vaccine that reduces CH_4 emissions of UK livestock by 30% [emissions data from 2020 UK inventory][65]

Using a 30% reduction of enteric CH_4 emissions as a best-case scenario, a ruminant CH_4 vaccine applied in the UK would have the potential to reduce annual CH_4 emissions by 6.8 $MtCO_2$-eq based on figures from 2020 (Table 10). Given the enormous contribution of ruminant CH_4 to UK livestock emissions, this would be a massive contribution to the 64% reduction goal for UK agriculture by 2050.

AMBITION

New Zealand research is targeting a 30% reduction of CH_4 in ruminants for a commercial product[62]. While there is medium-high confidence a commercial product can be available by 2050, there is low-confidence this is possible by 2030[66]. There are also likely to be delays in implementation for a product developed overseas in order to register it for the UK market. So, it is highly unlikely a vaccine will be available to the UK livestock sector that could deliver a 30% reduction in CH_4 emissions by 2030 in line with the 'Global Methane Pledge'[68]. Such timelines should inform how regulations are applied to minimise delays and fast-track commercial products into industry.

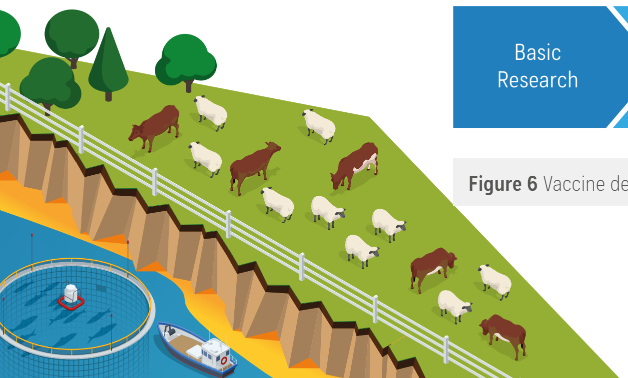
There is considerable interest from global animal health companies in methanogen targeting vaccines, but much is shrouded in confidentiality due to commercial competition. In December 2022, ArkeaBio announced that it had received investment in the USA to develop a vaccine to reduce on-farm emissions[69]. At present, it is unclear how this approach differs from work conducted in New Zealand.

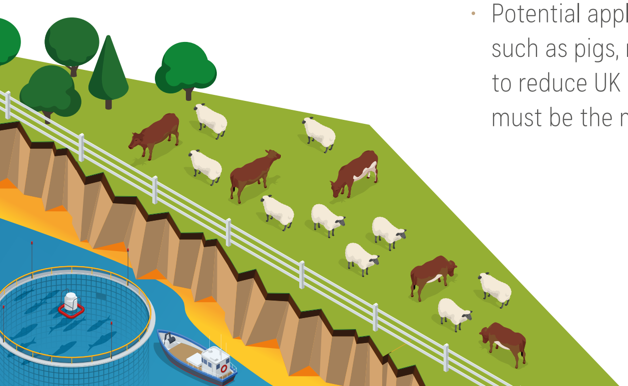
Both vaccine development and our understanding of methanogens are rapidly evolving areas of science and innovation, making it difficult to estimate CH_4 mitigation potential of vaccines[63] or when they may become available.

Costs of vaccines will only be known once developed to the commercial product stage. However, the speed at which science and industry developed vaccines to address the global Covid-19 pandemic suggest sufficient funding, competition and appropriate application of regulations can deliver much faster results at a lower cost, with government support.

Pigs emit less enteric CH_4 than ruminants, but this could also be targeted by vaccines. Pig production is increasing globally, so CH_4 mitigation could help reduce such emissions. Research and development of a ruminant vaccine could support opportunities for similar approaches for pigs. However, this area is much less well researched to date. Since ruminants make by far the largest contribution to UK livestock greenhouse gas (GHG) emissions, research should focus on cattle, using sheep as an efficient research model due to their smaller size.

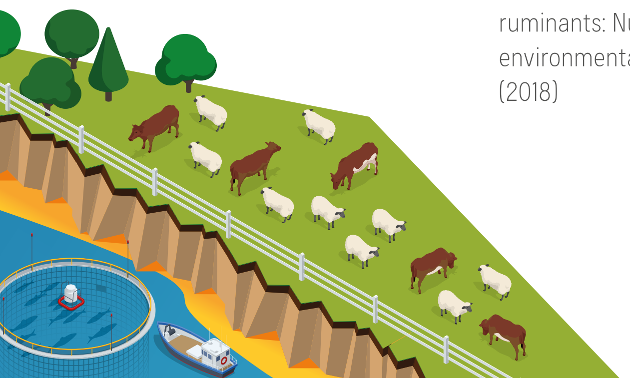
Figure 6 Vaccine development stages





GAPS TO ADDRESS

- CH_4 reductions obtained in laboratory conditions need to be demonstrated in farm trials at commercial scale to assess viability[63]
- Many microbial mechanisms in the rumen are not fully understood. Interactions between the various protozoa, fungi and methanogens present may reduce impact of vaccines targeting specific methanogens, or vaccines may have off-target effects
- Animals vary in the rate of production of saliva[66]. Impact of this on vaccine effectiveness (measured as CH_4 reductions) must be assessed for different animal types and feeds
- Inhibiting methanogens could lead to detrimental effects such as reducing digestive efficiency. Early research suggests this is not the case, but further studies are needed across more animal and feed types
- Globally, published research is largely from New Zealand and focused on sheep. Due to the same methanogens being found in all ruminants worldwide, a similar impact in cattle may be assumed. However, impact must be proven and quantified for UK conditions
- Potential application for monogastric species, such as pigs, remains to be investigated. However, to reduce UK GHG emissions quickly, ruminants must be the main focus for vaccine research
- Commercial cost of a CH_4 vaccine is unknown and could be a barrier to adoption. Public money may be needed to offset development costs
- UK capability is limited due to expertise gaps and having no major research groups or appropriate facilities at scale. The New Zealand model for vaccine development could be replicated in the UK, ideally through international collaboration e.g., through the Global Research Alliance[70]
- Development of "low CH_4 vaccines" must be undertaken with a full awareness of policy and regulation requirements to ensure changes needed in those do not delay introduction of such vaccines to industry



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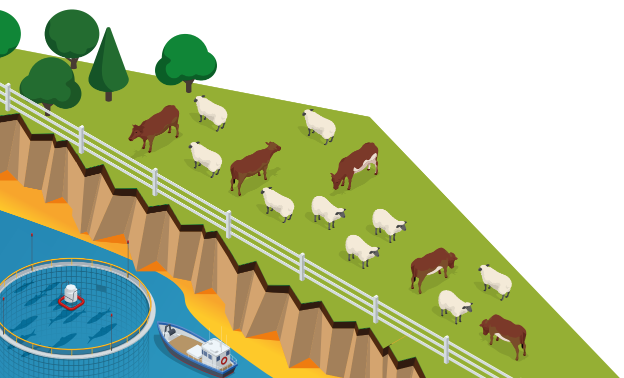

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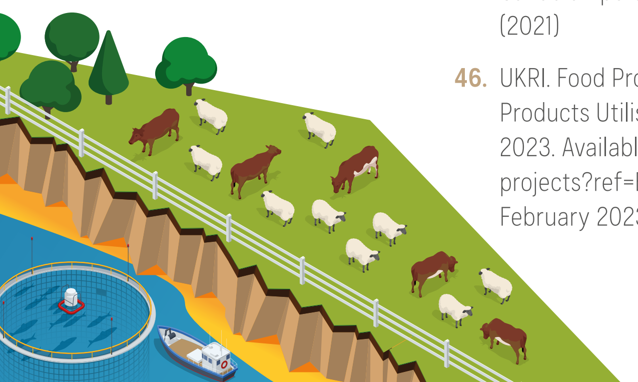

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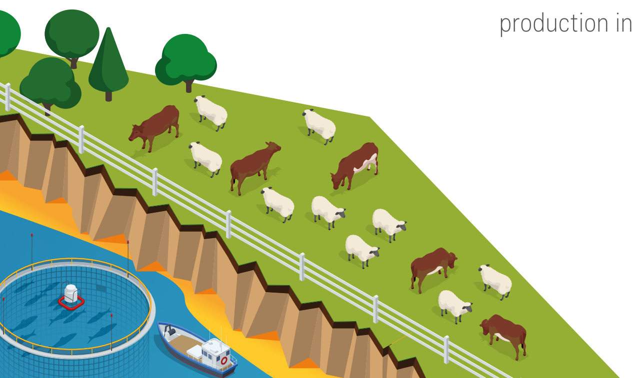

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4.3 Waste
Improving Manure Management

HOW IT WORKS

Overview

Manure management, comprising both solid form and liquid slurry, is accountable for 10% of total greenhouse gas (GHG) emissions from global livestock production systems; specifically methane (CH_4) and nitrous oxide (N_2O)[1,2]. In the first instance, digestibility and composition of animal feed influences the composition and nutrient content of manure. Once manure is produced, its storage and application have significant roles to play in mitigating GHG emissions.

Improving manure management can ensure that nutrients, particularly nitrogen (N), are retained and repurposed to reduce emissions while also improving soil health, preventing water pollution and reducing need for synthetic fertilisers. Achieving the latter would decrease indirect GHG emissions as well, i.e., from production and transportation of synthetic fertiliser, while reducing that input cost to farmers.

Manure storage

Manure management typically relies on storing manure until needed to minimise over application of nutrients to land. However, manure storage, if not appropriately managed, can itself result in considerable CH_4 and N_2O emissions.

Storage is therefore an area of high priority to address to help mitigate agricultural GHG emissions. It must be noted that identifying practices which can reduce both CH_4 and N_2O emissions simultaneously is both a great challenge[3,4] and an opportunity for major emission reductions.

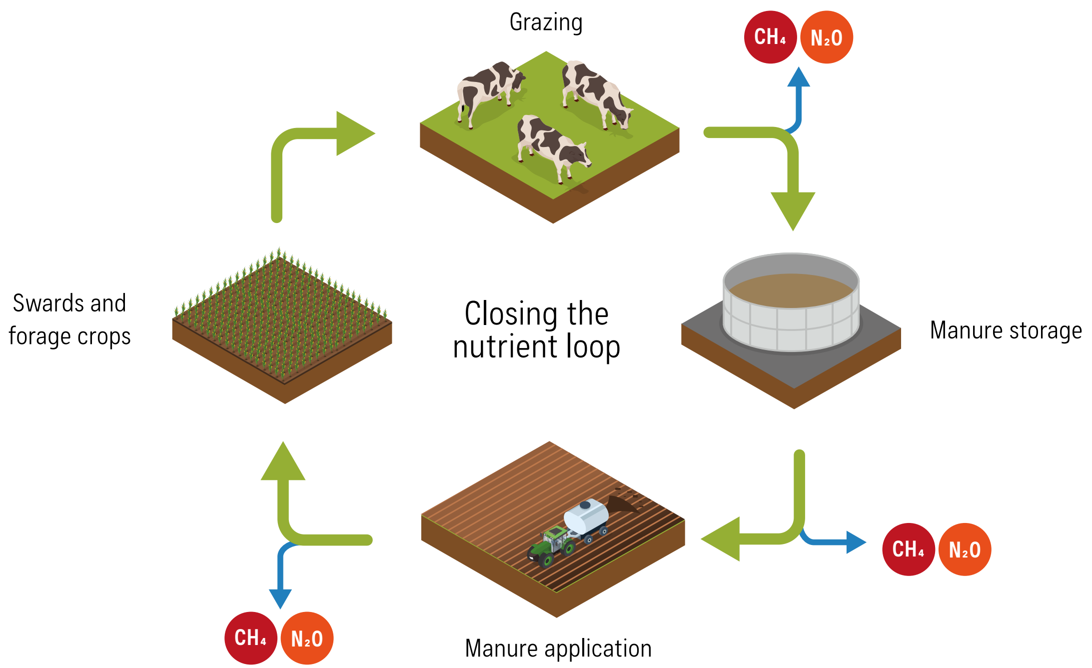
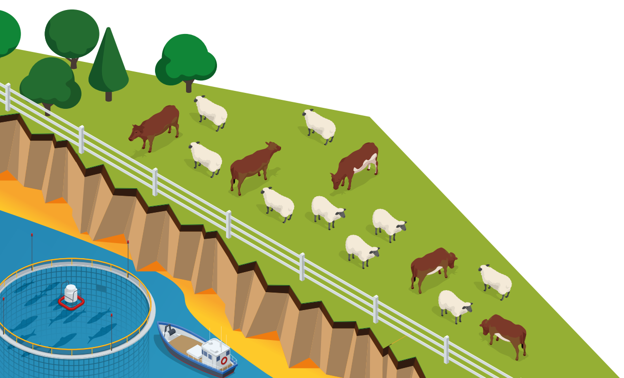
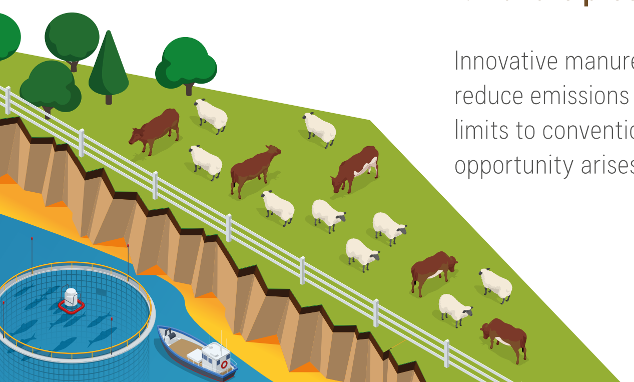


Figure 7 How manure management can help close the nutrient loop and reduce GHG emissions by addressing nutrient losses





POTENTIAL IMPACT

Traditional approaches

Maximising adoption of known strategies to mitigate manure emissions should be first priority. GHG emissions, particularly CH_4, can be reduced by changing how manure is stored; e.g., by adapting storage temperature to alter microbial activity. Covering slurry and manure stores, using manure separation techniques, and shortening the time that manure is stored have all been shown to be beneficial.

In terms of manure application, low emission techniques exist, such as soil injection, trailing shoes or hoses, targeting N_2O emissions. Also, nitrification inhibitors added to manures and the timing of manure and/or slurry application have been shown to decrease GHG emissions[4,5]. In addition, improved planning and integration of arable and livestock production systems offers an opportunity to enhance manure resource use efficiency and lower GHG emissions further[4].

Novel approaches

1. Manure processing

Innovative manure management approaches to reduce emissions are required as there are technical limits to conventional techniques. One such opportunity arises from improved manure processing to support either biogas or enhanced fertiliser production. Manure processing can help reduce GHG emissions both from stored farm manure as well as from manure application.

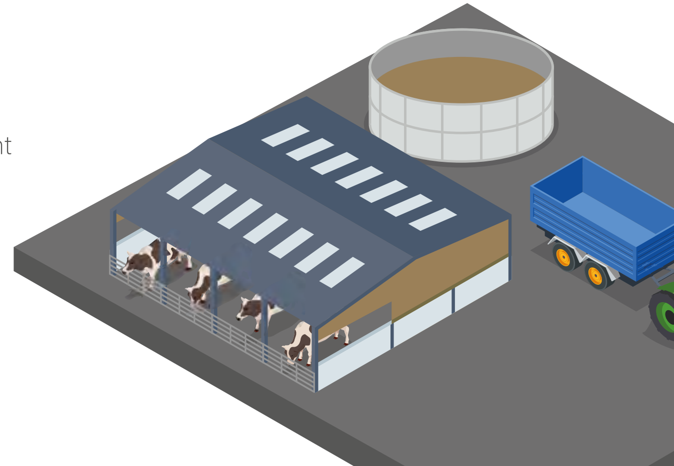
A plasma technology application developed by N2 Applied (Norway) treats livestock slurry to produce an enriched fertiliser[6]. Ammonia (NH_3) and CH_4 emissions from pig slurry storage are claimed to be reduced by 95% and 99% respectively with this treatment, with NH_3 captured as ammonium nitrate (NH_4NO_3), a powerful plant growth stimulant.

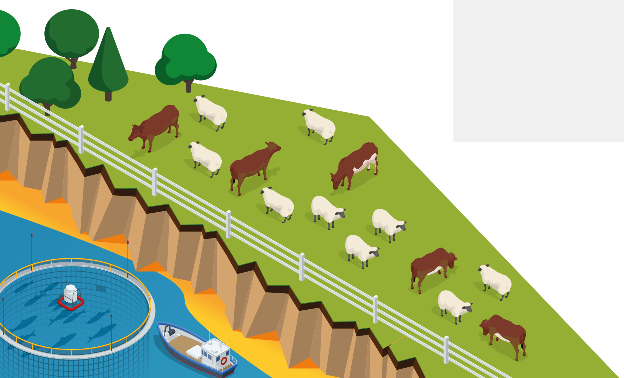
Another manure processing approach is anaerobic digestion (AD), already implemented on some UK farms[7]. Of current approaches available, AD provides the greatest GHG emission reductions[8]. However, innovative improvements of AD could reduce emissions further. For example, work is being undertaken to improve useful biogas yield and increase economic benefit[9]. This indirectly reduces emissions through use as an energy source that offsets fossil fuel use. Given the right economic and policy environment, farmer uptake of on-farm processing is likely to be high[10].

Innovation will come from establishing the best technical manure processing techniques and increasing these at scale as well as providing farm-scale, efficient systems such as the plasma treatment solution from N2 Applied.

Furthermore, there is interest in the integration of terrestrial livestock and aquaculture production systems to improve manure management. For instance, novel processes can reformulate fish waste, feed residue and faecal matter into a high protein powder that could be fed to livestock. At the same time, the process can capture biogas. This has become a commercially practical solution offered by companies such as Hyperthermics (Norway)[11] and Bakkafrost (Faroe Islands)[12]. Bakkafrost have taken the integration of production systems further, with fish waste and livestock manure combined in biogas facilities, lowering GHG emissions even more. The nutrient loop is closed: waste is returned to farm as organic fertiliser, while reducing need for imported fertilisers[13].

There are also wider opportunities for poultry manure management. One such example, StrongSoil™[14], involves poultry manure fed to black soldier fly larvae, reducing GHG emissions and eliminating pathogens. The resulting processed product can be applied to land and has been shown to help soil regeneration, increasing yields by 15% due to improved soil and microbial properties.





2. Manure additives

Research and development of manure additives is ongoing, for the purposes of reducing emissions of odours and gases and retaining or improving nutrient composition for application as fertiliser[15]. A selection of manure additives and their potential to reduce GHG emissions are listed in Table 11.

Table 11: Manure additives and technical feasibility to reduce emissions

Manure additives and processes	Technical reduction (%)
Reactive oxygen-based cocktail tested as a cattle slurry additive	Up to 90% reduction of total gaseous emissions from stored cattle slurry (including CH_4, CO_2, NH_3, and H_2S)[15]
Surface application of biochar to pig manure	Mixed results for GHG emissions and 19 – 39% reduction of NH_3 from stored pig manure (NH_3 can lead to subsequent N_2O emissions)[16]
Sulphuric acid treatment of dairy and pig slurry	Cumulative CH_4 emissions from stored dairy slurry reduced by 69 – 84%[17] Compared with untreated pig slurry, N_2O and NH_3 emissions decrease by 78.9% and 78.1% respectively[18]

3. Novel data approaches

Good manure management requires the application of manure to pasture or arable land at the right time and rate. Manure management plans are already used by the sector[19]. For best management practices, the nutrient composition of manure is a key factor. Currently, assessment of manure is mostly conducted by sending samples away for laboratory analysis; UK uptake has been estimated to be 23%[19]. However, enabling better knowledge of, and access to, data such as soil nutrient requirements and manure nutrient composition would further improve the effective and efficient application of manure to land[20]. Ideally, manure applied based on its N content and specific nutrient requirements of the soil and/or crop, ensures optimal N uptake and thus N_2O and CH_4 emissions would be reduced[21]. The scale of the mitigation potential of precision application of manure is not well understood and deserves more research.

Innovative data approaches that can help farm managers and policymakers understand nutrient management will be invaluable going forward. There needs to be appropriate assessment of manure volumes, nutrient contents, time in storage and storage system characteristics as these are the properties that can influence GHG production. Such data can be combined with modelling approaches to enable nutrients to be better monitored and associated GHG emissions mitigated further[5]. For instance, novel modelling approaches have been employed to help identify the optimal design of manure management for large-scale pig production systems[22].

AMBITION

Manure management innovations may improve technical capabilities and potential to decrease GHG emissions. However, they must be practical and cost-effective at farm-scale for their uptake and so that sector-wide mitigation contribution can be realised[3,23]. It is also important that there remains a focus on reducing GHG emissions from manure management collectively, taking into account potential interactions, trade-offs and unintended consequences.

GAPS TO ADDRESS

- New ways to increase uptake of existing technological solutions for reduced GHG emissions
- Understanding factors that influence farmer uptake of novel manure management strategies
- Investigation of good examples from other countries for closing the nutrient loop
- Need for a systems approach, extending scope of assessment beyond classic livestock production systems
- Development and testing of manure additives to better estimate potential GHG emission mitigation at scale
- Strategies to show the value data has in delivering improved manure management and GHG emission mitigation, including the value gained from sharing data

4.3 Waste
Plasma Treatment Of Slurry

HOW IT WORKS

Overview

Plasma treatment could address many of the challenges farmers are facing with the storage and spreading of slurry. This is achieved by upgrading farmyard slurries to high value nitrogen (N) fertilisers while greatly reducing ammonia (NH_3) and methane (CH_4) emissions. The technology can be used to treat slurries (i.e., cow or pig manures) and biogas digestates.

- 99% CH_4 emissions reduction from storage[24]
- 95% ammonia-N retention from storage and spreading[25]
- 27% reduction in $kgCO_2$-eq per litre of milk[24]

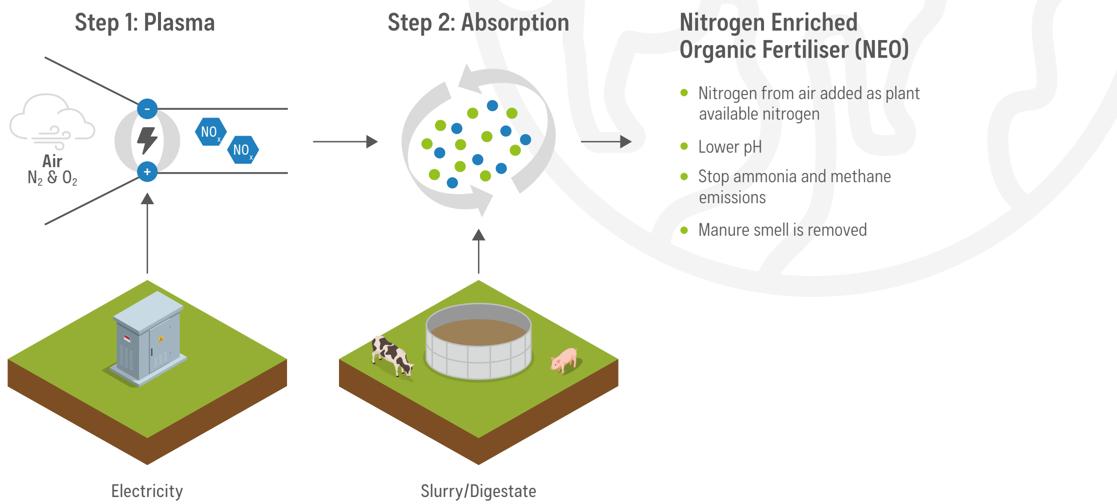


Figure 8 On-farm plasma treatment of livestock slurry to produce an enriched nitrogen fertiliser. The process uses N_2 and O_2 molecules to form NO_x that are the absorbed into the slurry while reducing CH_4 and NH_3 emissions

Process

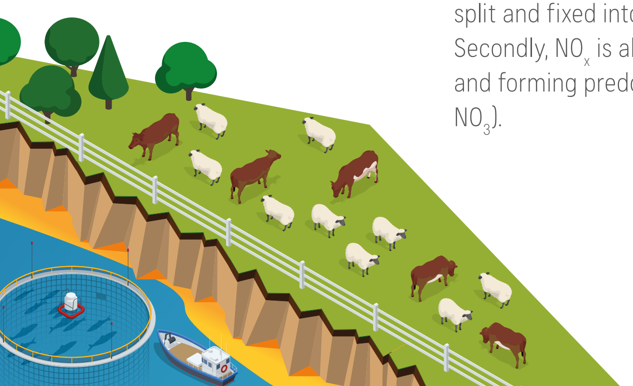
The technology comprises an on-farm plasma reactor contained in a standard shipping container that enables local production of fertiliser using only air, electricity, and the liquid slurry fraction. The treatment is a two-step process. Firstly, atmospheric nitrogen (N_2) and oxygen (O_2) molecules in the air are split and fixed into gaseous nitrogen oxides (NO_x). Secondly, NO_x is absorbed into the slurry, reducing pH and forming predominantly ammonium nitrates (NH_4NO_3).

Benefits

The plasma treatment process has several positive effects on slurry. It adds N as nitrate (NO_3), greatly increasing fertilising potential of slurry. Also, the process acidifies the slurry, locking in NH_3, further improving the fertiliser potential while simultaneously decreasing NH_3 emissions as an air pollutant.

Three main mechanisms are involved in the reduction of on-farm GHG emissions during plasma treatment:

1. CH_4-producing microbes in the slurry are destroyed due to unfavourable conditions, leading to a 99% reduction of CH_4 emissions from storage and spreading
2. By increasing the fertiliser value of slurry, less mineral fertiliser is needed on-farm, reducing emissions associated with production and transportation of that fertiliser
3. By stopping NH_3 emissions, secondary N_2O formation is reduced. Low NH_3 emissions will be a transformational change for many farms through increased air quality, addressing a major environmental impact outside GHG emissions



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POTENTIAL IMPACT

Plasma treatment of slurry has a substantial impact on its environmental and agricultural performance, rendering the technology a real tangible solution for achieving climate targets on a farm-by-farm basis.

Implementing plasma technology on a typical 200-head dairy herd is expected to reduce emissions by roughly 200 tCO_2-eq/year. This is 15 – 25% of CO_2-eq produced by the farm. Total emissions reduction varies depending on several factors, from how slurry is stored and spread, to how quickly it is plasma treated.

The mechanisms for reducing the environmental footprint of a farm are not exclusive to dairy or beef farming. The impact that the technology can have on pig slurry and biogas digestate is equally impactful.

AMBITION

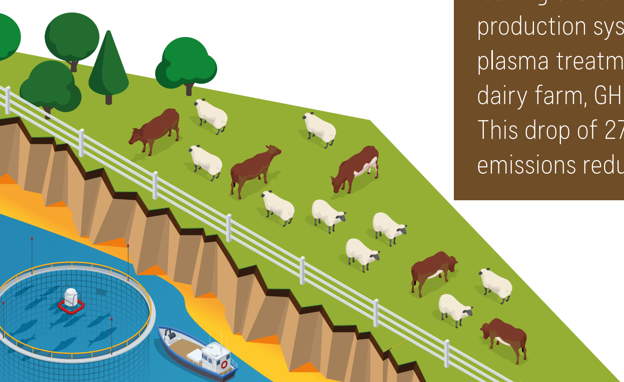
Plasma treatment technology could revolutionise the way fertiliser is produced. Moving fertiliser production from fossil fuel-based products shipped across the globe to local, on-farm up-cycling of nutrients available in farm slurries allows farmers to produce environmentally-friendly fertiliser locally. This is a simple, easy-to-implement solution with the only inputs required being slurry, air and electricity. Due to the scalability and practical implementation of the technology, this solution could be used on any sized farm, from smaller independent farmers to larger, more integrated and intensive operations.

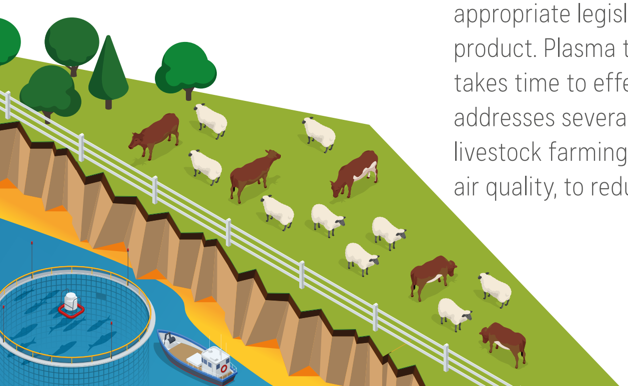
Furthermore, the technology can significantly reduce dependencies upon imports. Recent and current globally-challenging events have highlighted the vulnerability of global food production to trade restrictions.

Using plasma technology to produce fertiliser locally contributes to a cleaner environment, farmer independence and, importantly, makes UK agriculture more self-sufficient in periods of global unrest.

Dairy case study

The Danish milk sector, one of the most efficient globally and sharing many similarities with the UK sector, was selected to model the impact plasma treatment can have on real farms. The model considers emissions from the birth of the animal to the milk it produces leaving the farm gate and is used as a baseline for comparison. In this study the baseline production system was estimated to emit 0.76 $kgCO_2$-eq/kg of milk produced. When plasma treatment technology is implemented on slurry produced by a typical Danish dairy farm, GHG emissions decrease substantially from 0.76 to 0.55 $kgCO_2$-eq/kg of milk. This drop of 27% is predominantly due to decreased use of synthetic fertilisers and CH_4 emissions reduction, factors also important for UK dairy farms.





GAPS TO ADDRESS

1. Electricity demand

One challenge of on-farm plasma treatment of slurries is electricity demand for the process. There are two ways to successfully deal with this issue. Firstly, the start-stop nature of the process provides an excellent opportunity to make use of low cost or surplus renewable electricity or cheap electricity from the grid. This means that plasma technology is a good example of a Power-to-X solution for utilising unused energy to produce N fertiliser. Secondly, plasma converts energy to heat in a confined area where roughly 65% of the heat is recovered as hot water through heat exchangers. Full assessment of specific cases and individual farm situations need to be considered to see how to best integrate the system and optimise energy efficiency of the farm enterprise.

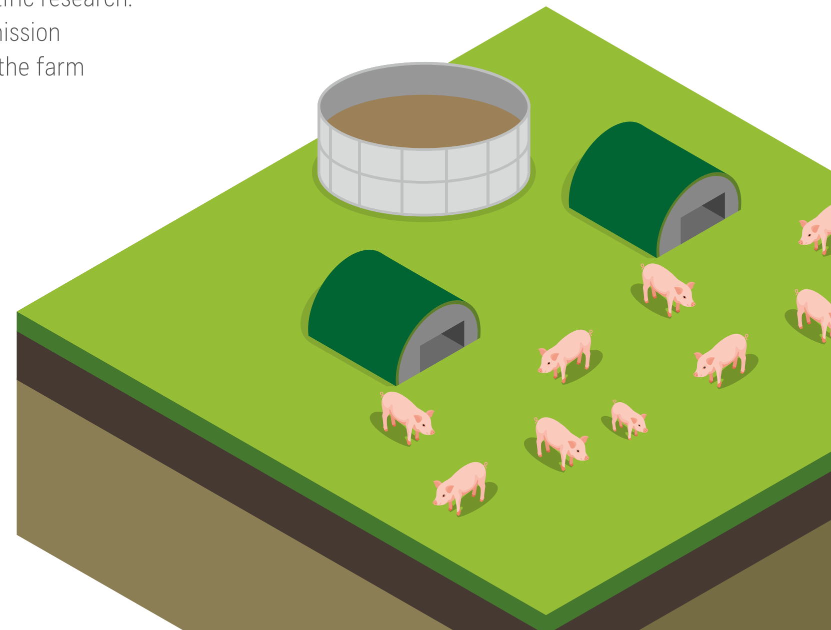
2. Legislation

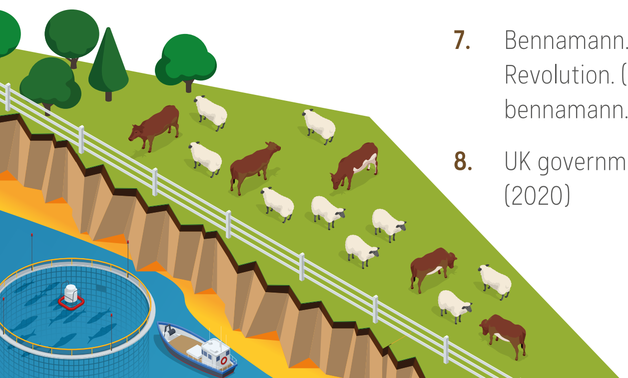
The uptake of new technologies on the market depends on several factors, one of these being appropriate legislation and categorisation of the product. Plasma treatment is a novel process which takes time to effectively legislate for. The process addresses several of the major concerns related to livestock farming, from GHG reduction and improving air quality, to reducing the reliance on imported nutrients and increasing self-sufficiency. However, like many solutions that address environmental and political concerns, subsidies and regulations play an enhancing and sometimes crucial role in their uptake, particularly given the urgency needed to reduce farm emissions.

Legislative bodies must have confidence in the claims that private companies make concerning their products. As such, protocols and conditions under which technologies are approved to enter the market need to be put in place. However, fitting new technologies into old protocols comes with challenges to compatibility. Independent researchers, funded both through government grants and privately, have spent several years extensively working on documenting and improving the effectiveness of the plasma treatment process. Norwegian company N2 Applied are leading the way in this technology, in terms of market readiness and scientific research. They have published reports from emission measurements to improving yield of the farm systems[26,27].

3. Slurry infrastructure grant (Defra)

The extensive research and development, and the impact the technology can have, is beginning to be recognised within the legislative bodies in government. An example of this is with the Defra slurry infrastructure grant[28] specifically including plasma treatment as an alternative method for NH_3 mitigation. This is a first step in legislative bodies helping farmer uptake of this technology. However, closer work with the UK authorities is needed to specifically recognise plasma treatment as a realistic and implementable solution that can also have a major impact in decarbonising the cattle and pig sectors of the UK.





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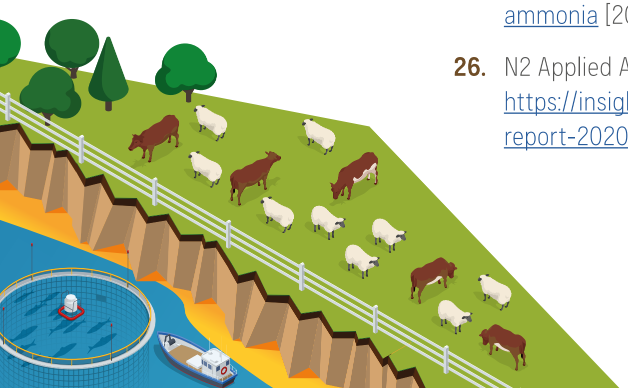

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4.4 Land
Optimising Soil Carbon Squestration

HOW IT WORKS

Overview

Soils play a significant role in the global carbon (C) cycle, with twice as much C stored in the soil than the atmosphere. As a result, changes in soil C can have a dramatic impact on atmospheric greenhouse gas (GHG) levels[1]. UK soils store around 10 billion tonnes of C, roughly equivalent to 80 years of annual UK GHG emissions[2], and can act as either a sink or a source for C[3]. UK data available indicate the general pattern is one of net source, with more C released from soils to the atmosphere than taken in i.e., captured or sequestered. Between 1998 and 2007, UK soil C stocks declined by 21.2 megatonne (Mt)[4].

Soil carbon

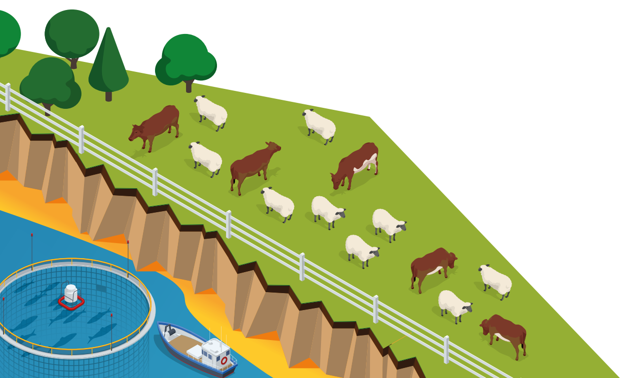
Soils contain C either inorganically (within minerals) or organically (within organic matter). Soil organic C (SOC) is defined as "carbon that remains in the soil after partial decomposition of any material produced by living organisms"[5] and originates from C removed from the atmosphere as carbon dioxide (CO_2) for photosynthesis by plants.

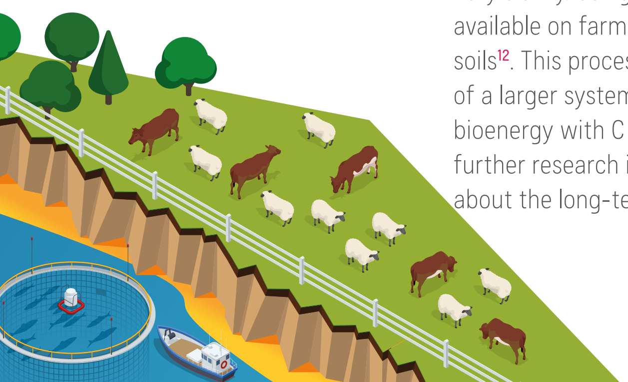
Agriculture and soil carbon sequestration

SOC is dynamic and diverse. Variation in C stocks may be due to several factors including seasonal changes, different agricultural production systems and their associated management practices.

Agricultural soils store almost half of the UK soil C stock (pasture 29% and arable 16%)[6]. It is estimated that UK grassland soils sequester 242kg (±199) of C per hectare per year on average. Therefore, agriculture can impact SOC stocks considerably. For instance, manure from grazing livestock can return i.e., sequester, C into the soil and, if kept under permanent grazed pasture, soils can accumulate C for several decades. However, the permanence of soil C sequestration can vary. Furthermore, when soil C equilibrium is reached, further accumulation of C in the soil is not possible. Default Intergovernmental Panel on Climate Change (IPCC) values suggest soil C sequestration can reach an equilibrium within a 20 year period, although this will vary based on climate, site conditions, and agricultural management.

Soil C is not stored uniformly across the soil profile. Consequently, quantification of SOC can be challenging. Soil C sequestration is regarded as a cost-effective GHG mitigation option that would provide wider environmental and economic benefits[7,8]. Innovation opportunities presented below encourage both sequestration and storage of SOC, to reverse losses and to deliver the benefits that high soil C can deliver.





POTENTIAL IMPACT

1. Increased focus on subsoil

The soil profile can be split into topsoil (0 – 30cm) and subsoil (30 – 100cm). Topsoil has received more research focus as it is nutrient rich, yet C sequestration in topsoil is easily reversible in the short-term. A large proportion of SOC is stored in subsoil (around 50%)[9]. Carbon storage in the subsoil is more stable and long-term due to low disturbance at such depths as well soil characteristics that lead to greater C residence times[10,11]. Regrettably, study of subsoil has been neglected due to measurement challenges. Therefore, innovation should increase focus on subsoil where C can be stored long-term.

2. Soil amendments

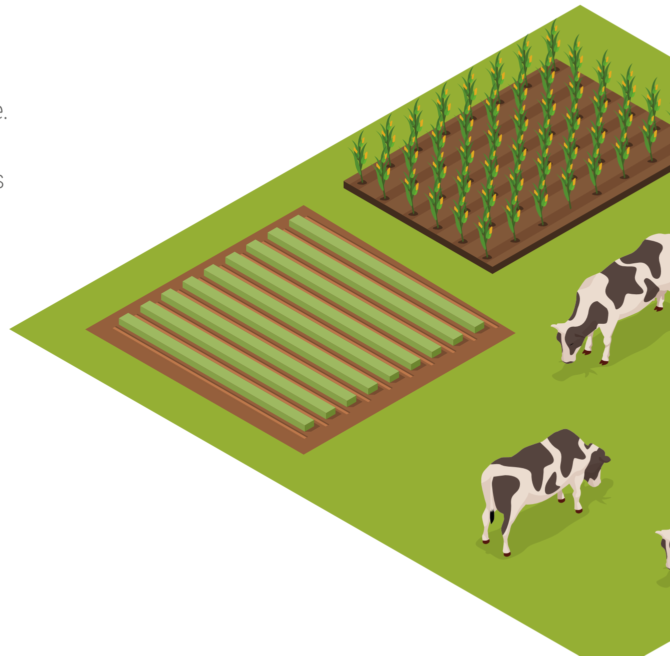
Biochar is a C store created by the process of pyrolysis when organic waste (which could include agricultural by-products) is heated to very high temperatures without oxygen. This C store is considered stable because biochar decomposes very slowly. Using mechanical tools already widely available on farms, biochar can be put into pasture soils[12]. This process could have potential as part of a larger systems-based approach supporting bioenergy with C capture and storage[13]. However, further research is needed since little is known about the long-term C storage potential of biochar in the soil and some concerns have been raised regarding overestimation of C sequestration potential of biochar[12]. It is expected that the Biochar Demonstrator project, a UK interdisciplinary project, will provide clarity and address key uncertainties[14].

Iron (hydr)oxides commonly found in soils have been shown to collect and hold SOC. Therefore, iron (hydr) oxide amendments have been tested as an option to increase soil C sequestration, which could involve ochre or iron oxide nanoparticles. Further research is needed in this area to determine their potential in soil[15].

3. Multi species swards and forage crops

In the UK, ruminants traditionally graze perennial ryegrass-based pastures. However, there is evidence that multi-species swards for pasture (a mix of grass, legume and herb species) have greater C sequestration without impacting animal performance. This benefit is largely derived from deeper plant roots which increase C storage. Specific storage rates vary depending on management practices, erosion and compaction, as well as location and climate. Innovation in this area should be concerned with selecting the best swards for both C storage and livestock production. Where swards require frequent reseeding, the reseeding practice may disturb soils and negate any C sequestration benefits. Reseeding practices that minimise soil disturbance and consequent C loss should be a focus of innovation. Alternatively, plant breeding could focus on the ability of pasture species to reseed naturally.

Gene editing can be used as a tool to increase the root length of pasture crops to penetrate further into the subsoil[12], particularly with the Genetic Technology (Precision Breeding) Act being passed into law (covering England) in March 2023. Deeper roots below ground will increase C capture and thus SOC stocks[16]. Research is currently exploring a gene called Enhanced Gravitropism 1 (EGT1) that could support a modification to make crop plant roots longer and thus enable more soil C to be stored[17] with additional root growth of 100cm estimated to store 100 tonnes (t) more C per hectare[12]. This research has potential for pasture plants.



4. Improved measurement and monitoring of SOC

More data about the health of soils is needed to inform decisions and actions. This requires increased and improved soil monitoring. Traditional laboratory testing of soil samples to determine C storage is expensive, laborious and limited to assessing topsoil only. New technologies have scalability potential that may allow regular soil C monitoring of both topsoil and subsoil. Companies such as Geotree[18] and Remote Sensing Solutions (project SOCmonit)[19] are using satellite data to model SOC to high spatial resolution. Others, such as Agricarbon[20], provide stratified soil sampling down to 100cm. This will give greater clarity on SOC storage potential. The UK government has already taken steps to encourage soil assessment, such as the Sustainable Farming Incentive for arable land and grassland. Broader requirements for routine testing would help local managers manage soil C and would be an important starting point for a UK-wide effort to improve C storage in agricultural soils.

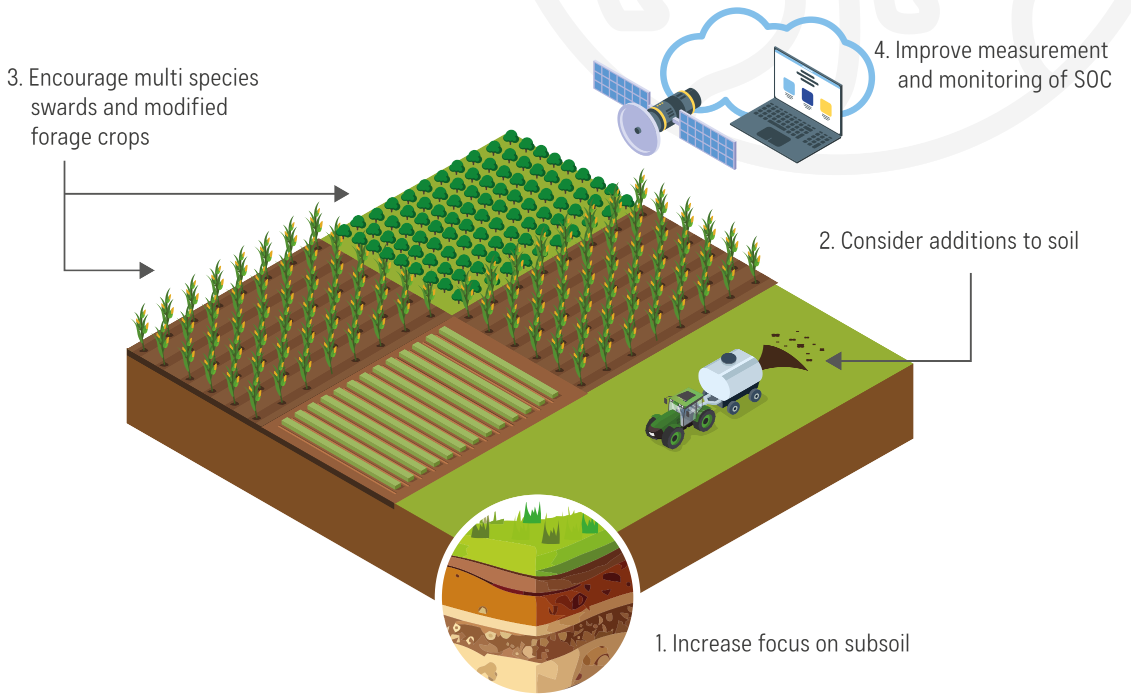
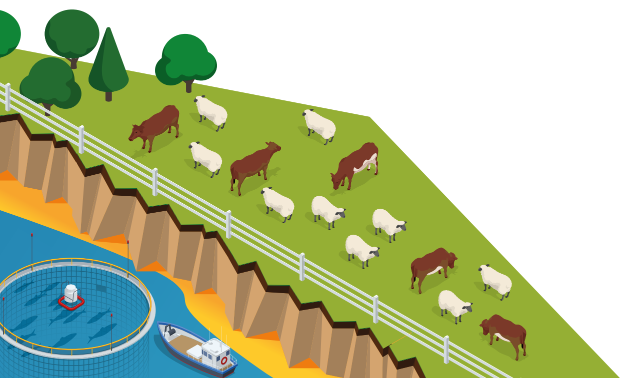


Figure 9 How agricultural innovations can optimise soil carbon sequestration and mitigate GHG emissions

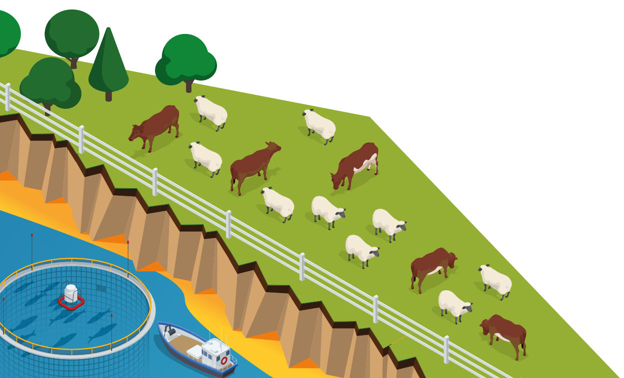


AMBITION

Policy and innovations which consider both topsoil and subsoil have the greatest chance of maximising the GHG emission mitigation potential of SOC sequestration and storage. To achieve this, approaches must measure SOC at scale, without the need for laborious soil analysis. Data, for both existing stocks as well as changes in SOC, are needed to support the agricultural sector in selecting the best agricultural practices for C storage. Broader uptake of measurements will better inform soil C mapping, such as NATMAP Carbon[21] and the international Global Soil Organic Carbon Map (GSOCmap)[22]. Furthermore, soil C sequestration innovations can support the sector in a variety of schemes and accreditation programmes to meet science-based targets. Given that peatlands are the UK's largest C store and support agriculture, monitoring must also ensure that C can be retained within these peaty soils as a priority.

GAPS TO ADDRESS

- Soil C measurements that include both topsoil and subsoil as best practice
- Better understanding of the future potential for C sequestration and storage interventions, including longevity of storage
- Investment to drive innovations that can assess current UK soil C stocks at scale
- Soil C storage, particularly in subsoil via wide-scale adoption of relevant technologies
- Appropriate baselines for soil C stocks and sequestration rates, to benchmark and assess impacts of agricultural management
- How soil C sequestration is impacted by changing climatic conditions
- Technical and practical barriers to delivering greater soil C sequestration on farms
- Economic barriers to uptake of innovations



4.4 Land
Biochar To Boost Soil Carbon

HOW IT WORKS

Overview

The Carbon (C) in plants and other living materials naturally decomposes and is released back into the atmosphere. However, if this material is instead pyrolysed i.e., turned into a type of charcoal by heating under low oxygen conditions, this C becomes stable and can remain stored in the soil for potentially hundreds of years. But how effective is this at locking away C? And what are the key barriers to implementation?

Production

Biochar is made from feedstocks such as grasses and wood, each producing a unique type of biochar. Using waste as a feedstock e.g., biosolids or food waste, can be an affordable and sustainable solution. Pyrolysis produces a black charcoal-like substance. The conditions for pyrolysis and type of feedstock affect the type of biochar produced[23].

Storing biochar in soil

Biochar can be applied directly to the soil surface by hand or by using conventional agricultural machinery e.g., lime spreaders, then incorporated into soil during tillage. In grasslands, direct drilling and subsoiling are possible methods. In the UK, 1 tonne (t) per hectare per year is the legal limit. However, up to 50t have been used in research with no obvious detrimental effect on plant growth[24,25].

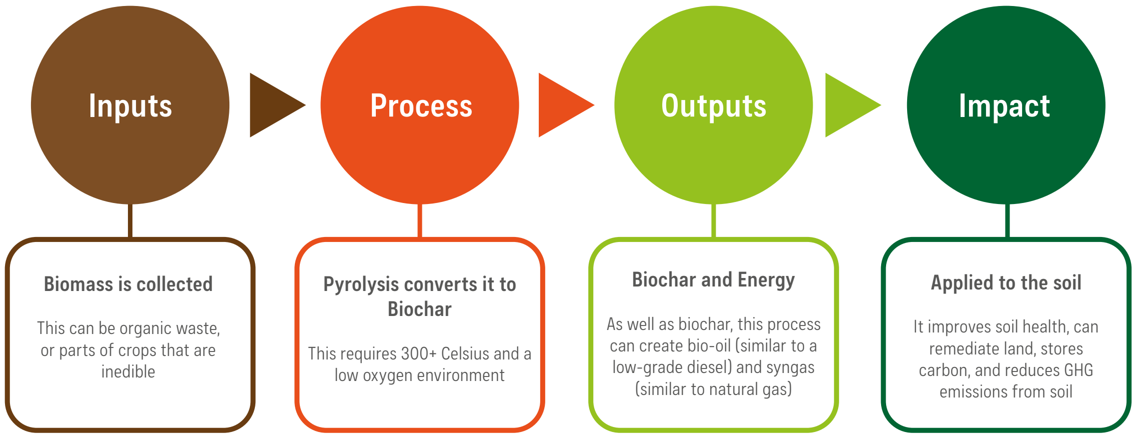
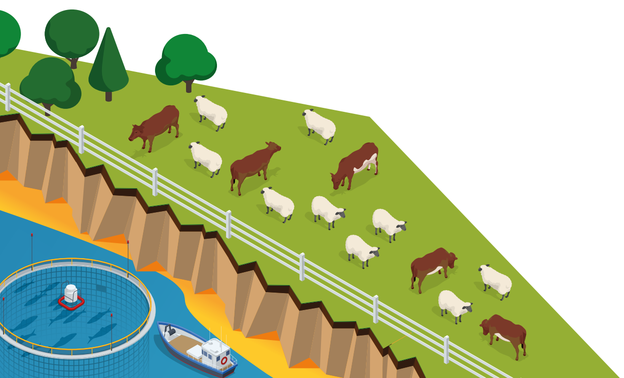


Figure 10 An outline of the biochar process



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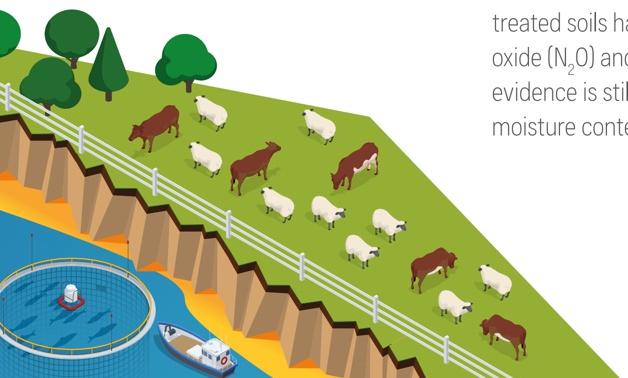


POTENTIAL IMPACT

1. Global C removal and cost [26,27,28,29]

- **Production cost:** To produce and spread 1t of biochar in the UK costs an estimated **£148 – £389**
- **Carbon unit cost:** This equates as **£144 – £208** to store 1 t of CO_2-eq (NB: 1 t of CO_2-eq is more than 1 t of biochar)
- **Carbon sequestration:** Estimated potential for carbon sequestration in UK is 6 to 41 $MtCO_2$/year
- **Carbon emissions avoided:** Global estimates in terms of carbon emissions avoided range from 1 – 6.6 $GtCO_2$/year

2. Land use[30]

Biochar is applied on agricultural land already in production, as well as potentially rehabilitating degraded soils, therefore minimising additional land requirements and clearance.

3. Co-benefits

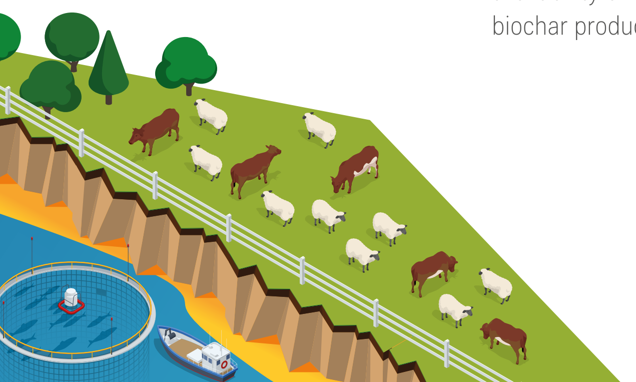
- **Further GHG emissions reduction:** Some biochar-treated soils have been shown to release less nitrous oxide (N_2O) and methane (CH_4) emissions, but evidence is still limited for application to different soil moisture contents
- **Soil health:** Soil health is improved by reducing bulk density, enhancing the water holding capacity, nutrient retention, stabilisation of soil organic matter and heavy metal sequestration
- **Drought resilience:** Resilience to drought is improved as a result of increased soil water retention

RESEARCH AND EVIDENCE

With over 20 years of research into impacts and benefits of biochar application, key literature sources are highlighted below.

- **Smith et al. (2016)**[30] Assessment of the negative emissions potential of soil carbon sequestration (SCS) and biochar addition to land (each estimated at 2.6 $GtCO_2$-eq/year)
- **Smith et al. (2015)**[31] Quantification of negative emissions technologies (NETs) on land, GHG emissions, water, albedo, nutrient and energy, alongside limits to implementation due to economic cost, energy demand, land use and water use
- **Defra commissioned report (2010)**[32] Critical review of biochar application, identifying gaps, uncertainties and risks, as well as estimated emissions removal and economic cost evaluation
- **IPCC AR6 WGIII report (2022)**[33] Identification of emissions mitigation options available to policymakers at a global scale, providing a quantitative analysis of cost and emissions avoided at scale
- **Biochar Meta-analysis Database (2012)**[34] Collection of studies focusing on the effects of biochar application on crop productivity, highlighting the current studies and gaps in knowledge

There are a number of trials currently in the UK, with the University of Nottingham leading a £4.5m project[35]. Previous studies have predominantly taken place in tropical climates.



GAPS TO ADDRESS

1. Barriers to adoption

At present, UK biochar is produced at a small scale in kilns, and is primarily sold as mulch for horticulture. IPCC[33] outline the following barriers to upscaling:

- **Financial:** Insufficient financial incentives for, and investment into, commercial pyrolysis facilities, coupled with high production costs at small-scale
- **Applied research:** Lack of field-scale scientific evidence over the long term and limited applied research or adoption by farmers
- **Accounting uncertainties:** Due to early-stage of commercialisation, mitigation estimates are based on pilot-scale facilities, leading to uncertainties for quantifying impact at scale
- **Regulation:** Regulatory environment unclear[25], particularly for use of waste feedstocks
- **Standards and quality control:** Limited global standardisation and quality control of biochar production and its application to soils, restricting user confidence. UK standards are currently in development by Bangor University
- **Sourcing sustainable material:** Uncertainty over availability of sustainably sourced biomass for biochar production

2. Knowledge gaps

Several areas require further investigation and research:

- Observations of biochar stability over longer time periods (15+ years)
- How use of different feedstocks affects sustainability
- Optimising production of biochar because improper selection of biomass feedstocks, preparation conditions, and preparation methods can result in production of harmful components such as heavy metals, polycyclic aromatics hydrocarbons (PAHs), environmentally persistent free radicals (EPFRs), dioxins, and perfluorochemicals (PFCs)[36]
- Applicability to typical UK soils and land use types

It is clear from existing research that use of biochar could help deliver UK net zero goals and can deliver co-benefits through improvements in soil health and soil water retention. However, to deliver these benefits at scale requires technical upscaling, greater technological readiness, and changes to current regulations before it can be considered a viable large-scale solution.

4.4 Land
Data For Nutrient Management

HOW IT WORKS

Overview

Nutrient management is the ability to retain and make use of nutrients rather than lose them to the wider environment by balancing crop nutrient requirements with soil nutrient inputs. Improvements to the efficiency of nutrient management provides a key opportunity for the livestock sector to contribute to the UK's net zero ambition.

Nitrogen management

Nitrogen (N), a key nutrient in numerous biological processes, is a limiting factor for crop and grass growth. Efficient use and management of N helps increase economic benefits while minimising N losses and pollution, including nitrous oxide (N_2O) and ammonia (NH_3) emissions.

Livestock production systems play an important part in the N cycle and, consequently, in exacerbating or mitigating N pollution. A portion of N excreted by animals in manure can be recycled back as 'organic fertiliser' for crops or pasture. Another portion will be lost from the productive system, either as gaseous emissions of NH_3 and N_2O, or as nitrate (NO_3) leaching to soil or water with cascading impacts to other ecosystems. As such, determining the amount of N in the system, in different other locations and forms, is needed to improve N use efficiency[37].

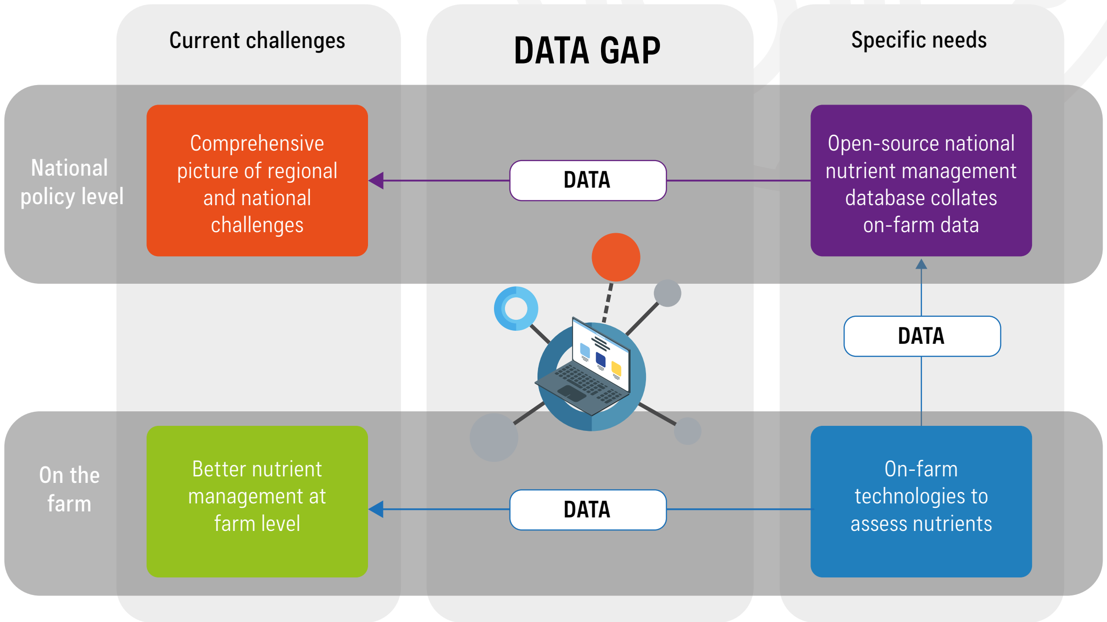


Figure 11 Opportunities to close data gaps for improved nutrient management

Management practices and the local environment vary across different livestock production systems. Therefore, it is imperative that understanding of N balances is at the farm level. Data to understand this variation is a significant gap to improving nutrient management and reducing greenhouse gas (GHG) emissions.

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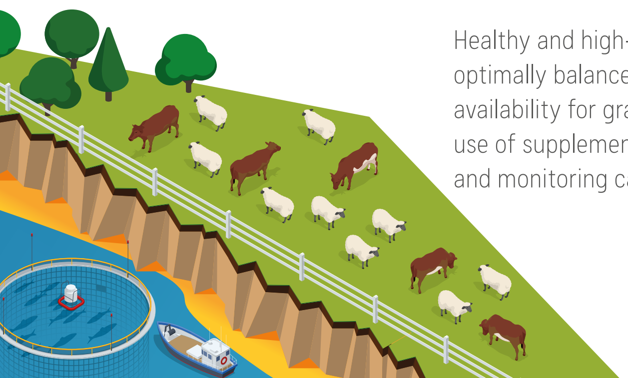


POTENTIAL IMPACT

1. Precision nutrient management

Precision agriculture (PA) is a farm management strategy that seeks to optimise resource use, productivity and profitability through use of technology and data. Precision nutrient management, a key component of PA, addresses spatial and temporal variability in soil nutrients to reduce inputs and losses and, therefore, GHG and NH_3 emissions.

An inherent characteristic of PA is the requirement for supply of sufficient, appropriate and consistent data. Although PA has become more accessible for farmer adoption at scale due to technological advances in gathering data, adoption of PA by livestock farmers for managing pasture is lower than for arable systems[38]. Where farmers are working with low profit margins, technologies with high start-up costs are not considered. Understanding the economic benefits of improving nutrient management is key to driving uptake by these farmers.

2. Monitoring grass growth

Healthy and high-performing livestock require optimally balanced diets. Monitoring on-farm feed availability for grazing livestock is key to minimising use of supplements. Grass growth measurement and monitoring can also provide support regarding nutrient requirement i.e., manure and/or fertiliser application, of the grassland feed resource.

Due to sub-optimal nutrient management, grass growth in the UK rarely reaches full potential[38]. The capacity to confidently monitor grass growth on-farm, and with sufficient data to predict future growth, would support the appropriate application of nutrients to pastures as well as feeding of grass to livestock. Both would likely reduce nutrient loss to the environment and improve cost-effectiveness.

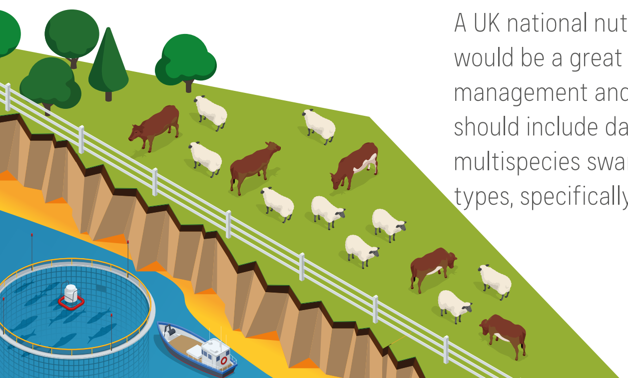
Devices such as rising plate meters enable the measurement of grass growth and calculation of feed dry matter available[38]. Also, addition of micro-sonic sensors e.g., Grasshopper II[39], to rising plate meters dramatically improves accuracy of measurement and makes digital data capture easier[40].

Furthermore, remote sensing using satellite images can provide extensive, spatial dense data. Through crop growth models, this data can be used to estimate grassland biomass production. At present, this is best applied over large areas and timescales. However, remote sensing is developing rapidly and, in the future, will allow monitoring at field scale, providing sufficient granularity to support more precise farm nutrient management decisions[38].

At a policy and farm strategy level, building awareness and understanding of grass growth potential across regions can be supported through monitor farm programmes such as the GrassCheckGB and GrassCheckNI initiatives.

3. Plant sensors

CropCircle™[41] and Greenseeker™[42] are examples of commercially available plant sensors which help indicate whether N needs to be applied to pastures. This reduces unnecessary N inputs, and so nutrient losses, including GHG emissions associated with fertiliser application. However, challenges to their wide adoption include the requirement for regular careful calibration at the field level in order to be effective, a process not yet particularly user friendly[38].



4. Rapid on-farm kits for nutrient testing of manure and slurry

When nutrient content is known, manure and slurry can be more effectively managed to reduce GHG emissions, so measuring nutrient content and dry matter of manure and slurry on-farm is highly encouraged. For example, manure can be distributed where needed and applied with precision to match pasture nutrient requirements. However, on-farm nutrient assessment kits can vary in reliability compared with laboratory testing kits[43]. Increasing the quantity of samples and data available for calibration, as well as the application of sophisticated modelling approaches, shows promise in improving accuracy of rapid test kits[44,45]. New technology development such as portable near infrared spectroscopy also has the potential to further improve nutrient testing of manure[46]. Further research is required here to increase accuracy and advance translation from experimental results through to on-farm tools and services.

5. National nutrient management database

A UK national nutrient management database would be a great addition to improving nutrient management and reducing GHG emissions. This should include data points such as grass and clover multispecies sward reseeding rates[47], sward species types, specifically the proportion of clover; and grass lengths. In this way, the N fixing potential of pastures and the nutritional value of grass could be estimated, that would then help identify (i) GHG emissions mitigation potentials and (ii) areas where technology would be best applied to manage nutrients more effectively.

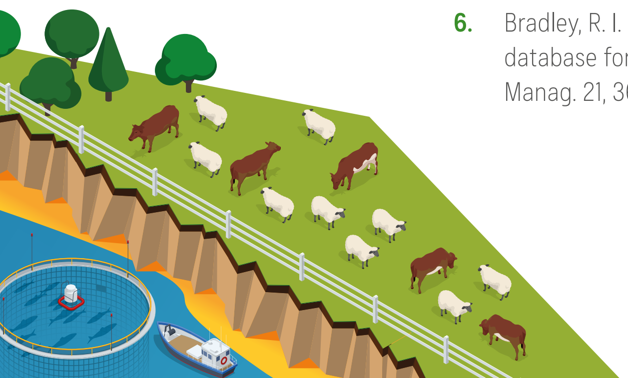
The database would therefore support a national N budget, similar to resources that have been developed in other countries such as Germany[48], providing a valuable tool for policymakers. Such a database should be open source, offering free access to the data available for all interested parties. This would help overcome data sharing challenges between commercial entities and promote identification of future areas with the potential for innovation. Data from precision technology used on farms will be critical to establishing such a database. Clear protocols and standards for collection of data will be important[49]. Leadership from government data units such as the Department for Environment, Food & Rural Affairs (Defra) and the Office for National Statistics (ONS) would be helpful here.

AMBITION

Data is fundamentally important for increasing the application of PA for livestock production and improved nutrient management. Technological innovation is developing rapidly to improve on-farm capabilities to capture and apply data that will improve nutrient use efficiencies. Barriers to the adoption of technology should be identified and removed as data captured at farm level is needed to develop fine grain data in a UK national nutrient management database. Such a database should provide all stakeholders with access to data that will improve their own nutrient management, delivering local and regional reductions in GHG emissions.

GAPS TO ADDRESS

- Improved data capture systems
- Translation of research results into relevant and user-friendly applications
- Understanding and removing obstacles at farm level that prevent uptake of new technology
- Addressing costs and barriers to developing an open-source national nutrient management database



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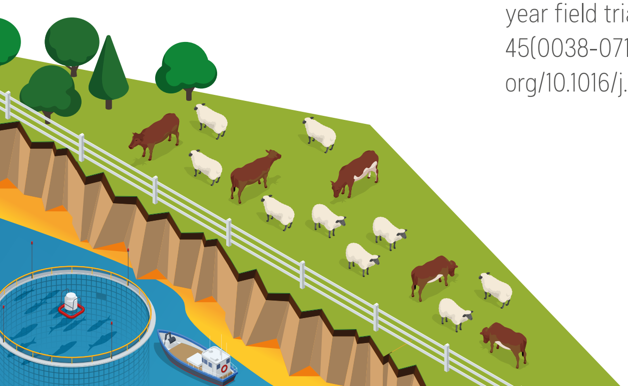

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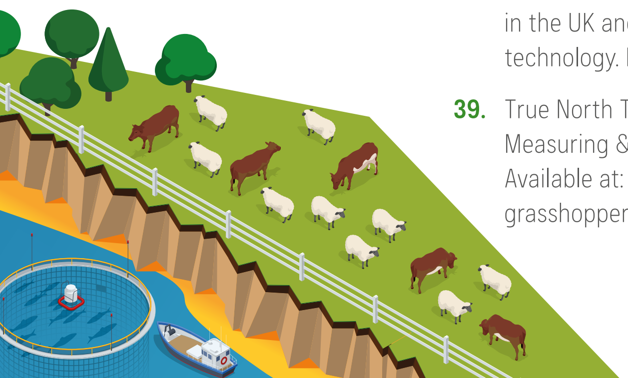

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5. Accelerating Innovation To Deliver Net Zero

There is growing consensus that timely development and application of emerging technologies is critical for the UK's goals to deliver net zero emissions by 2050. However, significant obstacles inhibit the process of livestock-related innovations and a systematic approach to the management of innovation is needed to create an enabling environment.

A successful technology development system (illustrated as the arrow in Figure 12) requires multi-stakeholder collaboration to take innovative products from proof-of-concept stage to market availability[1]. For innovators and entrepreneurs, there is a balance in ensuring the financial sustainability and economic viability of the business alongside the urgency to reduce the carbon footprint of the UK livestock food sector. The innovation ecosystem (illustrated as the blue shaded area in Figure 12) brings into focus key roadblocks and enablers such as stakeholder engagement, intellectual property landscape, markets, funding models and industrial dynamics, to accelerate innovation.

Ultimately, rethinking existing governance of innovation is required, focusing on:

- Policies, regulations and standards designed to foster innovation and/or ensure that innovative products are safe for people and the environment
- Views – positive or negative – of stakeholders on specific technologies or business sectors

National policies on governance of innovation are changing rapidly and regulators are now charged with ensuring regulatory systems, while continuing to ensure technologies are safe for people and the environment, do not unnecessarily inhibit innovation[2].

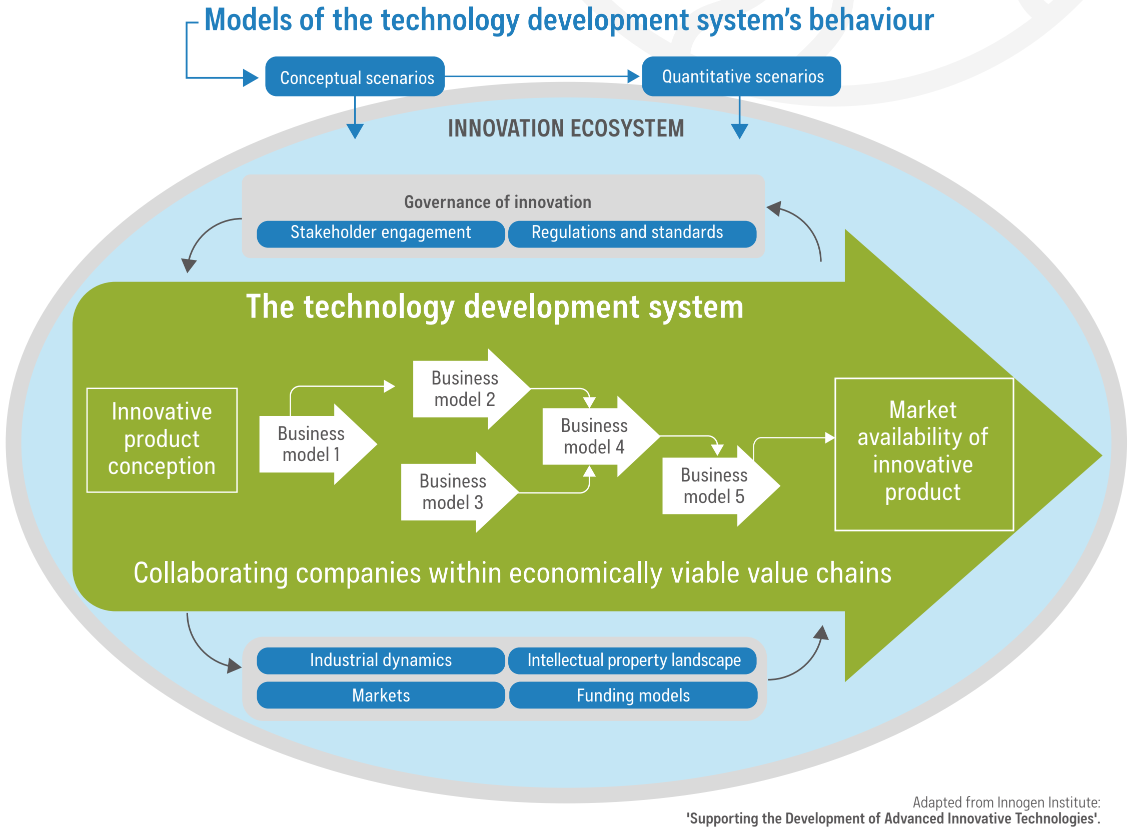
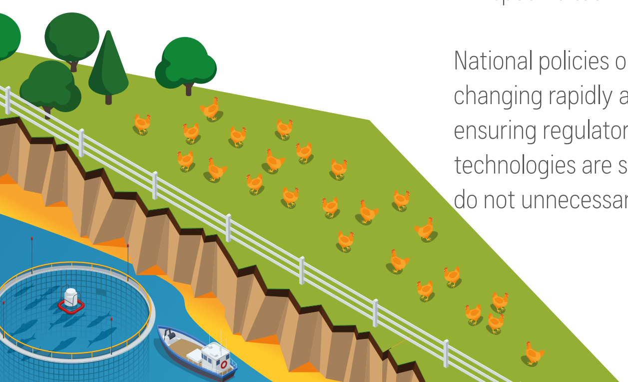


Figure 12 The innovation ecosystem approach



CASE STUDY

Cross-sector learning: The state of innovation in UK aquaculture

Aquaculture can supply high quality protein to feed our growing population, but could be considerably more sustainable than it is today. The growing UK aquaculture sector is investing heavily in innovations to increase productivity and reduce environmental impact. A systematic approach was used here[3] to scope a range of innovative technologies, either available or in late stages of development, that could contribute to these goals, as well as assess combinations of technology and policy initiatives that could accelerate their adoption.

Sustainable aqua-feed

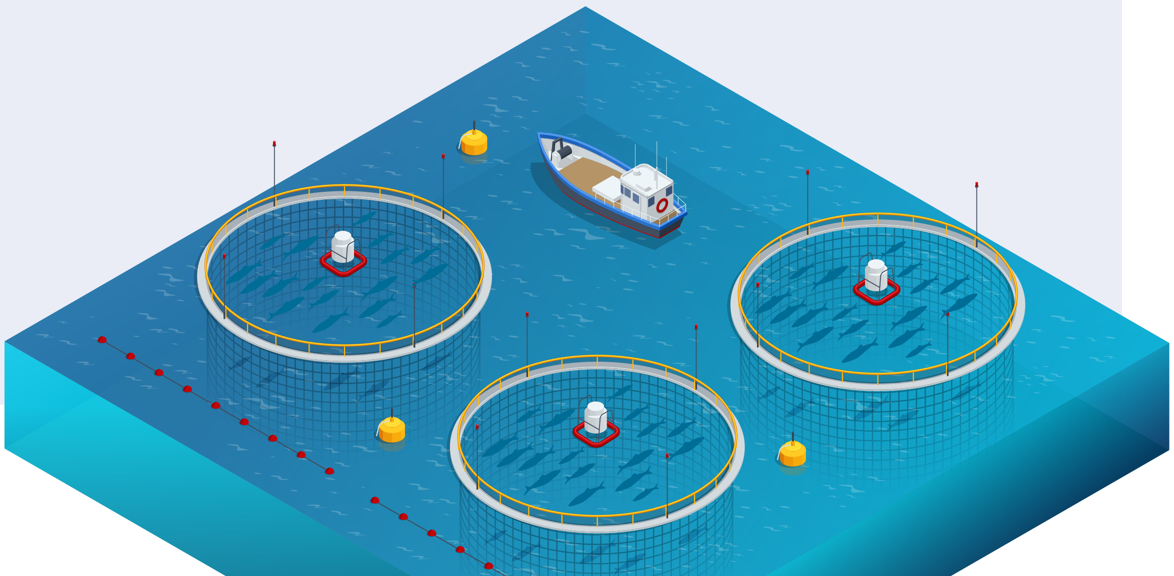
Innovation in aqua-feed production (based on single-celled protein (SCP), plant-based protein, or insect larvae) is considered the most promising route to sustainable expansion of the aquaculture sector, reducing global warming and negative biodiversity impacts[4]. Currently in Scotland, producing feed for aquaculture production accounts for more than 90% of associated emissions. There has been a move away from reliance on wild-catch fishmeal toward plant-based ingredients. This has increased emissions associated with feed and shifted some of the biodiversity impact from marine to land ecosystems[3]. SCP feeds (using micro-algae, yeast, bacteria or fungi), derived from by-products from fish farming or other industry sectors, could also contribute to a circular economy, reducing emissions associated with production, improving biodiversity in marine and land ecosystems, and sparing foods that could be used for human consumption.

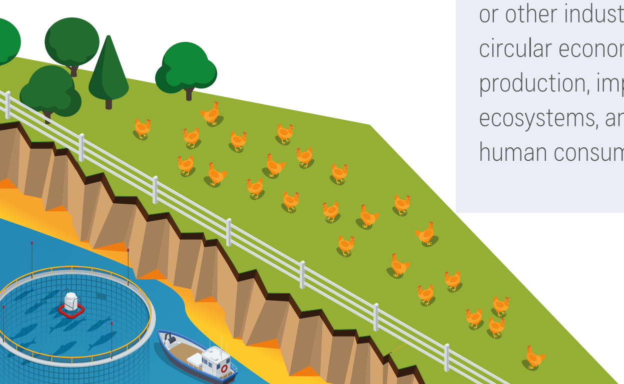
Renewable energy aquaculture systems

Offshore renewable energy aquaculture systems, where energy production and aquaculture production co-locate, could increase UK production capacity, as well as benefiting fish health and reducing localised environmental impacts. However, they face technical challenges and pose risks to workforce health and safety[5].

Waste treatment and disease control

Recent innovations in closed containment aquaculture systems (either inshore or offshore), mainly for hatcheries and smolt (young fish), have improved waste treatment and disease control, reducing fish mortality and thus increasing feed conversion and reducing energy consumption by up to 75%[3].





CASE STUDY

Circular models

Innovation at the processing stage of the value chain includes reusable bulk bins for transport – already estimated to be saving thousands of tonnes of carbon (C) emissions. Biodegradable packaging is being developed based on chitin, a by-product from farmed crustaceans[3].

By-product utilisation and non-renewable input minimisation are important core elements to a circular economy approach:

1. Where the production system allows capture of un-eaten food and faeces, they can be used as biofuel or fertiliser
2. Fish mortalities can be used to produce biofuel for fishery service vehicles
3. Food processing by-products can be used for terrestrial livestock feed, pet food or pharmaceuticals, further reducing reliance on fishmeal and fish oil from wild-capture fisheries

Across all production-related elements, Figure 13 shows how the core fish farming value chain is becoming part of a circular economy based on innovative technologies. This core value chain could also contribute to, and benefit from, links with other value chains through a 'networked economy' to deliver more gains in circularity. The goal should be efficiency or circularity of the whole system and that of each component enterprise.

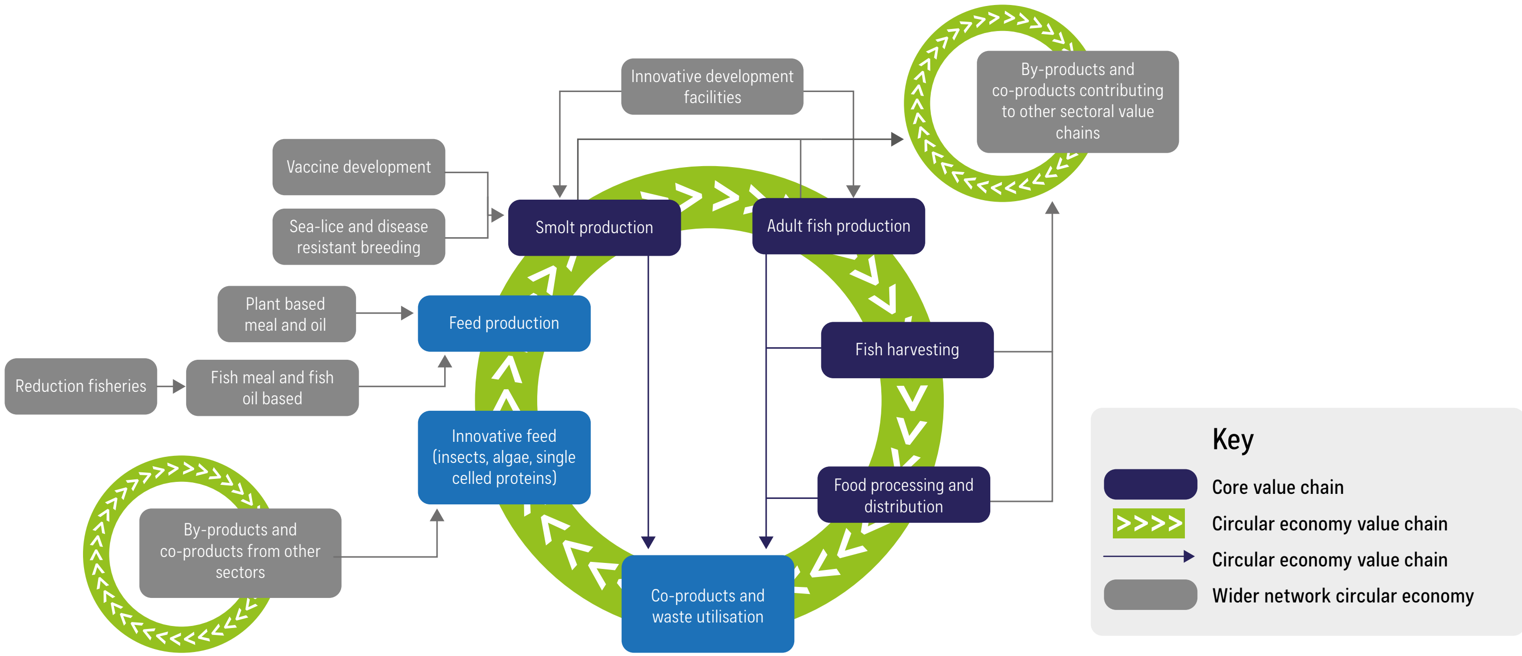
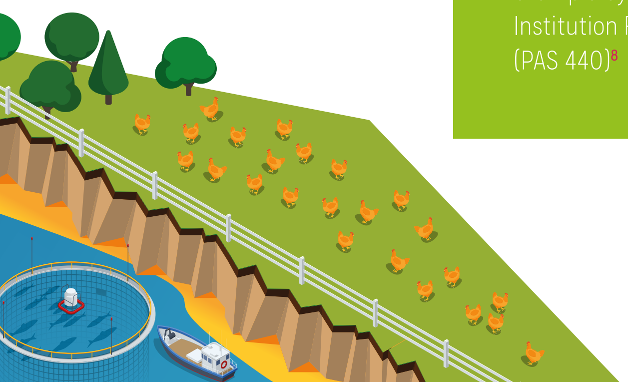


Figure 13 Innovative technologies: Circular economy value network



Policy initiatives for consideration

- Incentives for uptake of novel protein products in aqua-feed to cover the gap where there is a price disadvantage for new products in the value chain[6]
- Innovative solutions that reduce fish disease and mortality, particularly using innovative biotechnologies such as new breeding techniques or fish vaccines
- Supporting technologies to enable cost-effective disease control that improves both productivity and animal welfare
- Adaptive and proportionate regulatory approaches along with policy encouragement for adoption of new genetic technologies to improve plant and micro-organism strains, and increase production efficiency[7]
- Adaptation of planning rules to allow for new experimental facilities. This should be accompanied by a positive initiative from the private sector to demonstrate that companies are innovating responsibly, for example by adopting the British Standards Institution Responsible Innovation Guidance (PAS 440)[8]

Roadmap to net zero

To meet UK net zero emissions targets in livestock production in the required timescale, 'quick wins', using innovative technologies already in early stages of development, will be needed. The approach described and the case study example for aquaculture demonstrate that this is possible.

A systemic approach to selecting an integrated set of initiatives that deliver optimised outcomes in other livestock sectors is also required. This relies on an improved understanding among industry and policymakers of where innovations are needed to optimise value chains of different livestock sectors, supported by sector-specific innovation ecosystems.

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Accelerating innovation to deliver net zero

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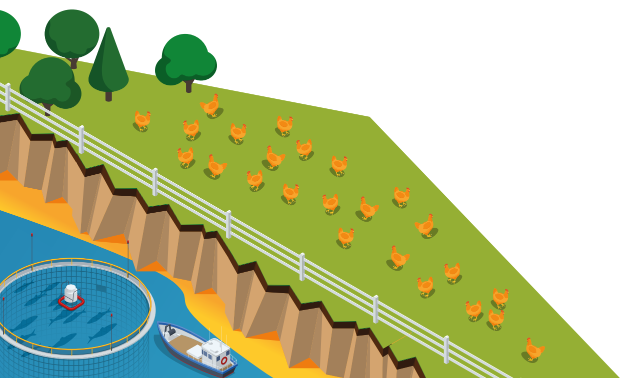

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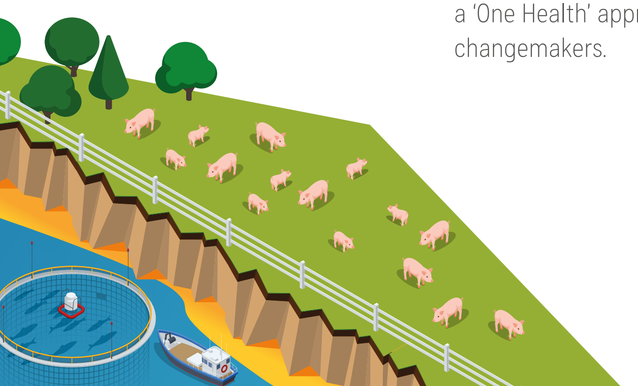


6. CIEL Commentary

By Paddy Tarbuck and Katerina Karpasitou, CIEL Sustainability Team

CIEL's previous Net Zero & Livestock reports provided benchmarks to guide industry in reducing its emissions and identified crucial intervention areas for farmers to help deliver net zero for the UK. This report serves as a guide to accelerating new innovation and enabling further travel on the pathway to net zero for the livestock sector. Underlining the complexities of the sector and production systems, a toolbox of solutions for farmers and industry to adopt is required to empower transformation across farm systems.

Health and Genetics

In this report, we have seen that systems efficiency gains, improved decision making, increased productivity, improved health and reducing both emissions and other nutrient losses are all areas where innovation can be targeted. Such innovations should focus on nutrition, fertility management, animal health, genetic improvement and systems analysis. Trade-offs between efficiencies, well-being and environmental impact need to be realised and a 'One Health' approach should be championed by changemakers.

Nutrition

For nutrition, the twin goals of reducing emissions from ruminant digestion and from production of feed for non-ruminants present a unique challenge. Innovation for CH_4 inhibitors and novel vaccines has the potential for widespread impact on scale, but regulatory approval and on-farm trials are proving to be difficult barriers to navigate for innovators.

Waste

Circular approaches to waste management are increasing in urgency and demand for the sector. Manure processing and effective management paves the way for circularity in the livestock sector, with additional waste valorisation achieved through innovations such as plasma treatment of slurry. Global knowledge sharing on nutrient cycling and manure management might be the key to unlocking circularity potential in the sector.

Land

The crucial role of soil health for climate mitigation also requires significant attention. Technologies to better enhance soil carbon, such as biochar, and the need for precision agriculture therefore present opportunities to align strategies for both carbon dioxide (CO_2) removal efforts and the overall productivity of food systems.

Recommendations

Ultimately, solutions exist for the livestock sector, but as highlighted in the chapter 'Accelerating Innovation', the ability to deliver them quickly must be addressed. Akin to global climate policy challenges, we have tools to reach net zero, but we lack systems to guide effective decision making for policymakers and industry alike.

CIEL, recommends a four-point plan for maximising uptake of innovation:

1. Farmer engagement and capacity building

Innovations must deliver on farm. It is vital to understand what works and what doesn't work for farmers to identify barriers and risks, tailoring solutions to meet the needs of producers and empowering sustainable production. To gain this understanding requires good engagement with farmers, and there are critical roles here for automated data services and real-time insights to avoid burdening farmers with data management and instead focus on information services that empower climate-smart farming.

On-farm innovation is already taking place, with many farmers charting their own journey to net zero. There is a need to maximise the role of peer-to-peer learning for farmers to share knowledge, as well as interactive and engaging training for farmers to access knowledge and insights with appropriate support.

2. Enabling regulation and policy

Entrepreneurs and innovators take on significant risk when developing a new product or service, with innovation often taking place away from regulatory and policy frameworks, creating a disconnect that often limits market uptake.

There is a fine balance to tread between the urgency for market-ready solutions to address the climate and ecological emergency, while also safeguarding the health and well-being of our food systems. Open communication and effective scientific dissemination will be vital for getting technology to market and in the hands of farmers.

3. Effective financial flows

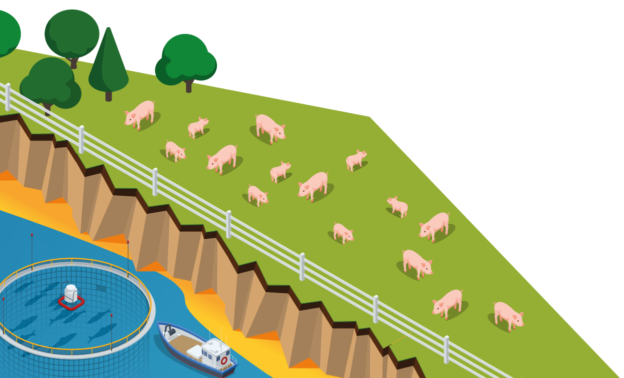
Deployment of affordable and accessible capital is needed to encourage innovation. Accelerator programmes, for instance, play a key role in fostering innovation, guiding emerging agri-tech businesses through the start-up process, but there is often a gap to finance for many innovators to scale their solutions after this.

Within effective financial flows, we also need to consider grants that don't just focus on infrastructure and system costs, but also on training to design and run systems optimally, with the primary goal of improving self-sufficiency of farmers and their ability to diversify production.

4. Supply chain and cross-sector collaboration

In line with UN Sustainable Development Goal 17, 'Partnership for the Goals', we must not innovate in isolation; we need to breakdown siloed thinking. Strengthening knowledge sharing and transfer within the supply chain and across sectors globally provides a platform for collaboration and the opportunity to partner for impact. Data sharing and traceability will be fundamental for enabling productive engagement and openness, further driving our collective vision for net zero.

CIEL and its membership network are well placed to facilitate the transition to net zero for the wider livestock sector and we will continue collaborating for our shared vision of sustainable food systems.



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Authors

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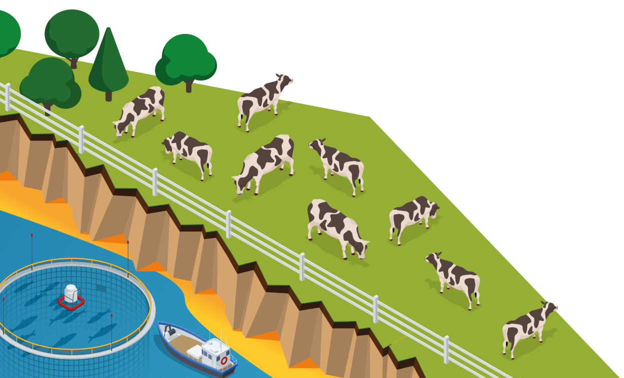

8. Endorsements

Our thanks to industry experts from the following academic institutions who have endorsed topics within this report:

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- **Dr Rafael De Oliveria Silva,** Global Academy of Agriculture and Food Systems, University of Edinburgh (Optimising soil carbon sequestration)
- **Dr Gregor Gorjanc,** Roslin Institute, University of Edinburgh (Genetic improvement)
- **Prof. Jonathan Hillier,** Global Academy of Agriculture and Food Systems, University of Edinburgh (Improving manure management)
- **Dr Michael MacLeod,** SRUC (Novel protein feeds) (Genetic improvement)
- **Prof. John Newbold,** SRUC (Methane inhibitors in feed)
- **Prof. Geoff Simm,** Global Academy of Agriculture and Food Systems, University of Edinburgh (Accelerating innovation)
- **Dr Kim Thompson,** Moredun Research Institute (Health innovations in aquaculture)
- **Prof. Christine Watson,** SRUC (Data for nutrient management)
- **Dr Neil Wedlock,** AgResearch New Zealand (Methane vaccines)

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Moredun Research Institute

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ROSLIN

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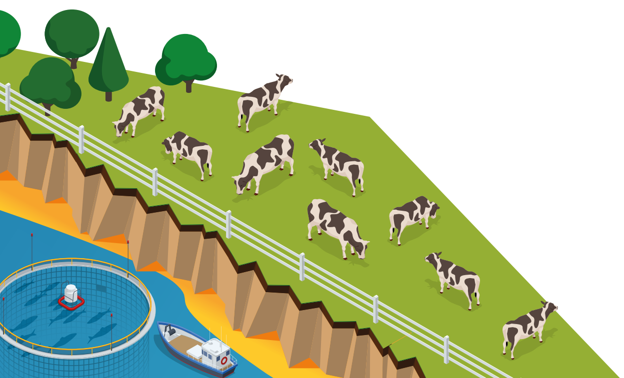

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