CIEL
Centre for Innovation Excellence in Livestock

NET ZERO CARBON & UK LIVESTOCK

CONTENTS

1. Preface – CIEL CEO - 3
2. Executive summary - 5
3. Background - 11
4. Current carbon benchmarks for livestock - 17
   - Dairy cattle - 19
   - Poultry for eggs (layers) - 21
   - Poultry for meat (broilers) - 22
   - Pork - 23
   - Lamb - 24
   - Beef (suckler) - 25
   - Beef (dairy bred) - 27
5. Comparison of production systems - 29
6. Carbon accounting and reporting - 33
7. Options for achieving Carbon net zero goals - 38
   - Mitigation - 38
   - Carbon capture - 41
   - Other approaches to carbon net zero - 43
8. Where to from here? - 45
9. Recommendations - 49
10. Conclusion - 52
11. Glossary - 53
12. References - 54
13. Acknowledgements - 56

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

01. Preface - CIEL CEO

CIEL has a goal to ensure future research supports the sector's ambition to deliver net zero carbon. However, achieving this requires a strong consensus on where the industry is currently and a clear understanding of the areas which can contribute the most towards achieving this ambition.

The impact of UK livestock production systems on the environment and perceptions surrounding this topic are evident across the sector, the media and wider society, but what is lacking is a consistent and independent voice on the latest scientific truth. Different groups and organisations discuss the carbon impact of agriculture, and livestock in particular, and what is needed to reach the net zero carbon goal. There is however a lot of rhetoric, emotive language and seemingly contradictory facts on the subject.

Livestock farming and its impact on land-use is unique in major industrial sectors in that it provides both a sink for carbon as well as being a source of carbon emissions. It is this biological interaction that we need to gain greater scientific insight on, to inform discussions, define industry baselines with industry buy-in and identify critical knowledge gaps that we must address in the short and medium term in order to deliver net zero carbon commitments.

For these reasons, CIEL has commissioned this report to span the UK livestock production systems and join up existing streams of research. It is written by a consortium of scientists from eight leading universities and institutions, involving prominent, world leading environmental and livestock scientists.

Experts from a further six research organisations have endorsed the opportunities identified and recommendations made within this work. The report provides a summary of what is currently known about the carbon impact of the main livestock production systems in the UK, based on the best science and evidence available.

This is a huge, complex area which is not possible to cover completely in one publication. Therefore the report identifies and focuses on critical opportunities where changes can be made immediately and where there are significant knowledge gaps to address to deliver further gains. Ultimately it provides a roadmap for the future of livestock production systems in a net zero carbon era, setting out the challenge and a pathway forward.

Our industry has the responsibility for ensuring consumers are supplied with healthy, safe food produced with high standards of animal welfare and low environmental impact. Although there are still challenges to overcome, it is a priority to use a science and evidence-based approach to tackling carbon emissions, that can inform best practice, offer solutions and provide future guidance to policymakers.

CIEL is committed to supporting collaborative work that drives the UK forward in delivering improvements towards net zero carbon for livestock production systems.

L E Chapman

Lyndsay Chapman, CIEL CEO

Lyndsay Chapman

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

Research partners

Our thanks go to our partners in the research consortium who have written and been involved in the production of this report, and to those who have endorsed it.

Written by:

SRUC

Rothamsted Research

afbi Agri-Food & Biosciences Institute

Prifysgol Bangor University

The University of Nottingham – United Kingdom · China · Malaysia

Queen's University Belfast

UK Centre for Ecology & Hydrology

Duchy College – The Cornwall College Group

Endorsed by:

The University of Edinburgh

Prifysgol Aberystwyth University

Newcastle University

University of Bristol

University of Leeds

Harper Adams University

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

02. Executive summary

Climate change is the greatest environmental challenge currently facing our planet and the way we live. Addressing this will require concerted and coordinated efforts to reduce greenhouse gas emissions from human activity. Farmed livestock are one source of such emissions.

This report quantifies current emissions associated with UK livestock food production and assesses technologies that can put this industry on an immediate trajectory to deliver a key component of the net zero carbon goals for UK agriculture and the UK as a whole.

The UK farmgate value of livestock products is over £12 billion per year. We import £10 billion and export £4 billion worth of livestock products each year – which makes the UK broadly 60 - 70% self-sufficient, on a calorific basis, for meat, milk and eggs. The livestock industry is vitally important to the economy and provides society with an essential source of high-quality protein and other micro-nutrients. It also manages our landscapes and supports rural communities.

Food production is part of a cycle whereby energy from the sun and carbon dioxide from the air are converted into plant nutrients. Some of these are incorporated into soils, while others are eaten by animals which upgrade them to high-quality protein for human diets. Animals produce carbon dioxide and ruminant animals produce methane, both of which are greenhouse gases. Whilst methane is cycled in the atmosphere, some of which is converted to carbon dioxide, the presence of methane in the atmosphere significantly impacts global warming.

Since no biological processes are 100% efficient, we cannot expect to maintain an efficient food production system without emissions. However, we must work to eliminate, as far as possible, net losses of carbon into the atmosphere, and to reduce the levels of greenhouse gases emitted to decelerate and eventually halt global warming. Livestock agriculture can make a contribution to achieving this.

The Committee on Climate Change has recommended a 64% reduction in greenhouse gas emissions from the agriculture and land-use sector to meet a 2050 net zero carbon target in the UK. Whilst livestock does not have a specific target, it is considered that the same target is appropriate. The fact that this is not a 100% reduction reflects the natural biology of food production, as well as the importance of food security to the UK.

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

A 64% reduction from 2018 baseline livestock emissions (total 29.1Mt CO_2-eq) is 18.6Mt CO_2-eq. Over the 32 years between 2018 to 2050, this is a reduction rate of 0.58Mt CO_2-eq/year. To achieve this will require application of a range of mitigation and carbon removal strategies. For all agricultural emissions, a recent assessment of cost-effective mitigation strategies available concluded there is the potential to reduce emissions by 7.1Mt CO_2-eq by 2035. This is only 19% of the goal for total agricultural emissions, leaving 81% to be delivered between 2035 and 2050.

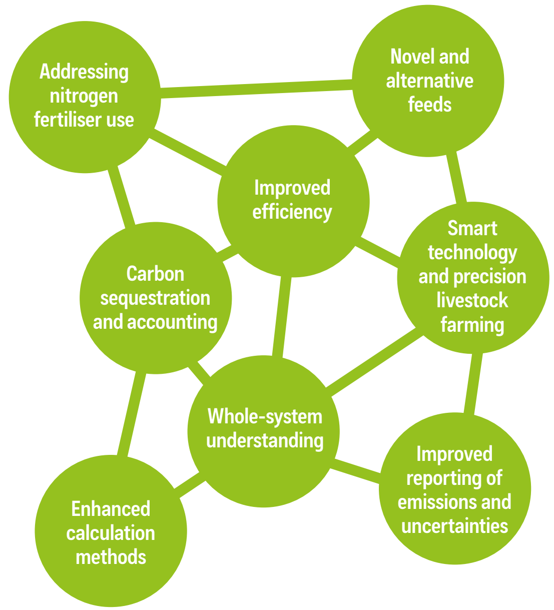
In the most recent national inventory assessment of the UK's emissions, agriculture was responsible for 10% in 2018 (45.4Mt CO_2-eq), with nitrous oxide and methane emissions accounting for 31% and 56% of this respectively. Most methane emissions (87%) originate from ruminants as part of their natural digestive process, so almost half (49%) of all agricultural emissions come from ruminant livestock [1]. Other emissions come from nitrous oxide, produced from the application of nitrogen fertilisers and livestock manures, and from the production of imported feedstuffs, such as soya (which if associated with land use change, such as deforestation, can be very significant).

Ruminant farming is considered a major source of greenhouse gas emissions in UK agriculture, but changes effected here can reduce UK emissions significantly.

Much of the focus for livestock is around reducing emissions at source, on-farm. However, maximising carbon capture will also be important in soils, hedgerows and woods. Off-farm emission load can also be reduced through sourcing of inputs that have low carbon footprints themselves, such as green energy or locally produced inputs (such as fertiliser and feed).

An important part of working towards net zero includes the accurate accounting of greenhouse gases. However, this is complicated within agriculture. There are two accounting systems in common use to assess carbon footprints, each with different assumptions. Our net zero carbon targets are based on inventory accounting, which relates only to emissions originating in the UK. This method of accounting forms the basis of international climate change treaties. Another method, life cycle assessment, includes emissions occurring in other countries for imported products associated with food production, such as animal feed (e.g. soya imported from the Americas), or fertiliser chemicals. As such, it provides a more globally holistic view of the carbon footprint for any product. However, because of the interconnected natural world, life cycle assessments must make assumptions about system boundaries, and these can vary considerably from assessment to assessment. So, careful consideration of accounting method and assumptions made is needed to avoid misinterpretation of data and unintended consequences. For instance, we can lower the UK inventory carbon footprint by replacing home grown feedstuffs with imported equivalents, but this will negatively impact global emissions if those imports have a higher footprint overall.

This report has identified the following eight areas of opportunity to advance the livestock industry towards net zero carbon at pace and with efficacy. To maximise speed of uptake and rate of change, most require coordinated and collaborative work within and across sectors, between farmers, food processors and their supply chain partners, and partnerships between government, scientists and consumers.



01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

On-farm

1. Improved efficiency

Significant opportunities exist to further improve the efficiency of resource utilisation in the form of fertilisers, feeds and manure management on livestock farms using currently known and proven technologies and strategies. Furthermore, new approaches and solutions need to be developed in the areas of animal husbandry, plant and animal breeding and livestock health, welfare and productivity to deliver further needed improvements in efficiency. However, there is also a need to avoid improvements in efficiency solely being used to increase production output (and hence increase or maintain current emissions).

2. Novel and alternative feeds

Addressing the carbon footprints associated with feed production and utilisation, and designing diets and feed ingredients/supplements to improve nutrient utilisation, and reduce methane emissions, will offer huge potential towards efficiency improvements and thus net zero. For ruminants, a greater understanding of rumen microbial ecology may offer solutions to lower methane through microbial manipulation and reducing methane producing archaea (e.g. through gut microbial programming or dietary supplements). Use of home-grown sources (especially protein), will reduce reliance on imported soya and the impacts associated with deforestation. Use of co- and by-products in livestock feeds, especially those which do not contribute to the competition between food and feed, will significantly reduce impacts.

3. Addressing nitrogen fertiliser use

New fertiliser formulations including new approaches to manufacturing (e.g. more environmentally friendly nitric acid production), nitrification inhibitors, and urease inhibitors, coupled with improved timing and rates of application and soil management, have the potential to contribute to significant reductions in nitrous oxide emissions and nitrate leaching. Reduction of inorganic fertiliser through the implementation of novel and alternative species mixtures for grassland hold promise, such as those including atmospheric nitrogen-fixing leguminous clovers or deep-rooting grassland plants. Furthermore, breeding targets to improve persistency and nutritional value of these species will increase their use in seed mixtures and uptake by the industry.

4. Smart technology and precision livestock farming

In the livestock sector, further development and new approaches to animal genotyping and phenotyping, including greater understanding of the rumen microbiome, precision feeding, precision animal surveillance, land use, and manure management, which is tailored to the natural variability between animals, will reduce emissions. Advances in remote sensing can be used to guide the precision application of fertiliser and manure, to mitigate hotspots of emissions on farm (e.g. nitrate leaching and nitrous oxide). Precision application of manures and other organic matter returns also offer opportunities to improve arable systems (soil health and nutrient provision) and offset their emissions by replacing/reducing inorganic fertiliser use as a direct benefit from the livestock sector.

5. Carbon sequestration and accounting

Mitigation alone will not achieve net zero in livestock farming. Carbon sequestration by the natural landscape and other approaches to remove greenhouse gases from the atmosphere, can contribute significantly to balancing emissions from livestock. Carbon accounting will need to include the potential of certain land-types for carbon sequestration. Moreover, where relevant, these land-based benefits need to be credited to the livestock sector (e.g. hedgerows on-farm and land set-aside for forestry). Land use, including improvement of soil health will play a critical role in contributing to this, but there remain large uncertainties about the relative contributions of land management, where land remains under different land use, as opposed to land use change where a new land use such as forestry, is introduced.

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

Decision support tools

6. Whole-system understanding

As the industry moves towards the target of net zero emissions, multiple interventions and modifications to farming systems will need to be implemented. The complexity of interactions between component farming systems requires an understanding of how these interactions will influence overall emission reductions, as well as other sustainability metrics such as economic performance, human health and other issues surrounding pollution such as waterbody quality. The wider impacts of system management, both within and between them, on the environment and agricultural productivity also need to be studied, to ensure trade-offs are identified and understood to identify appropriate "best case scenarios", and subsequently manage them as far as possible. The challenge of climate change offers the UK livestock industry a unique opportunity to achieve true sustainability in a holistic manner, if emphasis is placed on systems improvements.

7. Enhanced calculation methods

Significant opportunity exists to reduce the uncertainties with regard to calculating the quantities of greenhouse gas emissions, as well as how to account for the warming effect of methane on the atmosphere. There is growing evidence to support an approach that treats methane more appropriately as a short-lived greenhouse gas, differently to carbon dioxide and nitrous oxide, both of which have longer atmospheric residencies in the order of hundreds of years, compared to methane's ~12 to 15 years.

8. Improved reporting of emissions and uncertainties

Past improvements to reporting of emissions have helped identify opportunities for mitigation that target the highest emission sources and hotspots. Further development of our inventory reporting will help to reduce uncertainties in emission estimates and produce more effective mitigation interventions, as well as simultaneously recognising complementary interactions across sectors, rather than simply pitting sectors against each other as rivals, which has become commonplace due to current reporting practices. Future reporting needs to have improved spatial and temporal resolution to accurately reflect the complexities of land-based management interventions. This will also support the development of more effective and refined farm-based emission tools.

In order to harness the opportunities identified above we recommend immediate action in three key areas to deliver what is required in the next 5 to 10 years if we are to achieve our goal for emissions reduction. These recommendations deserve urgent attention by leaders in the food and farming sectors, government and science.

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

Investment

The application of current technologies will not achieve net zero, but new solutions continue to emerge. In order for the UK to minimise its greenhouse gas emissions, significant investment will be needed to advance the development of innovation in terms of both mitigations and carbon capture technologies.

The impact of many mitigations and carbon capture technologies is currently based on a number of assumptions linked with scientific investigations. As such, investment is also required to refine and quantify the impact of some key mitigations and carbon capture technologies, individually and collectively, to better inform accounting practices and decision support tools.

In order to inform investment decisions on a national and regional scale, significant modelling is required at macro and micro levels to test the economic and environmental impact of a large range of scenarios, while considering the diversity of livestock farming across the UK. This modelling will be key in order to put in place informed action plans aligned with the opportunities and constraints of regional areas. Ideally, this modelling also needs to be cognisant of wider sustainability issues.

Carbon accounting

Accounting for greenhouse gases from agriculture at national and international level is complicated, and overall can confuse the achievement of goals. This report recommends that improved transparency in the way in which we report the emissions of greenhouse gases from agriculture and livestock is needed. Reporting must fully consider on-farm mitigation and carbon offsetting for the production of that product (i.e. interventions on-farm/sectors to mitigate and off-set are fully taken into account to reduce the farm/sector's carbon cost). To achieve this there needs to be an improved representation of farm management interventions in space and time, in order to provide a better representation of mitigation opportunities.

Carbon accounting tools for use by the industry are effective, but further improvements are required to achieve the transparency noted above, as well as levels of accuracy required. Furthermore, linked with knowledge exchange above, the widespread adoption and uptake of state-of-the-art carbon accounting tools on-farm is needed, to enable farmers to track and reduce on-farm emissions including both carbon reduction and offsetting potential.

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

Education, knowledge exchange and adoption

Education programmes and knowledge exchange needs to accelerate and increase adoption of mitigation technologies with immediate effect, since significant opportunity exists to reduce greenhouse gas emissions through the implementation of currently available and proven approaches, which also align to win-win improvements in efficiency and profitability on-farm. The knowledge to be exchanged needs to be consistent and far reaching with the audiences spanning both farming and society, to ensure the effective roll out of new technologies as well as evidence based advice surrounding the benefits of responsible consumption of high-quality animal-based products, to align with public health advice and the new National Food Strategy. Scientists, technical support organisations and government need to play a key role in realising effective education and knowledge exchange.

In order to maximise the impact of knowledge exchange across all farming systems and individuals involved, barriers to adoption need to be addressed. A wide range of methodologies and incentives, including financial, will be required with flexibility to encourage and reward through multi sector approaches.

Achieving net zero carbon in the livestock sector is a major challenge. Furthermore, it is important to note that net zero carbon does not equate to sustainability. Reducing carbon emissions is a vital component of sustainable livestock systems, given climate change is our greatest global challenge, but it is not our sole challenge. A single focus on carbon may compromise gains needed in other sustainability metrics, such as food security and food quality, nutrient management, animal welfare, biodiversity, viability of rural communities and long-term farm profitability. This is an opportunity to tackle climate change while building systems that will help to deliver a sustainable farm and food future for our nation.

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

03. Background

The industry

The UK livestock industry is an important contributor to the UK economy, both directly through farming and indirectly through, for example, processing, supply chain and retailing. It also plays a major role in the lives of rural communities and maintains much of the nation's landscape which supports tourism, as well as providing many ecosystem services, for example biodiversity for crucial biological processes such as pollination.

Across the UK, there are over 9.5 million cattle, 33.5 million sheep, 5 million pigs and 187 million poultry **(Figure 1).** In combination, the value of their farm gate product is over £12 billion per year. Whilst the UK imports £10 billion worth of meat and milk per year, it also exports £4 billion. Overall, based on current consumption rates, the UK is broadly 60-70% self-sufficient on a calorific basis, with regard to meat, milk and eggs from domestic livestock production. It is highly possible these statistics will change in the coming years due to a number of political and environmental factors, but it is equally highly unlikely that the UK will not have a significant livestock sector - due to the land types across the UK and need to feed the population and drive the economy.

Livestock produce high-quality protein products for human consumption, which is the reason they were domesticated and form a significant part of modern agriculture. This protein is often of superior quality to plant protein, such that the recommended daily intake of protein can be greater for human diets that exclude animal products. It is also associated with other essential nutrients of particular importance to the diets of children and older adults.

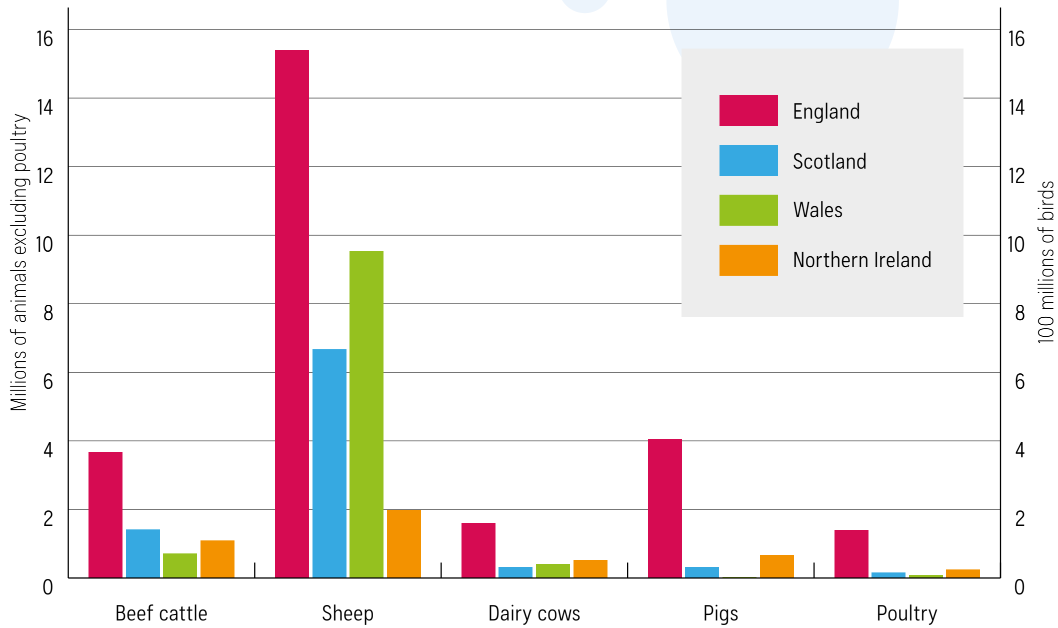


Figure 1. Livestock numbers across the UK. Data source: Defra statistics.

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

The soil-plant-animal-atmosphere dynamic is one where plants capture carbon from CO_2 in the atmosphere using energy from sunlight, and release oxygen. Some of this plant material decays and is incorporated into soil or is lost as emissions. Animals eat plant material and using oxygen, obtain energy from that, as well as building blocks for animal protein, releasing CO_2 in the process (**Figure 2**). Digestive processes and animal waste release greenhouse gases, and some waste is incorporated into soil which enhances soil structure and supplies micronutrients to plants.

CO_2 stays in the atmosphere for hundreds of years, while methane breaks down relatively rapidly (i.e. ~15 years for complete decomposition) into CO_2 and water vapour. However, methane is a much more powerful greenhouse gas than CO_2 (around 30 times). Thus, while excessive man-made sources of methane are present in the atmosphere, the gas poses substantial issues for climate change burdens arising from livestock as a whole. To add to this complexity, a third gas, nitrous oxide (N_2O), is not only over 200 times more powerful than CO_2, it also lasts over 100 years in the atmosphere before it is broken down. Furthermore, agricultural soil is the main source of N_2O (~60% of global anthropogenic emissions), meaning the sector carries the most responsibility to reduce said emissions.

Our goal in addressing the issue of emissions from livestock, is to minimise emissions as much as possible, using a scientific understanding of the underlying biophysical processes.

There are two main types of livestock, with some crossover between them. Those that we manage for high production, optimising animal diets to achieve this; and those that we farm to convert feeds humans cannot digest into highly digestible, high quality protein.

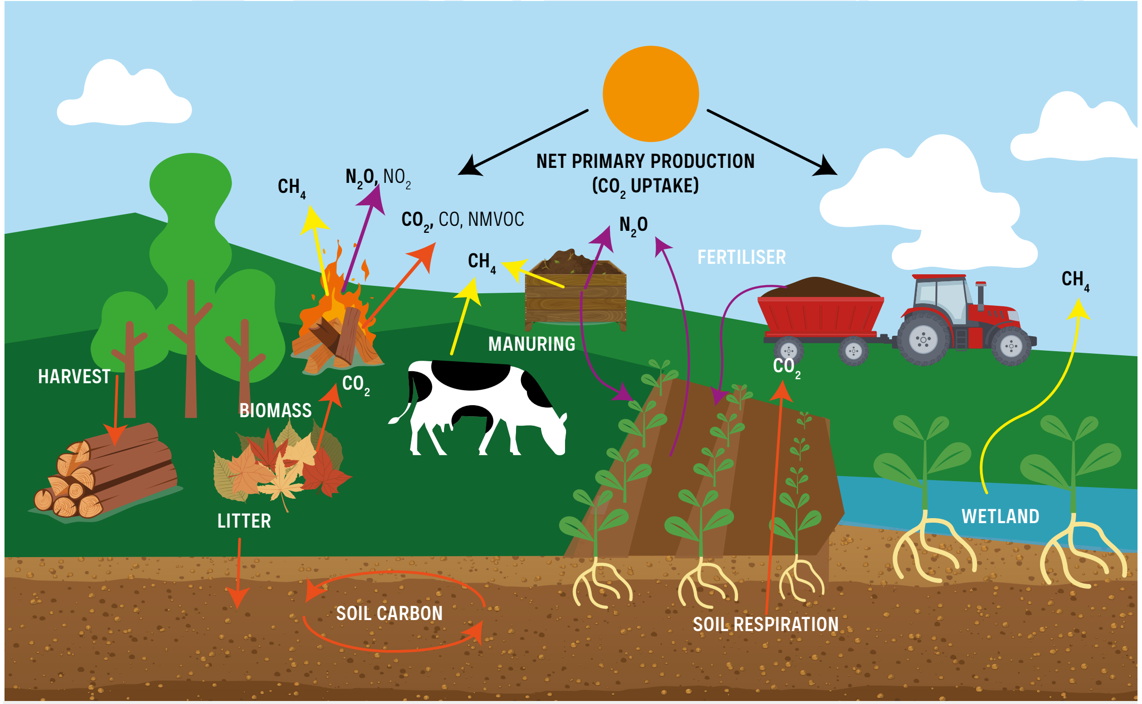


Figure 2. Greenhouse gas emissions and removals in agricultural systems[2].

Evolution has shaped ruminants for this latter role, with a rumen designed specifically to degrade plant fibre through microbial fermentation. On diets of low quality, the rumen "adds value" to what is eaten, but on high-quality diets it "subtracts" some value. This is why ruminants are suited to a large proportion of UK agricultural land, which readily grows grasses but is not amenable to arable farming. The downside to the rumen is that it produces methane as a by-product of microbial fermentation. The upside is that it converts low quality plant material into high quality protein for human food.

Poultry and pigs have been selected to be very efficient converters of feed into product. In the UK, their diets and production systems are managed to allow a focus on highly efficient conversion of feed into animal protein. Additionally, the high reproductive rate compared to ruminants serves to decrease emission overheads. However, despite these high efficiencies, there are still losses of nitrogen that are incurred as a result of using animals as a protein input to the human diet, rather than direct consumption of plant proteins.

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

The human food supply chain competes for resources with the pork and chicken supply chain, but little at all with ruminant animals at pasture or fed "forage". There is some crossover when ruminants are housed and partially fed diets with ingredients more similar to chicken and pigs. This can deliver high productivity, but ruminants are generally considered to be less efficient than pork or poultry for converting such feed into product. In fact, the major role of ruminants in some countries is to convert plant food waste or surpluses into high quality protein for humans.

This is relevant to carbon efficiency calculations and interpretation of results. Livestock are farmed to produce food containing a range of nutrients, but the dominant one is protein. For full comparisons of different products and production systems, the protein content quality should be considered. However, for comparison of animal protein products only, it is reasonable to compare protein content only, as their protein quality is similar compared to most plant proteins.

As a sector, agriculture is the fourth largest contributor to total UK greenhouse gas emissions (10% of total emissions in 2018), after energy, transport, business and residential construction sectors. Agricultural livestock-specific greenhouse gas emissions are dominated by emissions of methane from enteric fermentation and nitrous oxide emissions from manure management and fertiliser application, although part of the latter can also be allocated to the arable sector. It is notable that the emissions pre farm-gate, mainly aligned with rumen digestion, feed and fertiliser, far outweigh emissions post farmgate.

The 2020 Committee on Climate Change progress report[1] highlights that although agricultural emissions have shown an overall 16% decrease across the UK between 1990 and 2018 **(Figure 3)** an increase of 2% was reported over the period 2008 - 2018, signalling that progress towards net zero may at best be slowing, and at worst reversing based on most recent data. However, within the same period, carbon capture from land use, land use change and forestry has increased by 15% representing a 'carbon sink'. The combined effect is that net emission levels have been broadly stable in the past decade, and actually decreased 2% over the period 2008 - 2018 when considering land use, land use change and forestry sector combined which, we would strongly recommend, should become standard practice. Going forward, the Committee on Climate Change progress report to Parliament in 2020 has set the agriculture sector a clear objective to reduce emissions by 3Mt CO_2-eq by 2022. However, current evidence would indicate this may not be achieved.

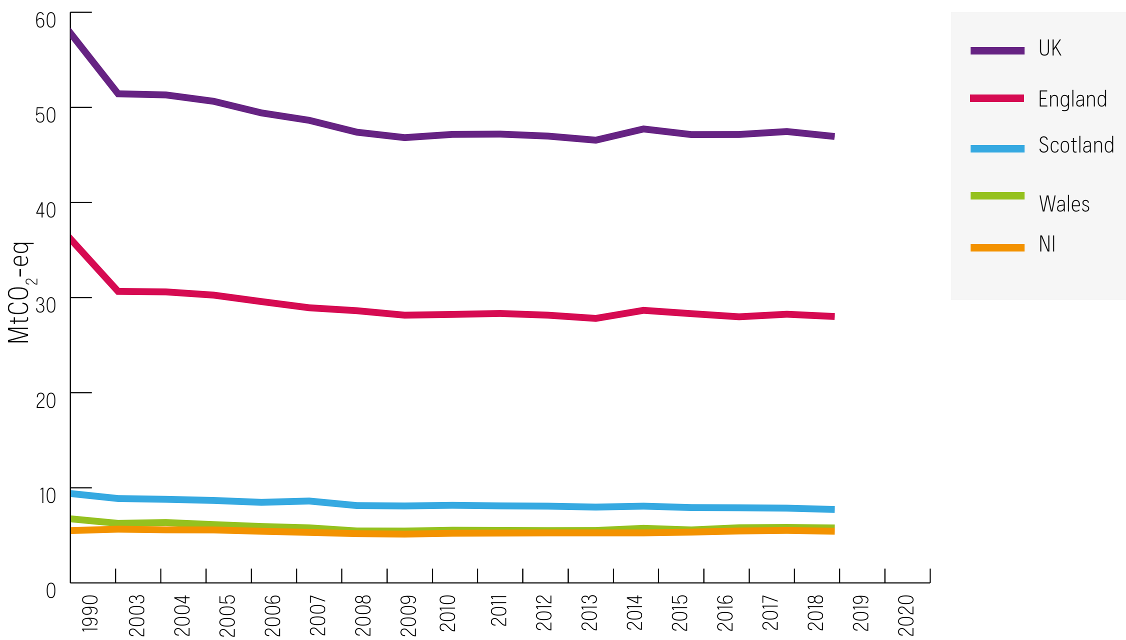


Figure 3. UK agricultural greenhouse gas emissions from 1990 to 2018 (data from BEIS Greenhouse Gas Inventories for England, Scotland, Wales and Northern Ireland 1990 - 2018).

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

Many reports to date have considered what roles, both positive and negative, livestock play in climate change. However, to the best of our knowledge, none of these studies have explored or assessed, at a regional or national level, the impact, risks and opportunities that exist for livestock farming to reduce its carbon footprint and achieve the national goals set. This report aims to address, so far as possible using current information, this major gap in knowledge and in doing so provide baseline knowledge to enable the UK and its devolved administrations to develop national and localised strategies to mitigate losses of greenhouse gas emissions, maximise carbon capture and, ultimately, begin the journey towards a cross-sector net zero carbon economy. For the first time, UK-specific literature, combined with leading international science and best practice recommendations, is collated and interpreted in this unique report, designed to inform a wide range of stakeholders with responsibility across the livestock industry.

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

The conundrum

Climate change is a global challenge and the production of meat, milk and eggs is a major contributor through the production of greenhouse gas emissions, as a result of complex biological processes in addition to anthropogenically generated pollution, i.e. pollution generated by humans or human activity (e.g. combustion of fossil fuels). Agriculture contributed 10% to the UK's cumulative greenhouse gas emissions in 2018. Livestock emissions are 63% (29.1Mt CO_2-eq) of UK agricultural greenhouse gas emissions, with primary sources being methane from enteric fermentation (21.9Mt CO_2-eq) and management of manure (7.2Mt CO_2-eq). There is a UK goal for reducing UK emissions from all sources by 15.5Mt CO_2-eq each year between 2018 and 2050, as recommended by the Committee for Climate Change. The livestock industry has a major role to play in delivering this goal.

Protein consumption in the UK is higher (by around 70%) than that recommended by WHO guidelines for a healthy diet. However, when consumed according to relevant dietary requirements and advice, the nutrients provided by meat, milk and eggs play an essential role in the health and nutrition of the UK's population. This is especially pressing due to rising cases of anaemia (iron), zinc and calcium deficiency in the human population, all of which are sourced most beneficially from livestock products. For example, the requirements for zinc may be as much as 50% higher for an individual selecting a vegan diet than those who do consume animal products, due to greater bioavailability. These nutritional benefits are in addition to wider co-benefits fulfilled by farmed animals, such as producing leather and wool (as critical alternatives to plastics), and as a vital provider of organic matter (manure) to improve soil health. The UK livestock farming sector is also unique in its role in rural cohesion and resilience. Finally, large parts of the UK's land mass, driven by geology and climate, are not suitable for arable and horticultural agriculture. Therefore, livestock carry out an important role in using a proportion of that land, converting inedible sources of nutrients (e.g. fibrous grasses) into highly valuable, bioavailable nutrient dense food for human consumption. Indeed, livestock are vital components of a green circular economy as important converters of nutrients from food waste and co-product streams of many crop production systems (e.g. distillers' grains).

It is clear from the brief discussion on UK animal production above, that there are convincing arguments in support of the production of meat, milk and eggs on UK land. However, it is equally recognised that emissions from the livestock sector are biologically unavoidable but need to be minimised as far as feasibly possible, and off-set based on current and future technological interventions.

"There is a UK goal for reducing UK emissions from all sources by 15.5Mt CO_2-eq each year between 2018 and 2050, as recommended by the Committee for Climate Change"

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

The policy environment

In 2019, the UK was the first economy in the world to put in place laws to legislate for the achievement of a net zero carbon economy by 2050, and in doing so end its contribution to global warming in line with recommendations provided by the Committee on Climate Change[3]. These new laws amended the Climate Change Act of 2008, which declared a target of an 80% reduction in greenhouse gas emissions compared with 1990 levels.

The Intergovernmental Panel on Climate Change define net zero emissions as being when anthropogenic emissions of greenhouse gases to the atmosphere are balanced by anthropogenic removals over a specified period. Therefore, greenhouse gas emissions need to be equal to or less than emissions removed from the environment, which can be achieved by a combination of emission reduction and removal strategies across all sectors including agriculture.

The Committee on Climate Change[3] considered that opportunities to reach net zero would not be equal across the UK's devolved authorities. For example, it was noted that Wales has less opportunity for CO_2 storage and relatively high agricultural emissions that are difficult to reduce, and therefore could not credibly reach net zero greenhouse gas emissions by 2050, whereas in contrast, Scotland has proportionately greater potential for emissions removal than the UK overall and can credibly adopt a more ambitious target[3]. As devolved administrations of the UK, England, Wales, Northern Ireland and Scotland are working towards net zero by 2050, variance exists in how each of the Home Nations are addressing the issue. For example, Scotland has set a net zero target by 2045 under the Climate Change (Emissions Reduction Targets Scotland) Act 2019, with interim targets of at least 56% by 2020, 75% by 2030 and 90% by 2040; Wales has raised their carbon reduction targets to 95%; England has established a range of task forces, such as the Greenhouse Gas Action Plan developed by agricultural industry representatives to act as a primary mechanism for delivering the commitment of a 3 Mt CO_2-eq reduction in annual emissions in England by the third carbon budget period (2018 – 2022). Northern Ireland continues to support the work of the Greenhouse Gas Implementation Partnership whilst also developing a cross-departmental 'Green Growth' Strategy led by the Department of Agriculture, Environment and Rural Affairs (Defra).

It is of critical importance for policymakers to note that the agricultural and forestry sectors (which are inherently intertwined) are uniquely positioned to support the livestock sectors, by offsetting greenhouse gases which cannot be reduced to zero due to inherent biological processes (i.e. livestock will excrete). This document takes a first step in achieving this urgently needed unity by:

(a) transparently acknowledging the burdens associated with livestock-based food production,

(b) recommending immediate uptake of available options which are economically viable to reduce these burdens, and;

(c) offering insights into how livestock farming can work with other sectors, such as energy and transport, to offset their burdens - a potential service rarely credited to farmers in reports.

CIEL

NET ZERO CARBON
& UK LIVESTOCK

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

04. Current carbon benchmarks for livestock systems

Carbon footprints differ significantly across the various livestock systems of the UK (**Table 1**). These differences are often driven by feed composition, animal efficiency and growth rates and/or egg/milk yields, and where applicable material inputs such as nitrogen fertiliser and, particularly in housed farming systems, fossil fuels. In addition, model assumptions, such as system boundary and functional unit definition, result in significant differences as evident by values reported between both data sources in **Table 1**. Based on these factors, it is important to note that both sets of values in **Table 1** cannot be compared like for like. They do, however, demonstrate how subjective decisions such as those mentioned above can affect the interpretation of a study. Regardless of this methodological issue, the major emission hotspots for livestock systems are usually methane produced via enteric fermentation for ruminants, and emissions associated with feed production for pig, poultry and, in certain circumstances, dairy systems. For example, methane, one of agriculture's dominant greenhouse gases, accounted for 56% of total emissions from agriculture farming in 2018. Furthermore, as reported in the Committee on Climate Change Progress report of 2020 [1], almost half of total agricultural emissions were from ruminant livestock and 31% of emissions from nitrous oxide.

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

Conversely and contrary to common belief, transportation, both of feed and food, has a relatively small contribution to the carbon footprint of animal-based products since feedstuffs are transported via sea cargo (which has significantly lower greenhouse gas emission potential than air freight). For example, the transport of feed items, including soya from Argentina to the British Isles to receiving commercial pig production units, accounts for only 8% of feed-related emissions, meaning the system-wide impacts of feed transportation (also known as "food" or "feed miles") are < 2%, making them, arguably, negligible relative to major hotspots (e.g. enteric methane or feed production). Lastly, it is important to note that, in general, post-farmgate activities such as processing, distribution and retail. play relatively small roles in supply-chain burdens, collectively accounting for less than 10% of system-wide emissions according to a study of US beef production.

	Defra	P&N[a]
	Global warming potential[b]	Global warming potential[c]
Beef (dairy herd)	10.7	25.9
Beef (beef herd)	25.3	48.4
Chicken (meat)	4.6	9.8
Chicken (eggs)	5.5	4.2
Lamb	17.4	37.4
Milk	1.1	2.3
Pork	6.4	11.9
Turkey	NA	12.6

Table 1. Carbon footprint per unit of production.

[a]P&N: Poore and Nemecek; a study published in Science in 2018 described above

[b]The system boundary of the Defra study is cradle-to-farmgate and adopts functional units of 1kg bone-in carcass weight, ~1kg eggs and 1kg milk; emissions are reported askg CO_2-eq

[c]The system boundary of the P&N study is cradle-to-retail, notably wider than Defra, and adopts functional units of 1kg edible solid product and 1 L milk, including impact of land use change for feed production overseas; emissions are reported as kg CO_2-eq

"Conversely and contrary to common belief, transportation, both of feed and food, has a relatively small contribution to the carbon footprint of animal-based products since feedstuffs are transported via sea cargo"

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

Dairy for milk (cattle)

Dairy systems in the UK vary widely in performance level and use of feed resources, particularly grazed grass, conserved forage and concentrates. The simplest classification of dairy systems is according to length of time that cows spend grazing. Five categories have been defined to describe the diversity of systems, with annual grazing time decreasing in three-month increments from nine months in System 1, to zero in System 5, where cows are housed all year[6]. A common characteristic across these systems is that as the proportion of grazed grass decreases, milk yield and feed efficiency increases as does forage and concentrate use, but total land use decreases.

National UK data for system 1 (nine months grazing), 3 (six months grazing) and 5 (fully housed) were used (C1, C2 and C3 in **Table 2**, respectively) to calculate greenhouse gas emissions from enteric fermentation, manure management, fertiliser application to pasture and feed production (**Table 2**)[7]. Feed and enteric methane were key contributors to the carbon footprint of each system across conventional and organic farms. On average, the overall carbon footprint of organic farms was high compared with conventional farms, and within the conventional farms the carbon footprint was highest when cows were grazed for nine months of the year. It is notable that the carbon footprint of fully housed cows was approximately 18.5% lower than that of cows grazing for nine months of the year. However, a review of high performing housed and grass-based dairy farms, based on UK, US and Republic of Ireland data, found that without the inclusion of soil carbon sequestration the grass-based and housed dairy systems could have similar carbon footprints[8]. When soil carbon sequestration was included, the grass-based system had a carbon footprint of milk 5% lower than the UK housed system, and 7% lower than the US housed system. This clearly highlights, for all systems, improvements in efficiency and increases in milk yield will improve the carbon footprint on a per litre basis.

As noted previously, it is important to consider other aspects of the system and not just carbon footprints when determining the sustainability of a given system. The impact on other polluting gases should be considered, e.g. whilst the work reported here found little difference in ammonia emissions across the conventional systems, modelling of dairy systems from Northern Ireland has demonstrated significant differences between indoor and grazing dairy systems, with grazing being promoted to reduce ammonia emissions. With regard to animal health, which is an indicator of social sustainability, production disease can increase the carbon footprint of dairy cows by ~10% each [9]. The impact of these complex real-world situations on model outputs, both directly (e.g. the effect of animal health on emissions) and indirectly (e.g. ammonia oxidizes to nitrous oxide) demonstrate the need for holistic systems-based research and modelling to aid the development of effective action plans within devolved administrations.

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

	Unit	C1	C2	C3	O1	O2
Grazing access	days/year	270	180	0	270	200
Milk yield (energy corrected)	kg/cow/year	5500	7800	9200	4700	6300
Culled carcass yield (beef)		85.6	77.3	91.1	73.9	79.1
Calves yield (beef)	calves/cow/year	0.6	0.7	0.6	0.7	0.6
Land use footprint	**(ha/cow+replacements)**					
Grazing land		0.4	0.1	0.0	0.5	0.3
Grass silage land		0.1	0.3	0.2	0.2	0.4
Maize silage land		0.0	0.0	0.1	0.0	0.0
Imported feed land		0.1	0.1	0.2	0.2	0.4
Total land use		**0.6**	**0.5**	**0.5**	**0.9**	**1.1**
Total occupied land	ha/t milk	0.1	0.1	0.1	0.2	0.2
Ammonia emissions	% of N excretion	12.2	15.7	19.7	9.1	13.6
	t/ha/year	10.0	15.0	19.3	5.4	5.6
	kg/t milk	2.5	2.1	2.5	2.1	2.4
Greenhouse gas emissions	**kg CO_2-eq/kg milk**					
Feed carbon footprint (minus N application)		0.3	0.4	0.4	0.4	0.4
Enteric methane		0.7	0.5	0.4	0.8	0.6
Manure management methane		0.1	0.1	0.1	0.1	0.1
Direct nitrous oxide		0.2	0.1	0.1	0.1	0.1
Indirect nitrous oxide		0.0	0.0	0.0	0.0	0.0
Total carbon footprint (beef + dairy)	**kg CO_2-eq/kg milk**	**1.2**	**1.1**	**1.0**	**1.3**	**1.2**
Burdens allocated to milk		1.1	1.0	1.0	1.1	1.0
Burdens allocated to beef		0.1	0.1	0.1	0.2	0.2
Dairy allocation factor	Proportion	0.9	0.9	1.0	0.9	0.9

Table 2. Carbon footprint hotspots for UK milk production. C1 - 3 are conventional dairy farms whilst O1 - 2 are both organic systems.[7]

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

Poultry for eggs (layers)

For egg production, less intensive supply chains such as organic systems, typically generate higher quantities of greenhouse gas emissions compared to intensive conventional operations (**Table 3**). This is largely due to slower growth rates to lay which often occur as a result of restricted inputs (e.g. certain feedstuffs and agrochemicals are banned in order to satisfy organic certification requirements) which can also affect mortality percentages negatively. However, for all UK poultry production systems, feed (and water) are the main hotspots (70 - 80%) of greenhouse gas emissions in these supply chain when using life cycle assessment. Within the overarching feed hotspot, as noted, imported commodities, most frequently soya, comprise large proportions of feed-related burdens. However, many of these imported commodities carry additional environmental impacts associated with land use change (e.g. deforestation of rainforests to grow feed causes loss of biomass and soil carbon, whilst simultaneously losing carbon uptake benefits of the forest itself, without even considering impacts on biodiversity). This creates an additional layer of complexity for global sustainability policymaking (e.g. who takes responsibility: consumer or producer) and perhaps paradoxically demonstrates the need to cease assessing pollution potentials at national levels because geographic boundaries offer no protection from atmospherically transient gases. Lastly, given societal pressures demanding improvements to animal health and welfare, there is a surprising gap in knowledge pertaining to the effects of animal health on the environmental impacts of poultry systems. This area of research requires urgent action.

Material or activity	Cage*	Barn	Free range	Organic
Feed and water	2,100	2,220	2,360	2,410
Electricity	240	480	200	240
Gas and oil	90	140	180	180
Housing and land	380	480	500	540
Manure and bedding	110	130	140	60
Total	2,920	3,450	3,380	3,430

**Cage systems have now been replaced by colony systems which are highly comparable.*

Table 3. Carbon footprint hotspots for UK egg production reported as kg CO_2-eq/tonne eggs. [10]

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

Poultry for meat (broilers)

In one of the most comprehensive environmental assessments of British poultry meat production to date, three major UK broiler systems were compared: standard indoor; free range; organic. The study covered impacts associated with cradle-to-farmgate activities, and adopted a functional unit of 1 tonne edible carcass weight (t CW) (though the authors of the study did not include abattoir-related burdens). Regarding the carbon footprints of the aforementioned systems, the authors reported that livestock performance played a substantial role. The global warming potential calculated as IPCC 100-year average was lowest on the standard conventional system (4,410kg CO_2-eq), followed by free range (5,130kg CO_2-eq) with the organic system demonstrating the largest impact (5,660kg CO_2-eq) (**Table 4**). Feed was the dominant hotspot, regardless of system, with production, processing and transport of the feed accounting for ~72% of global warming potential. There were, however, differences in single-feed items' contributions to emissions intensities across systems. For example, within the feed production phase, soya meal and wheat production were the primary greenhouse gas producing activities for standard (accounting for 41.9% and 28.3% of total feed burdens, respectively) and free range (45.1% and 33.7%, respectively). Nevertheless, wheat was the largest source of emissions for organic (62.8%) production, with soya meal contributing only 13.5% of feed-related emissions. In terms of land use, relative rankings were slightly different to those observed under global warming potential, with free range requiring the least land (0.19 ha/t CW), followed by standard (0.20 ha/t CW) and organic production, which required approximately three times as much land than the other two systems (0.59 ha/t CW). Whilst it has long been known that organic systems have higher global warming potentials per kg product compared to intensive agricultural methods, it is worth noting that, when the functional unit is changed to "impacts per area", organic systems can demonstrate lower emissions than their mainstream counterparts due largely to the extensive land use coverage typically observed in organic farming. Other trade-offs also need to be considered, for example, a major study across five continents examining 1,800 species concluded that land sparing (i.e. intensive farming) is better for biodiversity than land sharing if you assume the same demand and therefore production of the product (i.e. no differentiation driven by preference to consume less of a "higher quality"). Overall, like dairy systems noted previously, analysis of whole systems is a critical gap in the knowledge and understanding needed to address sustainability in its widest form.

Material or activity	Standard	Free range	Organic
Feed and water	3,140	3,690	4,080
Electricity	160	150	170
Gas and oil	430	340	310
Housing and land	530	780	1,030
Manure and bedding	140	160	80
Total	4,410	5,130	5,660

Table 4. Carbon footprint hotspots for UK poultry meat production reported as kg CO_2-eq/1,000kg edible meat. [11]

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

Pork

The UK is unique in Europe as it is one of the only countries which extensively adopts outdoor pig production during breeding. In fact, around 40% of all British pig production maintains breeding sows and piglets outdoors, whereas in the Republic of Ireland, for example, over 95% of commercial breeding occurs indoors. Greenhouse gas emissions per unit of product produced for the UK's pig production sector reduced by 37% (**Figure 4**) between 2000 and 2017 due, primarily, to improvements in performance (e.g. growth rates) whilst simultaneously minimising material inputs such as feed, with largely negligible (~2%) system-wide differences observed between indoor and outdoor breeding operations[12]. As is the case in all pig life cycle assessment studies, the authors reported that feed production was the dominant hotspot for global warming potential (**Table 5**) and naturally land use, and found that fluctuations in soya meal inclusion (due to a combination of decreased energy requirements and volatile prices) unequivocally displayed reductions in footprints when soya content was reduced. The high impact associated with soya is, to a degree, driven by land use change emissions in other countries. Similarly to poultry discussed above, pig production has garnered little attention when it comes to interactions between animal health and greenhouse gas emissions. This represents a gap in knowledge. Although pork is not typically associated with large carbon footprints, as supply and demand increases, it is critical to ensure environmental performance does not deteriorate, as well as focusing on sustainability issues where the sector has a larger impact, for example nitrogen and phosphorus pollution.

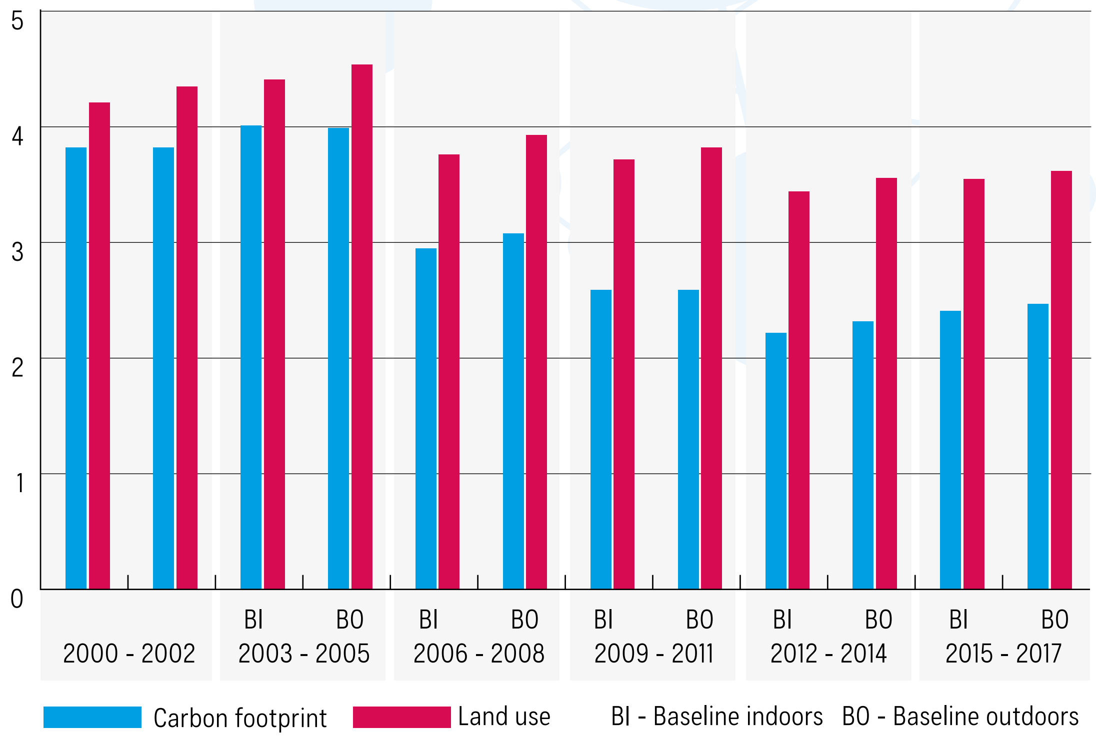


Figure 4. Carbon and land use footprints for UK pig production[12] reported as kg CO_2-eq/kg LW

	Indoor	Outdoor
Feed[a]	2.1	2.1
Manure management and enteric methane	0.1	0.1
Electricity	0.1	0.3
Total	**2.4**	**2.5**

Table 5. Carbon footprint hotspots for UK pig production reported as kg CO_2-eq/kg LW. [12]

[a] The life cycle assessment model used to calculate the above did not account for emissions arising from housing and land (such as the range in outdoor systems). These contributions to total carbon footprints are expected to be relatively small.

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

Lamb

In a study of the British sheep sector, the mean carbon footprints for lowland, upland and hill sheep enterprises were 10.9kg CO_2-eq, 12.9kg CO_2-eq and 17.9kg CO_2-eq per kg liveweight, respectively (**Table 6**). However, the range of values within a farm-type was considerable. For instance, the hill farm, which had the highest mean carbon footprint, also had the highest coefficient of variation (34%), with a minimum (8.8kg CO_2-eq/kg liveweight) lower than the mean lowland value and a maximum (33.3kg CO_2-eq/kg liveweight) considerably higher than the maximum footprint on lowland (21.5kg CO_2-eq/kg liveweight) and upland (18.3kg CO_2-eq/kg liveweight) farm-types. The major hotspots across all farm-types were enteric methane emissions and nitrous oxide emissions arising from excreta and manure. However, regarding carbon footprint differences within each of the farm-types, there are considerable opportunities to improve the poorest performing farms, through for example, better management and adoption of genetic selection to improve the efficiency of outputs, in line with the average or, ideally, the best performing flocks and animals. Another avenue for reducing emissions is through ensuring as far as possible, that sheep health is well-maintained: one study found that gastrointestinal nematodes can increase total greenhouse gas emissions by 10%, whilst another noted that lambs' methane emissions increased by 33% when they were infected with parasitic worms (specifically *Teladorsagia circumcincta*)[9]. As sheep production accounts for approximately 16% of the UK's enteric-associated methane emissions[13], reducing the carbon footprints of lamb, hogget and mutton could be a feasible opportunity to reduce agriculture's contribution to net greenhouse gases.

	Lowland	Upland	Hill
Carbon dioxide (manufacturing)			
Fuel	0.3	0.9	0.4
Electricity	0	0.1	0
Fertilisers	0.3	0.5	0.5
Lime	0.1	0.2	0.3
Agrochemicals	0	0	0
Bedding materials	0	0	0
Mixed greenhouse gas from growth of inputs			
Concentrates and other feeds	0.8	0.5	1.1
Purchased stock	0.5	0.3	0.5
Inputs total	2.1	2.5	2.7
Nitrous oxide (soils)			
Direct - fertiliser	0.4	0.4	0.3
Direct - excreta & manure	2.3	2.5	3.4
Direct - crop residues	0.1	0	0
Direct - peat soil	0	0.1	0.7
Indirect - volatilised	0.5	0.5	0.7
Indirect - leaching and runoff	0.6	0.6	0.8
Nitrous oxide (manure storage)			
Direct	0.1	0.2	0.1
Indirect	0	0.1	0.1
Nitrous oxide total	**3.9**	**4.4**	**6.1**
Methane emissions			
Enteric fermentation	4.6	5.6	8.6
Excreta	0.1	0.1	0.2
Methane total	**4.7**	**5.7**	**8.8**
Carbon dioxide from lime	**0.1**	**0.2**	**0.3**
Total mean carbon footprint	**10.9**	**12.9**	**17.9**

Table 6. Carbon footprint hotspots for UK lamb production reported as kg CO2-eq/kg liveweight leaving the farmgate. [14]

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

Beef (suckler)

The UK's suckler beef sector is largely permanent pasture-based (>70%), however, there is large variation between animal genetics (breeds – both late and early maturing, and crosses), grassland resources (upland and lowland-improved pasture) and management type (proportion of grazing to cereal in the finishing/fattening stage) within the sector. These differences result in a wide variation in the carbon footprint of the suckler beef sector, with age at slaughter (typically anywhere between one and three years) and feed quality (on-farm resources) being major connected contributing factors and focus points. Recent work at UKRI's National Capability, the North Wyke Farm Platform, compared the cradle-to-gate level (i.e. including the suckler herd) carbon footprints of the three most common lowland grassland systems in the UK, namely: permanent pasture (perennial ryegrass dominated); a white clover and perennial ryegrass mixed sward; and a ryegrass monoculture reseed; producing values of: 22.6, 21.2 and 23.5kg CO_2-eq/kg liveweight for the three pasture systems, respectively.

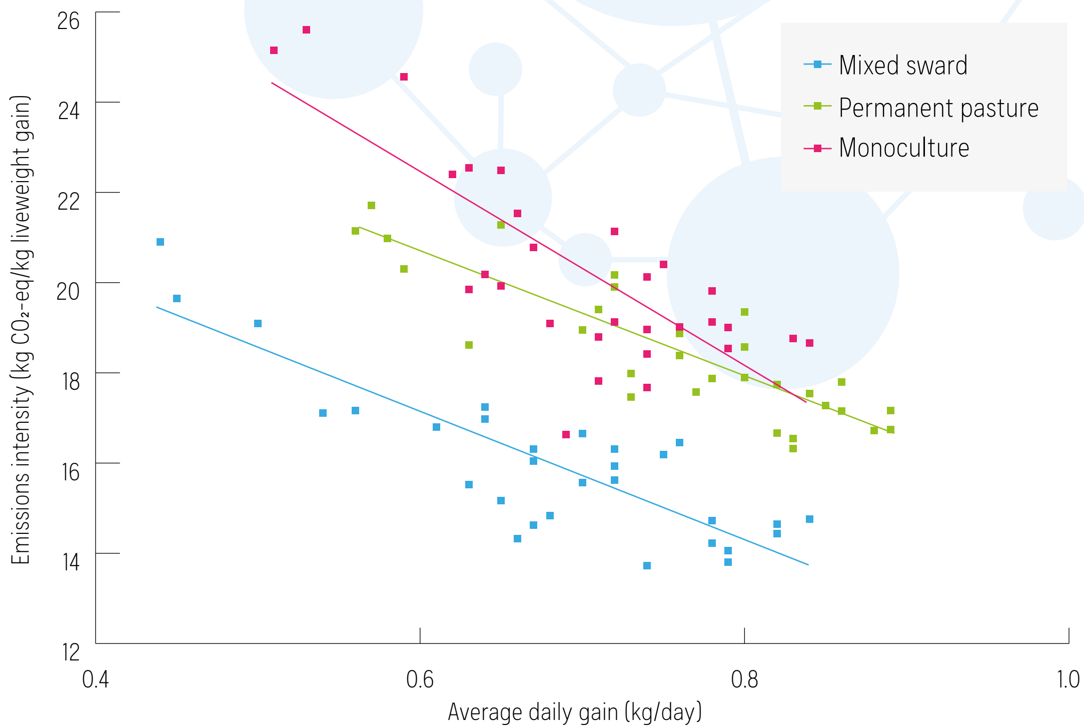


Figure 5. The relationship between carbon footprints and average daily gains for finishing cattle.[15]

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

The major hotspots across the systems were largely methane produced via enteric fermentation and, in the case of the permanent pasture and the monoculture, ammonium nitrate production and application, which resulted in the lower values for the mixed sward system as it relied on legume nitrogen-fixation. To emphasise the importance of growth rates on carbon footprints, the authors of the UKRI study calculated the environmental impacts of each finishing animal separately, and found that average daily gain is both strongly and negatively correlated with emissions (in other words, the higher the weight gains, the lower the carbon footprint; (**Figure 5 and Table 7**). These findings demonstrate there is considerable potential to reduce farm-level suckler beef emissions through improved genetic selection, focussing on faster growth rates, better fertility and overall output against inputs. However, it should be noted that the majority (~60%) of cradle-to-farmgate emissions in a suckler system come from the breeding phase, and are heavily dependent on the parity per cow. Finally, as with the other species mentioned previously, beef cattle that suffer from ill health are prone to producing higher carbon footprints. Salmonella, for instance, has been shown to increase greenhouse gas emissions by 30% while bovine viral diarrhoea (BVD) can increase suckler beef's carbon footprint by as much as 130%[9], once again highlighting that maintaining livestock's health holds multifaceted benefits with regards to sustainable food systems.

	Permanent pasture	Mixed sward	Monoculture
Enteric fermentation (CH_4)	7.1	7.7	7.5
Manure management (CH_4)	1.4	1.8	1.7
Manure management (direct N_2O)	1.2	1.1	1.1
Manure management (indirect volatilisation N_2O)	0.2	0.9	0.9
Barley production	0.7	0.6	0.6
Ammonium nitrate production	3.6	0.5	3.3
Fertililser application (N_2O)	2.0	0.3	1.9
Urine and dung from ewes on pasture (N_2O)	0.6	0.7	0.7
Farmyard manure application (N_2O)	0.4	0.5	0.5
Crop residues (N_2O)	-	0.3	0.3
Indirect emissions from leaching (N_2O)	0.2	0.1	0.2
Urine and dung from cattle on pasture (N_2O)	0.3	0.2	0.2
Single superphosphate production	0	0.2	0
Others[a]	1.0	1.8	2.0
Total	**18.5**	**16.0**	**20.2**

Table 7. Carbon footprint hotspots for beef production during finishing on grassland.[15]

[a]Includes processes which account for <1% of the total emissions intensity: lime production and decomposition, soya production, pesticide production, transportation and diesel combustion for machinery.

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

Beef (dairy bred)

Approximately half of beef produced in the UK comes from suckler herds and half from dairy herds (cull cows and calves for fattening). Beef from dairy-bred calves have half the carbon footprint of suckler beef because all the emissions for a suckler cow are allocated to beef, whereas over 90% of emissions for a dairy cow are allocated to milk, approximately 5% to cull cow beef and 1% to beef calves (**Table 2**).

Calves born in the dairy herd have a wide range in genetic makeup, which is reflected in the variety of fattening systems employed. The primary purpose of producing a calf from a dairy cow is to initiate lactation, and the secondary purpose is to provide female calves that can be reared as replacements for older cows that are culled from the herd. With typical replacement rates between 25 and 33%, at least 50 to 70% of dairy cows will be mated to a bull of a dairy breed (90% Holstein-Friesian). Dairy cows not required for breeding replacements can be mated to a bull of a beef breed. Many beef breeds are used for crossing with dairy cows. Late maturing breeds (e.g. Charolais, Limousin, Belgian Blue) grow rapidly and mature (fatten) at a heavy weight; early maturing breeds (e.g. Hereford, Aberdeen-Angus) grow more slowly and fatten easily at lighter weights. Thus, there are three breed types: pure dairy (bull calves and surplus heifer calves); late-maturing beef cross dairy; and early-maturing beef cross dairy. Fattening systems are matched to breed types.

Intensive systems are suitable for late-maturing bulls and steers, and aim to finish animals on cereals at 12 - 14 months of age, or silage at 14-16 months of age. Semi-intensive systems are suitable for all types of dairy-bred animals, and aim to finish animals at 18 months of age. Animals spend one or two summers grazing and one or two winters indoors. Extensive systems are suitable for early-maturing animals and aim to finish animals at 24-30 months of age mainly on grass and grass silage. The Cranfield Life Cycle Assessment model estimates carbon footprint (kg CO_2-eq/kg carcass) of 10.4 for intensive systems, 10.6 for semi-intensive systems, and 11.8 for extensive systems. Differences in emissions reflect differences in length of fattening period, weight at slaughter, and diet with enteric fermentation as the key source of methane driving the carbon footprint along with feed production.

Hotspots for fattening dairy-bred beef calves are enteric methane, feed production and manure management, but relative contributions change across systems. For national beef production, a hotspot is fertility of dairy cows, which affects the number of calves required for dairy replacements or available for beef production.

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

Summary

The previous sections identified key areas of each major livestock system which contribute to greenhouse gas emissions, and in turn the key areas of opportunity where improvements could be made. It is accepted that the intensive sectors have tended to adopt technology to a greater extent than the extensive sector, and this has been effective to improve efficiencies and reduce their carbon footprint. However, much improvement is still possible, on average, across all sectors to improve efficiency and animal health. For all systems, adoption of current known mitigations, especially to the poorest performing herds and flocks, could significantly improve their carbon footprint. Anecdotal evidence would suggest that such adoption of best practice by the lowest performing herds and flocks across the UK could contribute up to a 30% improvement across the livestock industry. The need for holistic system-based analysis is also needed to ensure true sustainability is achieved.

“For all systems, adoption of current known mitigations, especially to the poorest performing herds and flocks, could significantly improve their carbon footprint”

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

05. Comparison of systems

When life cycle assessments are used in a streamlined manner (e.g. both studies presented separately in **Table 1** in this report), they provide a highly informative approach to compare environmental burdens of different supply chains, although they may use different system boundaries and functional units. However, life cycle assessments for livestock systems have many pitfalls, such as inconsistent adherence to and interpretation of the method and the risk of bias due to the requirement of subjective decisions. In terms of burden comparisons, beef and sheep meat systems are typically associated with higher carbon footprints than chicken and pig meat, due primarily to ruminant enteric fermentation and the warming impact of methane, assumed under IPCC's 100-year average impact assessment (**Table 1**). Regarding land use, when all agricultural land is treated as equal (e.g. when sparsely vegetated uplands are considered to be as productive as lush lowlands and arable soils), the same relative rankings observed under the carbon footprint comparisons are true (**Figure 6A**) and pigs and poultry consistently perform better than ruminants. However, when the metric is changed to arable land use, ruminant systems such as upland lamb, have considerably lower land use footprints than pigs and poultry. Much of the land occupied by ruminants is unsuitable for human-edible crop production because certain soil types mean when they become waterlogged, it is near-impossible to operate machinery on the land to harvest cereals, demonstrating the weighty effect of subjective decisions (e.g. choice of functional unit) on the interpretation of life cycle assessment results (**Figure 6B**).

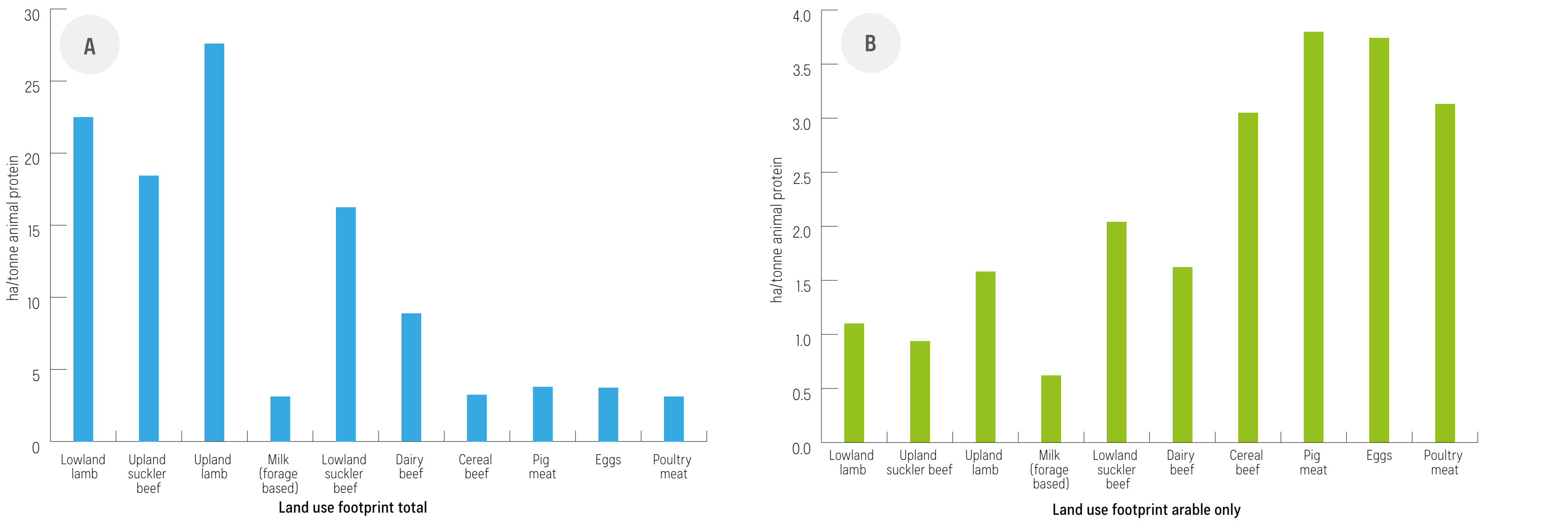


Figure 6. Land use footprints to support production systems: Overall versus arable only.[16]

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

Novel, alternative carbon footprint calculations, such as using a product's nutritional density as a functional unit, which seems more logical when comparing food items than purely its weight, can also reverse relative rankings (e.g. concentrate beef systems have been shown to have lower carbon footprints than certain pig and poultry systems, when nutritional density is considered; **Figure 7**). Furthermore, different feeding regimes can affect the nutritional quality of meat resulting from a given system, particularly long chain fatty acids such as omega 3 and omega 6 as well as their ratios of composition which are known to affect human health (in typical Western diets, it is favourable to have high levels of omega 3 fatty acids and lower levels of omega 6 fatty acids due to under consumption of the former), showing again the importance of communicating the effects of methodological choices clearly and transparently.

"In terms of international performance, the UK maintains a highly efficient agricultural sector with a strong track-record of animal welfare relative to other industrialised countries"

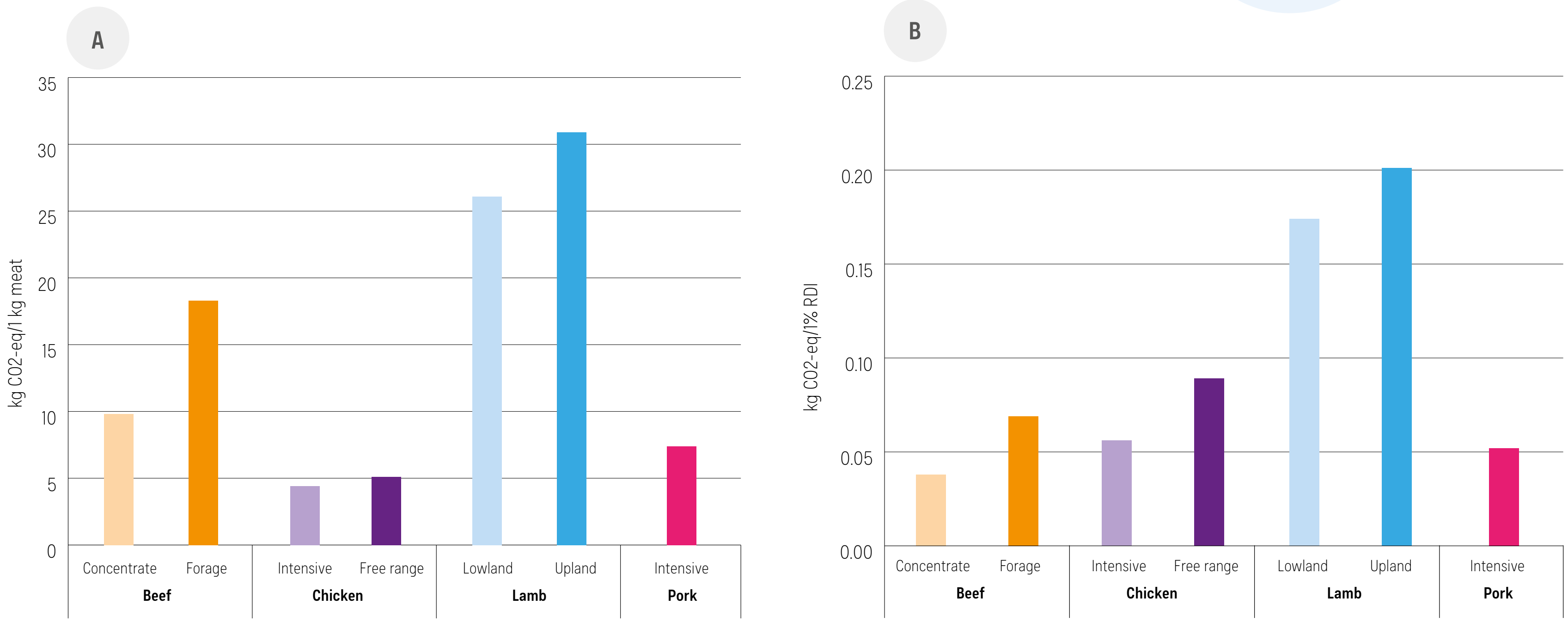


Figure 7. Carbon footprints relative to fresh weight or nutrient density, as recommended daily intake, RDI.[17]

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

In terms of international performance (**Figure 8**), the UK maintains a highly efficient agricultural sector with a strong track-record of animal welfare relative to other industrialised countries, but given parts of the nation are ideal for ruminant production (e.g. the uplands of Northern Wales, the clay soils of South West England and most of Northern Ireland), it also generates large quantities of methane. However, there are options for emissions mitigation, for example a shift in feeding regimes which have been shown to have considerable influence on both milk yield and carbon footprints (**Figure 9**).

Furthermore, although **Figure 8** demonstrates the UK's livestock sector produces the third largest amounts of greenhouse gas emissions across European countries due primarily to its large agricultural economy compared to small countries like Cyprus, when the emissions are scaled to yield (e.g. carcass weight or eggs produced), the relative rankings are notably different. For example, when dairy emissions are scaled to kg cows' milk, the UK has the sixth lowest carbon footprint out of 27 countries in the same study that reports total emissions for UK dairy are the third highest in total. This once again highlights risks of drawing different conclusions based on different assessment methods.

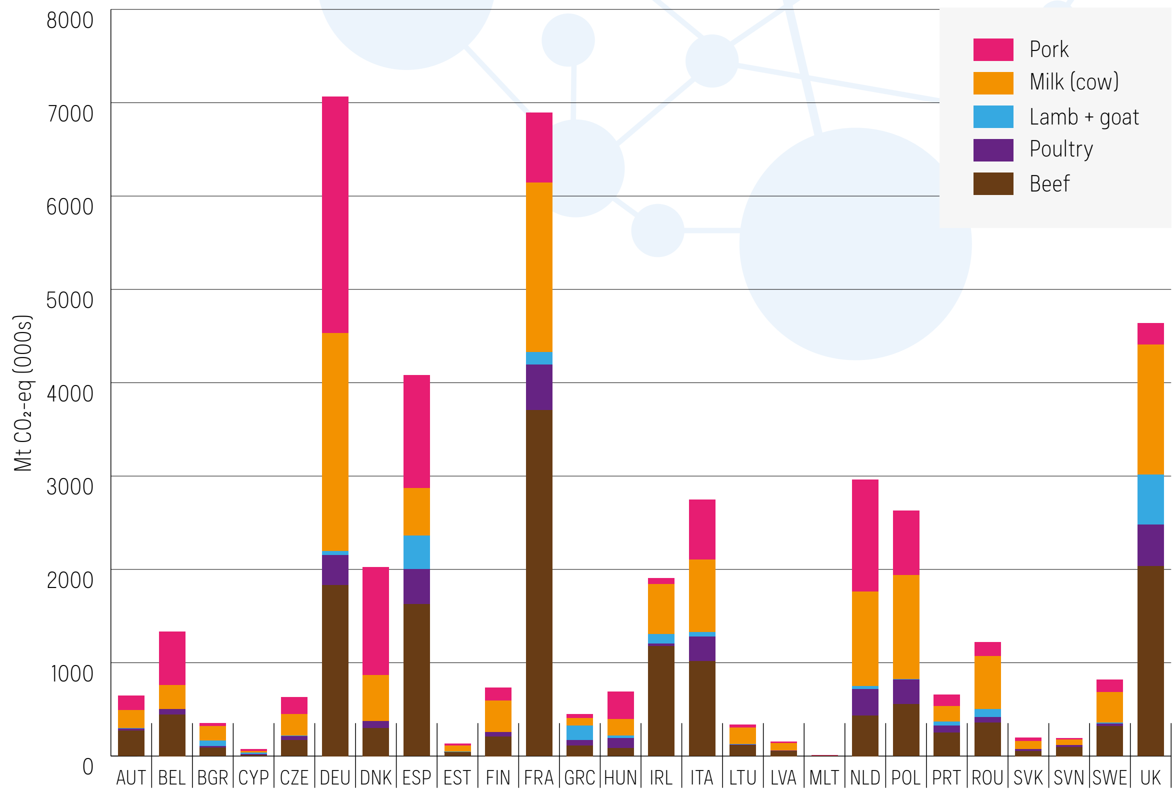


Figure 8. Total carbon footprint per country for livestock products.[18]

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

Whilst British pork and poultry production do not generate substantial greenhouse gas emissions per kg of product, given the sectors' throughputs (927,000kg for pork and 1,807,000kg edible product for poultry in 2017), their combined UK emissions do make notable contributions to the UK's national inventory in terms of greenhouse gas emissions, meaning it is critical to maintain, or ideally reduce, their emissions as far as feasibly possible.

Lastly, there are considerable opportunities regarding methodological improvement to reach a better-understanding of systems' interconnectedness (for example between dairy and beef) and wider implications of sustainability; some of these include assessing food items' roles in different dietary contexts accounting for biochemical issues such as nutrient digestibility (i.e. how much of a given nutrient a given person is capable of absorbing in their small intestine) and bioavailability (i.e. how much of a given nutrient is unbound to anti-nutritional compounds and therefore available to provide sustenance), both of which can vary drastically between certain food products and, naturally, food groups (e.g. protein or carbohydrate sources); nutritional uptake is also affected by gender and ethnicity, adding even more complexity to future efforts of devising potential reconciliation between food and the environment.

Overall, when comparing systems, transparency of accounting is required and the answer or issue to be addressed should be clear. **Section 6** outlines, in detail, the various accounting systems and provides information for stakeholders to make informed decisions on the use of accounting tools. However, with regards to addressing hotspots across and within the livestock sectors of the UK to achieve net zero (i.e. where emissions are reduced and carbon capture is maximised), it appears that beef and sheep systems could contribute significantly due to potential gains that are possible, especially with regard to efficiency of production and land management and due to their prominent presence across the UK collectively. Opportunities also exist within the intensive sectors of dairy, pigs and poultry, again through efficiency gains but primarily through improvement in feed production methodologies and dietary interventions.

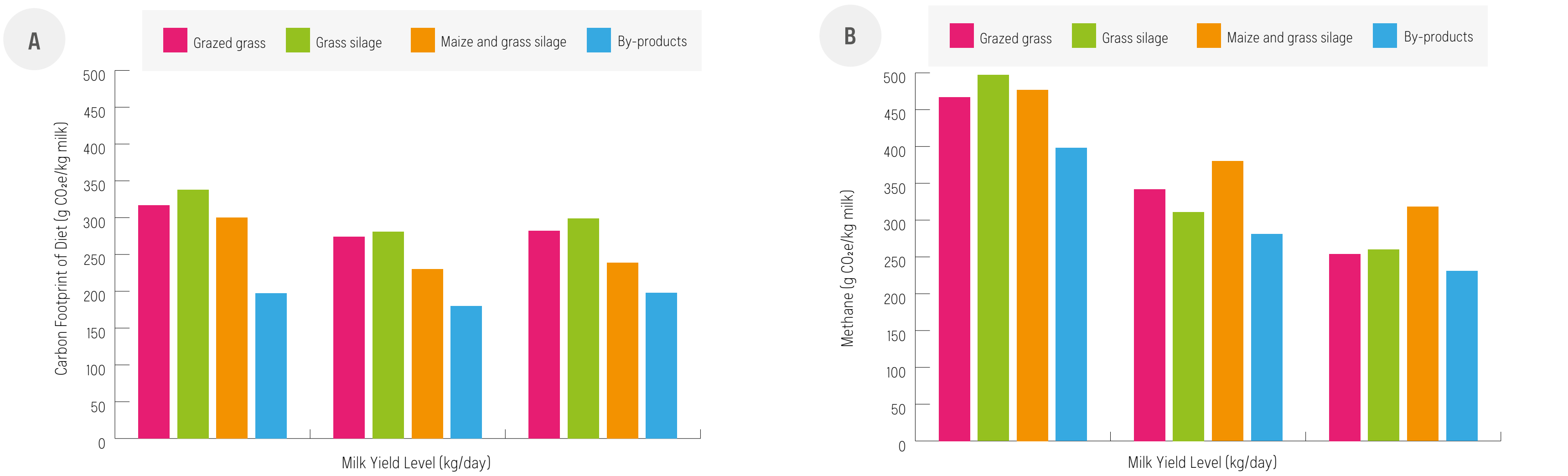


Figure 9. Effect of diet on methane emissions and carbon footprint of diet.[19]

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

06. Carbon accounting and reporting

A common framework for assessing carbon efficiency of UK livestock systems

Accurate assessment of greenhouse gases from agriculture is more challenging than that of other sectors. Unlike other areas of the economy which account mostly for CO_2 emissions from fossil fuel consumption, the agriculture sector needs to quantify multiple interrelated biological production processes of both CO_2 and non-CO_2 greenhouse gas emissions, in a heterogeneous environment that creates significant measurement challenges and uncertainties. There are two fundamentally different approaches that are used to quantify greenhouse gas emissions in agriculture. These are: 1) The inventory approach developed by the IPCC and, 2) life cycle assessment, both of which are considered in this report.

IPCC Inventory reporting:
Since 1996, the IPCC has published guidance that countries are obliged to use in reporting territorial greenhouse gas emissions to the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol, which cover all economic sectors including land use, land use change and forestry (LULUC). IPCC reporting involves the use of emission factors, which are an estimated conversion factor for a particular action or activity within a system, to provide a calculated greenhouse gas release. Emission factors and the IPCC greenhouse gas protocol provides a common and transparent methodology for greenhouse gas accounting, producing results that can be clearly communicated to stakeholders. The calculation of greenhouse gas emissions using IPCC emission factors is mandatory for those countries reporting emissions under the UNFCCC, and have been generated from the compilation of activity data from a wide range of sources, such as experimental studies, national energy balances and animal numbers. The IPCC has classified the methodological approaches in three different tiers, according to the quantity/quality of input data available, and the degree of analytical complexity required [20].

- **Tier one emission factor:** the most basic method using a simplified gain-loss approach described in the IPCC guidelines using default emission factors. (Including some simple assumptions about some C pools). This tier uses fixed values for greenhouse gas emissions per head of livestock, so changes in total emissions reflect only changes in livestock populations.
- **Tier two emission factor:** similar methodological approach as tier one, but applies emission factors and other parameters which are specific to the country. This tier requires more detailed information on the characteristics and performance of different sub-categories of livestock, can better reflect actual production conditions and their impact on greenhouse gas emissions.
- **Tier three emission factor:** higher-order method includes the use of models and can utilise plot data tailored to address more site-specific circumstances in climate, soil, livestock and management scenarios.

Life cycle assessments: life cycle assessments are holistic frameworks for calculating the environmental performances of products and services. Carbon footprints are simply one impact category assessed under life cycle assessment methodology (others include, acidification potential, eutrophication potential, fossil fuel depletion and land use). Many life cycle assessments focussing on or including carbon footprints use IPCC emission factors to calculate total carbon dioxide, methane and nitrous oxide emissions across a given supply-chain.

Although inventory accounting and life cycle assessments share common approaches to calculations, the results that they deliver can often look very different, particularly in the context of agriculture. IPCC define agriculture in a precise way which focusses mostly on farm-based emissions within a given territory (such as the UK). However, life cycle assessment of a food product will compile all emissions associated with the production of that product within defined system boundaries. In the case of UK livestock that can include large greenhouse gas emissions associated with overseas land use change that is associated with the production of feed supplies, such as soya.

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

A comparison of carbon calculating tools

In order to achieve net zero carbon, it is important to measure and monitor. Carbon accounting tools are therefore fundamentally important to understanding both baseline emissions for farms and modelling the impact of mitigations under a range of scenarios. Many tools exist to calculate carbon. This report focussed on tools which have been published and recently reviewed. These recent reviews and multi-criteria assessments [21, 22 and 23;] aimed at assessing and advising on the best tools for various situations; have highlighted that AgRE Calc, Cool Farm Tool and Farm Carbon Calculator were the 'best' performing tools they examined for UK-relevant farming systems. The key strengths of these tools are the capability of covering the main UK livestock and wider agricultural systems, free availability to farmers and advisers, and can provide comprehensive greenhouse gas budgets for both whole-farm and enterprise scenarios. However, there are still limitations in key areas, as shown by the highest-ranking tool only scoring 54% [21] for overall performance. Key strengths and gaps across tools are outlined in **Table 8**. Common knowledge gaps include a lack of representation for embedded emissions (emissions that occur outside the UK territory or inventory, but are caused by UK-based activities) particularly from livestock bought onto the farm, and land use change or management such as the robust quantification of carbon sequestration by soils, crop management practices (and crop variety types), shrub/hedge management and the need for improved quantifying improvements in animal breeding, performance and health in terms of the impacts on greenhouse gas emissions.

"Many tools exist to calculate carbon"

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

Continued development and refinement of the UK's inventory reporting will contribute to minimising uncertainties underlying emission factors, and therefore increase the robustness of life cycle assessments and carbon footprint tools that utilise these for greenhouse gas emission calculations. It is recommended that further work is required to develop the tools in order to better include land use, land use change and forestry practices contributing to offsetting greenhouse gas emissions, and to standardise the quantification of net zero carbon capability in the livestock sector. In addition, tools need to provide more granularity on animal diet composition and adopt an agreed methodology for calculating emissions from home-grown and imported feed sources (for example those outlined by PEFCR 2018[24]). Furthermore, there is a need to evaluate tool accessibility and comprehensiveness (how well it reflects the complex nutrient pathways) as well as the quality and quantity of data it utilises. International standards such as PAS 2050 and criteria defined by the International Dairy Federation can be used to objectively evaluate individual tools. It is also suggested that investment into robust monitoring of new technologies, techniques and advancements in livestock systems are essential to better quantify farm-scale budgets in relation to identifying pathways to achieve net zero carbon targets.

As noted, whilst current calculators have limitations, they do have an important role in measuring and monitoring farm activities and will be key to the urgent and efficient adoption of greenhouse gas mitigations across UK farms. This report suggests that the choice of which tool to use will depend on the user's specific needs, and **Table 8** sets out a framework of considerations which should be made when deciding which of the three calculators to use.

The application of carbon footprint tools to specific circumstances and farming systems needs to consider the following questions in relation to local circumstances:

Model/tool type:

- Is the tool a farm, enterprise or product-based calculator, national inventory or a process-based model?

Targeted scale and livestock system:

- Do the tools include relevant livestock types common to the UK and respective DA's?
- Does the model appear to be suitable for application to UK livestock production based on soil, climate and management factors included in the tool?

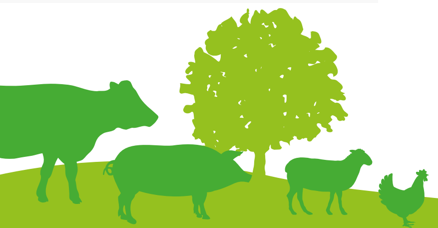
Documentation available:

- Does the tool/model have documentation available outlining its capability and how best to interpret tool outputs?

Model/tool available for evaluation:

- Can the tool/model be easily accessed (i.e. open-sourced) for the purpose of assessing its ability to be applied to the UK livestock sector?
- Do the tools use common data sources? For example, from existing legally required databases and surveys.

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS



	AgRE Calc	Cool Farm Tool	Farm Carbon Calculator
Function, scale, practicality & accessibility:			
Who is the target user?	Farmers, advisers, scientists		
Indicate the level of expertise required	These tools are similar in terms of requiring knowledge and experience of farm-based operations and nutrient/energy flows. Supplementary information available for each tool.		
Does the tool appear to be user friendly? E.g. does it have an easy to follow interface and support material			
What spatial scale is the tool designed for?	Whole farm/ enterprise/ product	Enterprise/ product	Whole farm product
Does the tool rely on raw field data or can survey data be used?	Raw and survey data can be used depending on scale the measurements were taken for each input parameter		
How much data is required and are these clearly outlined in the tool descriptions?	The more data available, the less uncertainty there will be in the estimated values replacing missing data points. Supplementary tool descriptions provide advice about data input requirements		
What are the land use/farm types that the tool can be applied to?	Arable and livestock	Arable and livestock	Arable and livestock
Outputs: Total emissions/total sequestration/farm balance (emissions - sequestration)	Y/Y/Y	Y/Y/Y	Y/Y/Y
Is the tool capable of future predictions/scenario testing?	Y	Y	Y
Is the tool capable of providing management suggestions and/or mitigation options?	N	N	N
Are there any obvious gaps in the tool in generating a greenhouse gas budget?	Y	Y	Y
Are there any obvious sections of the tool that need to be updated/edited based on new understanding?	Y	Y	Y
Indication of comprehensiveness of nutrient pathway described	Y	Y	Y
Who is the model developer and how much does the tool cost to purchase?	SAC Consulting	Cool Farm Alliance	Farm Carbon Toolkit
Does the tool require a license agreement or specialist software?	N	N	N
Tool composition and comprehensiveness:			
Does the tool allow you to specify soil characteristics?	Y	Y	Y
Does the tool allow you to specify crop/grass characteristics (diversity/type)?	Y	Y	Y
Does the tool allow you to specify legume characteristics (diversity/type)?	Y	Y	Y
Does the tool provide an estimate of N-fixation and input based on legume coverage?	N	N	N
Does the tool allow you to specify rotation characteristics?	Y	N	Y
Does the tool allow you to specify some climatic characteristics?	Y	Y	Y
Does the tool allow you to specify N contribution from N deposition?	N	N	N
Does the tool allow you to specify contribution from mineral N-fertiliser type, intensity and application method?	Y	Y	Y
Does the tool allow you to specify livestock characteristics?	Y	Y	Y
Does the tool allow you to specify contribution from manures (amount) and composition (N, P, K)?	N	N	N
Does the tool allow you to provide an indication of manure application type (raw/slurry) and storage?	Y	Y	N
In the tool is nutrient excreta a function of animal diet?	N	N	N
Does the tool allow you to provide an indication of contributions from internal (on-farm) animal feed?	Y	Y	Y
Does the tool allow you to provide an indication of contributions from external (bought-in) animal feed?	Y	Y	Y
Does the tool allow you to provide an indication of contributions from embedded feed composition?	Y	Y	Y
Does the tool allow you to provide an indication of grazing type (cows/sheep) and intensity?	Y	Y	Y
Does the tool allow you to provide an indication of ploughing type, depth and frequency?	N	Y	N
Does the tool allow you to provide an indication of cutting frequency and residue returns?	Y	Y	Y
Does the tool estimate nutrient losses via leaching?	N	N	N
Does the tool estimate yield and grain quality?	Y	Y	Y
Can the tool account for embedded emissions from improving animal health and efficiency?	Y	Y	Y
Can the tool account for embedded emissions in mineral fertiliser production?	Y	Y	N
Can the tool account for on-farm carbon sequestration through afforestation?	Y	Y	Y
Can the tool account for on-farm woodland management?	Y	Y	Y
Can the tool account for direct land use change?	Y	Y	Y

Table 8. Checklist to assess relevance of farm carbon calculators

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

Summary

Accounting for greenhouse gas emissions from agriculture is complicated, and there are a range of carbon accounting tools available, which have been designed for specific (different) purposes and can vary in complexity, the systems they can represent and the spatial scale they are applied. Therefore, when deciding on which tool to use, some understanding of the tool's capabilities will be advantageous, and the framework outlined could assist with this. In terms of accounting systems for the purpose of determining net zero carbon potential, it is important to be aware of the differences between IPCC inventory and life cycle assessment approaches. Net zero carbon targets (from inventory accounting) relate only to those emissions that originate within the UK's boundaries. However, life cycle assessment includes emissions realised in other countries, aligned with imported products associated with food production, e.g. animal feed or other material inputs required for livestock production such as fertilisers. Overall, careful consideration of assessment choice is therefore essential to avoid unintended misinterpretations, which may affect the UK's progress towards net zero carbon emissions.

"Careful consideration of assessment choice is therefore essential to avoid unintended misinterpretations, which may affect the UK's progress towards net zero carbon emissions"

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

07. Options for achieving carbon net zero goals

Mitigation

In 2018, livestock emissions were 63% (29.1Mt CO_2-eq) of UK greenhouse gas emissions in the agriculture inventory sector, with primary sources being methane emissions from enteric fermentation (21.9Mt CO_2-eq) and the management of manure (7.2Mt CO_2-eq). In order to reach an overall target of net zero carbon for whole of the UK economy by 2050, it has been estimated by the Committee on Climate Change that emissions from the agriculture and land use sector must be reduced by 64%. Although livestock is not given a specific target, it is anticipated that reductions in this sector should align with that of the wider agriculture and land use sector. A 64% reduction in 2018 livestock emissions (total 29.1Mt CO_2-eq) is equivalent to 18.6Mt CO_2-eq. Over the 32-year period between 2018 to 2050, this relates to a reduction rate of 0.6Mt CO_2-eq/year. To achieve this will depend on the application of a wide range of mitigations as well as carbon removal strategies.

There are many mitigation strategies currently available, with varying abatement potentials and cost effectiveness. A recent state of the art analysis by UK scientists examined the mitigation potential and cost effectiveness of different management interventions. From over 70 potential options 24 measures were selected that were identified as having the greatest cost effective (i.e. below the projected carbon price) mitigation potential **(Table 9)**.

	Abatement potential and cost effectiveness		Confidence in the estimates		
Mitigation measure	**CE (£/t CO_2)**	**AP (Mt CO_2-eq/year)**	**CE**	**AP**	**SA**
Legumes in rotations	383	0.3	M	M	H
Catch and cover crops	6408	0.0	M	M	L
High fat diet for ruminants	225	0.2	L	M	H
Improving synthetic N use	224	0.0	L	M	H
Controlled release fertilisers	166	0.1	L	L	M
Low emission manure spreading	126	0.1	L	M	H
Slurry acidification	96	0.1	M	M	H
Behavioural change in fuel efficiency of mobile machinery	90	0.0	L	L	M
Nitrate as feed additive	82	0.3	L	M	H
Afforestation on agricultural land	37	1.8	M	M	H
Improving sheep health	30	0.1	L	L	H
Loosening compacted soils and preventing soil compaction	1	0.8	M	M	H
Anaerobic digestion: cattle slurry with maize silage	179	0.1	L	M	H
Anaerobic digestion: pig/poultry manure with maize silage	-19	0.1	L	M	H
Anaerobic digestion: maize silage only	-41	0.1	L	M	H
Improving ruminant nutrition	-29	0.1	L	L	H
Improving cattle health	-42	0.2	M	M	H
Legume-grass mixtures	-49	0.2	M	M	H
Selection for balanced breeding goals in beef cattle	-52	0.1	M	M	H
Improving organic N planning	-107	0.0	L	M	M
Precision farming for crops	-108	0.2	L	L	H
Plant varieties with improved N-use efficiency	-139	0.1	M	M	M
Shifting autumn manure application to spring	-155	0.0	M	M	M
Probiotics as feed additive	-230	0.1	M	M	M

CE: Cost effectiveness; AP: Abatement potential; SA: Significant abatement H: High confidence, M: Moderate confidence, L: Low confidence
= GOOD = POOR

Table 9: The magnitude of potential for UK greenhouse gas reduction strategies.[25]

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

When compiling this analysis, it was noted that the confidence and effectiveness of the different mitigation scenarios varied due to differences in evidence available to make informed judgements. Mitigation options which provide win-wins in terms of both saving money and carbon are represented by negative cost effectiveness values in **Table 9**. This represents a gap in knowledge but demonstrates the opportunity for improvement and refinement of mitigation potentials as well as education and training for more effective implementation.

In summary, key mitigation measures currently known to be effective in terms of abatement potential and improved efficiency of production are therefore:

- **Animal management:** Improved animal health and welfare to increase animal and system efficiency, and reduce culling and waste, and refinement of animal diets and breeding to increase nutrient use efficiency and reduce surplus nitrogen excreted.
- **Mitigation of individual feed ingredients:** Improved production practices and utilisation of co-products, food-waste streams and alternative feed sources such as home-grown proteins, and novel feedstuffs such as algae, microbial protein and insect sources.
- **Manure management:** Improved methods of manure use, storage and application to minimise greenhouse gas losses and anaerobic digestion of manure and other agro-food industry waste streams.
- **Land management:** Reduction in synthetic fertilisers, use of nitrification inhibitors, conservation cultivation, breeding and inclusion of legumes, improved organic and mineral fertiliser management (application of precision agriculture techniques to match crop and soil requirements to reduce surplus nutrients and increase efficient use for fertilisers), including making full allowance of manure nutrient content when estimating fertiliser application requirements. The improvement of soil health (the biological functioning of soil which increases plant growth) and associated management practices (avoiding excess inputs (nitrogen), overgrazing, compaction and bare soil) to reduce surplus nitrogen in the system contributes to improved soil carbon retention and soil fertility for crop productivity.

However, there is a lack of quantitative evidence outlining the cumulative and interactive effects of implementing multiple mitigation strategies on greenhouse gas emissions. This includes the practical applicability of multiple measures across different livestock systems as well as assessment into the potential knock-on effects in terms of efficacy to reduce greenhouse gas emissions, potential for pollution trade-offs (surplus nutrients that could be leached into local watercourses or released as indirect greenhouse gas emissions), impact on animal welfare (both positive and negative), transfer of impacts to other sectors, implications on product quality (both negative and positive) and the cost effectiveness of adopting mixed mitigation practices. Evidence supporting the applicability is also lacking.

Despite significant progress in developing a wide range of mitigation approaches, the abatement potential that they offer falls well short of that required to meet our net zero target. It has been estimated that there is potential to remove 7.1Mt CO_2-eq of total agricultural emissions by 2035 using currently available and economically viable (where the cost is below that of the projected carbon price) approaches to mitigation. However, this is only 19% of the 2050 UK greenhouse gas reduction target[1]. This is lower than the reduction proposed recently by the NFU which estimated a savings potential of 11.5Mt CO_2-eq from boosting productivity and reducing greenhouse gas emissions using existing and emerging technologies.

Therefore, in its current form, it is the opinion of this report, that with existing technologies, the livestock sector alone cannot meet the requirements for net zero emissions from agriculture and it will have to collaborate with other sectors aligned with land use.

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

Overall, research, development and innovation is needed to a) refine current estimates, reducing uncertainties and providing consistent robust estimates to better represent animal management (e.g. health and breeding improvements on nutrient efficiency across animal types) and land management (e.g. intensity and frequency effects of grazing and soil carbon sequestration potential) to confidently represent these mitigation options in inventory and life cycle assessment net zero calculations, b) identify barriers to uptake of current mitigation practices available, and c) identify, design and implement new mitigation measures. Additional greenhouse gas abatement would be possible if resources were available to finance more expensive mitigation options, such as the use of nitrification and urease inhibitors, improved slurry management and precision livestock farming. There are also many wider co-benefits that may influence the investment of such mitigation strategies. For example, the use of urease inhibitors to reduce both nitrous oxide and ammonia emissions, precision management can improve efficiency and cost effectiveness through decreasing nutrient surpluses within a system, decreasing the potential emissions and pollution from leached nutrients.

The impact of mitigation options within alternative farming systems on carbon footprints

Utilisation of by-products (e.g. distillers' grains as a co-product from ethanol distillation) and alternative feed sources hold some potential benefits such as creating a circular economy with minimal system-wastage for reducing emissions from pigs, poultry and ruminant feed-related emission hotspots. Some studies indicate that optimising diets of dairy cows by computationally limiting what commodities can, or cannot, be included in a ration by, for example, excluding protein sources which have environmental burdens over a set threshold, can reduce feed-specific carbon footprints by up to 40%.

In terms of direct livestock emissions, improving performance efficiencies (e.g. growth rates, milk yields and offspring per breeding animal) as far as possible is a win-win scenario, as improving the economic viability of an enterprise will most likely be met with a decrease in climate change burdens, as long as total outputs do not increase. However, typically outputs do increase when efficiency increases i.e. more is produced and so net emissions remain comparable. This needs to be avoided to achieve net zero. Lastly, improving the welfare of animals can often support efficiency gains. For example, improving the welfare of birds in poultry systems can be achieved without a compromise in their environmental impact, as has been shown for colony systems for layers.

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

Carbon capture

Unlike some other sectors (e.g. green energy), gross emissions from livestock at the higher trophic level to plants, cannot be reduced to zero due to natural/biological processes (such as enteric fermentation). Therefore, there is a role for carbon sequestration both on-farm and in the wider landscape to offset unavoidable greenhouse gas emissions from food production[26]. There are numerous greenhouse gas removal strategies ranging from afforestation and increased soil carbon sequestration to more technologically advanced direct air capture and storage of CO_2 (**Table 10**).

The afforestation and soil carbon sequestration removal options are most relevant to the UK farming sector. The Committee on Climate Change are not yet confident that enhanced weathering and biochar can be applied in the UK without significant adverse effects without further research. The Bioenergy with carbon capture and storage (BECCS) and Direct air capture and carbon storage (DACCS) options have not yet been deployed at scale in the UK, although the UK is well placed to take advantage of these technologies with investment CCC 2019[3]. However, BECCS deployed at scale would require large areas of agricultural land to be given over to biomass production in the immediate vicinity of power generation stations with BECCS. The land use intensity of BECCS ranges between 0.1 and 0.7ha/t C-eq/year, depending on whether specific energy crops or agricultural/forest residues are used[27]. The requirement for large areas of agricultural land may conflict with food production and biodiversity[3] and both BECCS and DACCS are expensive.

Afforestation, woodland management agroforestry and silvopasture, hedgerows and windbreaks	Growing new trees and improving the management of existing woodland. As forests grow, they absorb CO_2 from the atmosphere and store it in living biomass, dead organic matter and soils. These options may also provide other ecosystem and animal production benefits e.g. biodiversity, shelter belts, animal health and welfare. Technological readiness; **High** Relative potential for C capture; **High** Relative cost; **Low**
Soil carbon sequestration	Changing agricultural practices such as tillage or grazing management to increase the soil carbon content. Technological readiness; **High** Relative potential for C capture; **Low** Relative cost; **Low**
Biochar application to soils	Incorporating partially-burnt biomass into soils. Biomass is grown and burnt in the absence of oxygen (pyrolysis) to create a charcoal-like product which can stabilise organic matter when added to soil. Technological readiness; **Low** Relative potential for C capture; **High** Relative cost; **High**
Enhanced weathering (EW)	Ground silicate rocks spread on land react with CO_2 to remove it from the atmosphere. Technological readiness; **Low** Relative potential for C capture; **Low** Relative cost; **High**
Bioenergy with carbon capture and storage (BECCS)	Utilising biomass for energy, capturing the CO_2 emissions and storing them to provide life cycle greenhouse gas removal. Technological readiness; **Low** Relative potential for C capture; **High** Relative cost; **High**
Direct air capture and carbon storage (DACCS)	Using engineered processes to capture atmospheric CO_2 for subsequent storage. Technological readiness; **Low** Relative potential for C capture; **High** Relative cost; **High**

Table 10: Capturing carbon – existing opportunities and new ideas.

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

For example, using domestically produced bioenergy costing less (£125/t CO_2-eq) than using imported bioenergy (for which we assume the price increases to £300/t CO_2-eq to reflect its carbon content and potential to offer an emissions removal credit). Therefore, despite their carbon offset potential the financial investment and land sacrifice may prove to be key barriers to uptake in the long term.

> *"It is the opinion of this report, that with existing technologies, the livestock sector alone cannot meet the requirements for net zero emissions from agriculture"*

Using current data, soil carbon sequestration appears to offer limited potential as a long-term strategy. However, the quantity of additional carbon that can be stored in UK soils is currently unknown and depends on the capacity of different soil systems to retain additional carbon, which depends on inherent soil characteristics (e.g. texture, clay and pH) and management practices (e.g. fertiliser, grazing and tillage intensities). Stored soil carbon is not permanent with turn-over of soil organic matter occurring continuously over a range of timescales which is sensitive to management and climate factors, resulting in some soils being a net source or net sink of carbon. The challenge is to identify soils that have been depleted of carbon by farming practices (e.g. intensively cultivated arable mineral and organic soils) or natural events and that can be restored by management that fosters soil carbon repletion. However, while there are undoubtedly some circumstance in which carbon sequestration can be used to increase soil carbon storage, it is likely that grassland soils will tend to move towards an equilibrium state as they age in which the quantity of carbon gained is equal to carbon losses. A recent Scottish soil inventory data showed no significant change in grassland carbon stocks over a period of two decades. However, data from long-term permanent grassland experiments such as the Park Grass at Rothamsted, England or the AFBI Hillsborough long-term slurry (LTS) experimental site in Northern Ireland (www.ecologicalcontinuitytrust.org/sites) suggest that soil carbon accumulation can continue for over three decades or longer with no evidence, for example, that soil carbon storage at the LTS site has reached an equilibrium state after a period of five decades. Because many UK soils are relatively rich in organic carbon when compared to those elsewhere, there may be challenges but also opportunities to manage these soils associated with maintaining or increasing existing soil organic carbon stocks. Notwithstanding soil as a carbon capture approach, improving soil carbon storage will improve overall soil health (biological functioning) through improved physical structure and microbial aerobic processes i.e. more nutrients in the soil will be assimilated into biomass (plants, animals and microbes) rather than dissimilated into pollutants (e.g. nitrous oxide) allowing it to be more productive with lower inorganic inputs. Therefore, increasing soil organic carbon will contribute to net zero carbon targets either directly (carbon capture) or indirectly (soil health). The world's longest running experiment at Rothamsted Research, the classical long-term experiments (over 175 years), has shown that animal manures are the best approach to return carbon and therefore health to soil. However, more research is required in this area to establish the long-tern potential for soil carbon sequestration and soil health improvement to contribute to net zero.

Enhanced carbon sequestration by trees (live and dead biomass and underlying soil) on agricultural land can be achieved by afforestation, woodland management, agroforestry and hedgerow planting. This is the best understood of the greenhouse gas removal options for the UK[3] and there is a policy drive to rapidly increase rates of afforestation in all countries of the UK. Additional benefits of woodland on agricultural land can be the provision of shade and shelter for livestock (e.g. open woodland for poultry production), the reduction of agricultural ammonia emissions[28], enhancement of biodiversity, improved water management and the potential for an additional income stream from fuel and timber production. However, trees take decades to achieve their full carbon sequestration potential and extensive planting in the 2020's and 2030's will make most contribution to carbon removals post-2050. It is also essential to manage the planted woodlands so that they can achieve their carbon sequestration potential: this requires farmers to have ongoing access to woodland management expertise otherwise plantations will grow poorly or even fail, wasting the investment in both land and money [29].

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

Other approaches to net zero

Sector shrinkage has been proposed as an approach to reduce the UK's livestock sectors emissions. However, this should be aligned to dietary guidance developed in the new National Food Strategy. UK-based livestock products contribute to the UK's food security and reducing such products should not be at the cost of exporting our carbon emissions abroad to meet livestock product demands, or even at the expense of UK exports which have a lower net carbon than other international production systems, as shown by global average data estimates that are significantly higher than UK production. For example, the global average grassland beef production system generates 99kg CO_2-eq/kg meat compared to 48kg CO_2-eq/kg meat in the UK; regarding lamb, the global average is 40kg CO_2-eq/kg meat vs 37kg CO_2-eq/kg meat in the UK; dairy milk has a global average of 3kg CO_2-eq/kg milk compared to the UK's 2kg CO_2-eq/kg milk; globally, pigs produce 12kg CO_2-eq/kg meat which is approximately the same as the UK whilst the global average for poultry production is 10kg CO_2-eq, again similar to the UK's value (using global and UK data extracted from [5]; see **Table 1**). The overall offset potential through removal strategies is likely to be relied upon by other sectors including transport and aviation in which it is difficult to achieve zero emissions.

The reduction of losses through ill health is a further area where gains can be made. These losses include premature culling of animals, mortality and loss of products, such is the case of discarding milk due to mastitis. Improvements in animal health and welfare have the potential to reduce such losses and therefore lead to improvements in system efficiency.

There is the potential for energy savings in the livestock sector using green energy and potential to provide to the national grid. Agriculture is one of the lowest sectoral consumers of fossil-fuel energy across the UK, accounting for around 1% of national consumption. Energy consumption in the agriculture, forestry and fishing sectors combined decreased by ~10% from 1990 to 2018.

The production systems which require the most energy in terms of livestock are indoor dairy and poultry operations, which demand 42% and 32%, respectively, of energy consumed across all animal production systems. Most of this energy is used to heat and ventilate buildings and, where applicable, provide energy for feeding and/or manure management systems and in some situations be used to help deliver biodiversity by carefully prescribed grazing.

On-farm bioenergy production provides modest opportunities to offset system-wide natural resource consumption (e.g. fossil fuels). For example, one study predicts that anaerobic digestion of dairy slurry could reduce the global warming potential of a largescale farm in the UK by 14% and the generation of bioenergy reduces the farm's reliance on fossil fuels by 67%.

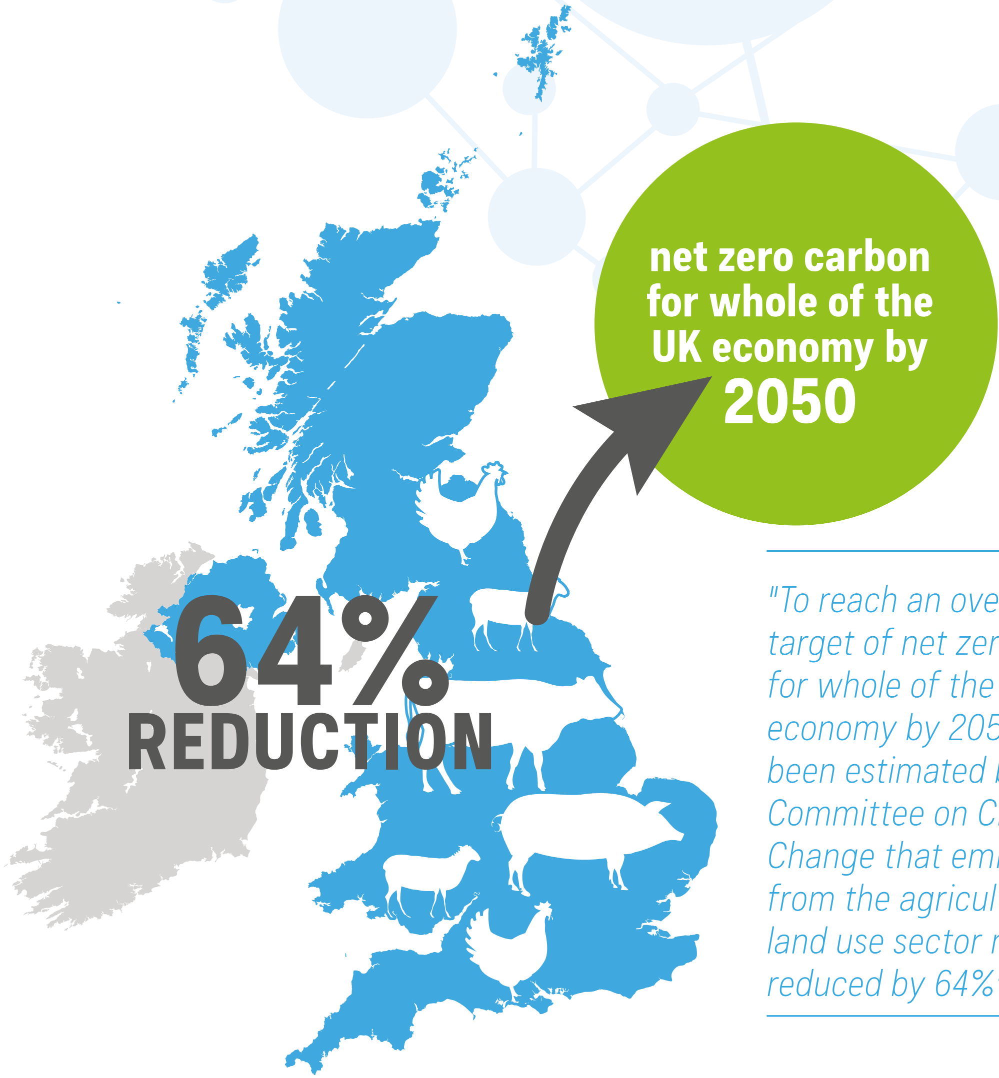
63%
UK greenhouse gas emissions

In 2018 livestock emissions were 63% (29.1Mt CO_2-eq) of UK greenhouse gas emissions in the agriculture inventory sector

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

However, variance exists across the devolved administrations regarding the opportunity for on-farm bioenergy production. At present, there is low appetite in Northern Ireland for the uptake of bioenergy technologies on small-scale agricultural enterprises due largely to uninviting tariffs. In England, bioenergy uptake in agriculture is low (e.g. 5% of all farms produced bioenergy in England in 2010), and the technologies tend to be adopted mostly in the South East and South West of the country. Scotland and Wales tell more positive stories in terms of renewable energies as the respective devolved authorities have placed considerable emphasis on the cross-sector benefits of selling energy back to the grid. Both Scotland and Wales have set ambitious targets to maximise reliance on renewable energies by mid-century; for instance, the Welsh government aims to produce 70% of the country's energy via renewable technologies by 2030.

Whilst agriculture's shift to renewable energies will play a small role in achieving a net zero carbon economy, farming does hold potential to support other sectors by producing energy on agricultural land (e.g. solar PV, hydro-electric, wind) and selling back to the national grid, a potential which has not been fully realised to date. There is considerable scope for cross-sector collaboration; however, under current greenhouse gas reporting frameworks, farmers do not gain any benefits or credit for reducing direct energy consumption which may be restricting uptake.



"To reach an overall target of net zero carbon for whole of the UK economy by 2050, it has been estimated by the Committee on Climate Change that emissions from the agriculture and land use sector must be reduced by 64%"

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

08. Where to from here?

The UK has made significant progress in understanding and reporting the emissions associated with livestock production. There have also been major advances in our capacity to mitigate emissions through a range of innovative management interventions targeted at the core livestock industries.

However, the magnitude of the challenge facing UK livestock producers cannot be underestimated. Despite significant improvements in, for example, cow milk yields and pig growth rates, greenhouse gas emissions from agriculture have shown little change over the past decade and yet, in order to meet government targets, these emissions need to be reduced by over 60% within the next 30 years. Critical gaps in our knowledge of how to achieve the scale of mitigation required will demand further innovation and development across the industry as well as joined up approaches and informed action plans at national, regional, sectoral and farm levels.

Collation of information to deliver this report has identified eight key areas of opportunity which could advance the livestock industry towards net zero at pace and with efficacy.

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

On-farm

1. Improved efficiency

Significant opportunities exist to further improve the efficiency of resource utilisation in the form of fertilisers, feeds and manure management on livestock farms using currently known and proven technologies and strategies. Furthermore, new approaches and solutions need to be developed in the areas of animal husbandry, plant and animal breeding and livestock health, welfare and productivity to deliver further needed improvements in efficiency. However, there is also a need to avoid improvements in efficiency solely being used to increase production output (and hence increase or maintain current emissions).

2. Novel and alternative feeds

Addressing the carbon footprints associated with feed production and utilisation and designing diets and feed ingredients/supplements to improve nutrient utilisation and reduce methane emissions will offer huge potential towards efficiency improvements and thus net zero. For ruminants, a greater understanding of rumen microbial ecology may offer solutions to lower methane through microbial manipulation and reducing methane producing archaea (e.g. through gut microbial programming or dietary supplements). Use of home-grown sources (especially protein), will reduce reliance on imported soya and the impacts associated with deforestation. Use of co- and by-products in livestock feeds, especially those which do not contribute to the competition between food and feed will significantly reduce impacts.

3. Addressing nitrogen fertiliser use

New fertiliser formulations including new approaches to manufacturing (e.g. more environmentally friendly nitric acid production), nitrification inhibitors, and urease inhibitors, coupled with improved timing and rates of application and soil management, have the potential to contribute to significant reductions in nitrous oxide emissions and nitrate leaching. Reduction of inorganic fertiliser through the implementation of novel and alternative species mixtures for grassland hold promise, such as those including atmospheric nitrogen-fixing leguminous clovers or deep-rooting plants. Furthermore, breeding targets to improve persistency and nutritional value of these species will increase their use in seed mixtures and uptake by the industry.

4. Smart technology and precision livestock farming

In the livestock sector, further development and new approaches to animal genotyping and phenotyping, including greater understanding of the rumen microbiome, precision feeding, precision animal surveillance, land use, and manure management, which is tailored to the natural variability between animals, will reduce emissions. Advances in remote sensing can be used to guide the precision of fertiliser and manure application to mitigate hotspots of emissions on-farm (e.g. nitrate leaching and nitrous oxide). Precision application of manures and other organic matter returns offer opportunities to improve arable systems (soil health and nutrient provision) and offset their emissions by replacing/reducing inorganic fertiliser use as a direct benefit from the livestock sector.

5. Carbon sequestration and accounting

Mitigation alone will not achieve net zero in livestock farming. Carbon sequestration by the natural landscape and other approaches to removal of greenhouse gases from the atmosphere can contribute significantly to balancing emissions from livestock. How carbon is accounted for will need to realise the potential of certain land-types for carbon sequestration. Moreover, where relevant, these land-based benefits need to be credited to the livestock sector (e.g. hedgerows on-farm and land set-aside for forestry). Land use, including improvement of soil health will play a critical role in contributing to this but there remain large uncertainties about the relative contributions of land management, where land remains under different land use, as opposed to land use change where a new land use such as forestry is introduced.

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

Decision support tools

6. Whole-system understanding

As the industry moves towards the target of net zero emissions, multiple interventions and modifications to farming systems will need to be implemented. The complexity of interactions between component farming systems requires an understanding of how these interactions will influence overall emission reductions, as well as other sustainability metrics such as economic performance, human health and other issues surrounding pollution such as waterbody quality. The wider impacts of system management, both within and between them, on the environment and agricultural productivity also need to be studied to ensure trade-offs are identified and understood to identify appropriate "best case scenarios", and subsequently manage them as far as possible. The challenge of climate change offers the UK livestock industry a unique opportunity to achieve true sustainability in a holistic manner if emphasis is placed on system improvements.

7. Enhanced calculation methods

Significant opportunity exists to reduce the uncertainties regarding calculating the quantities of greenhouse gas emitted, as well as how to account for the warming effect of methane on the atmosphere. There is growing evidence to support an approach that treats methane more appropriately as a short-lived greenhouse gas differently to carbon dioxide and nitrous oxide, both of which have longer atmospheric residencies in the order of hundreds of years, compared to methane's ~12-15 years. Several alternative calculation methods are gaining traction, with perhaps the most currently notable being GWP. IPCC-recommended calculations define global warming potential (GWP) without adjustment for the length of time gases last in the atmosphere, whereas GWP treats short- and long-lived gases differently, meaning it holds the potential to deepen our understanding of how each greenhouse gas affects anthropogenic climate change differently. However, it is important to note that, under GWP*, even a minor sustained increase in methane emissions over short periods of time will exponentially increase the climate change related burdens associated with methane relative to what would be expected under IPCC calculations.

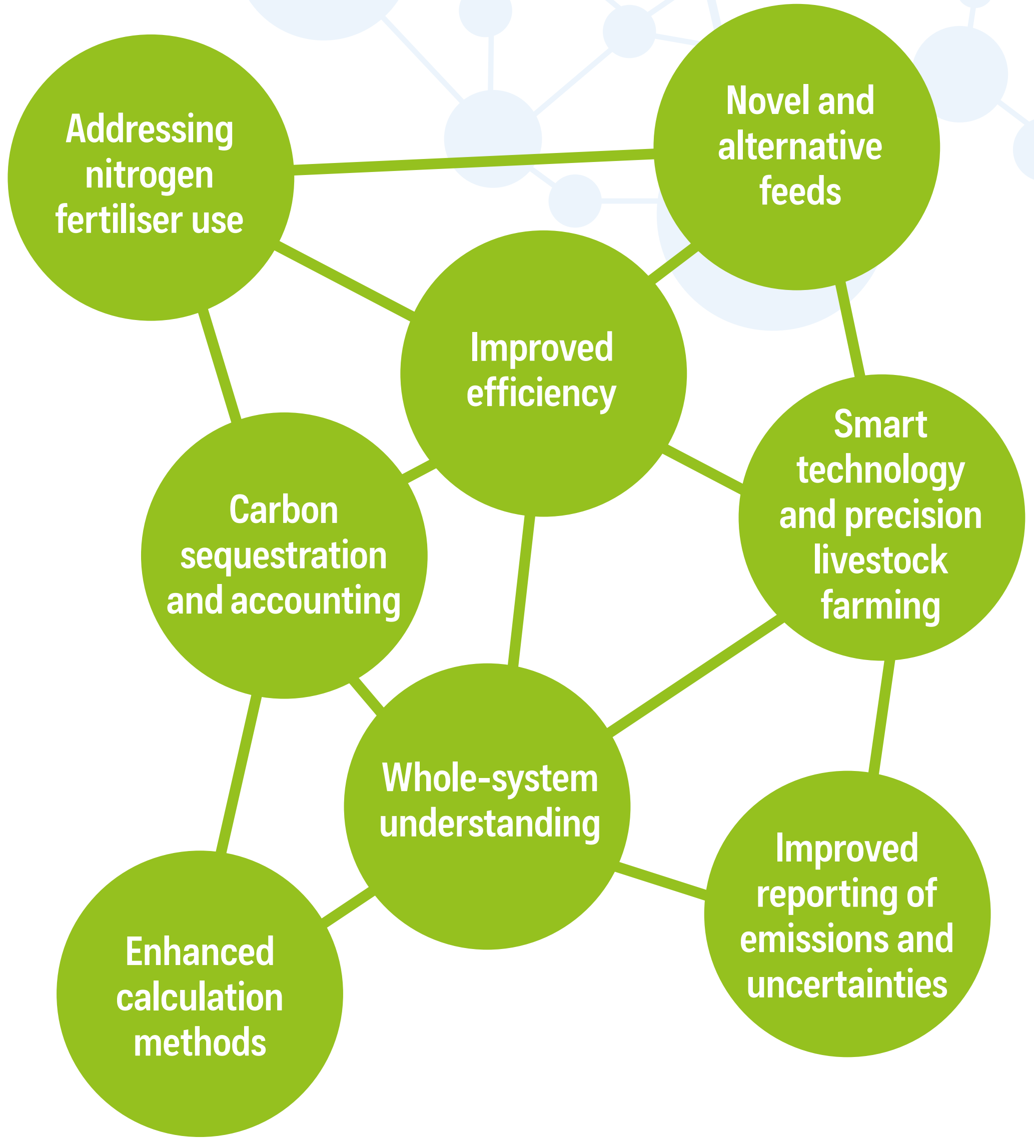
8. Improved reporting of emissions and uncertainties

Past improvements to reporting of emissions have helped identify opportunities for mitigation that target the highest emission sources and hotspots. Further development of our inventory reporting will help to reduce uncertainties in emission estimates and produce more effective mitigation interventions, as well as simultaneously recognising complementary interactions across sectors rather than simply pitting sectors against each other as rivals which has become commonplace due to current reporting practices. Future reporting needs to have improved spatial and temporal resolution to accurately reflect the complexities of land-based management interventions. This will also support the development of more effective and refined farm-based emission tools.

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

Collaboration and synthesis to collectively deliver carbon net zero

The areas listed above highlight the opportunities which exist to take the livestock industry to net zero. However, on its own this will not be enough to deliver enough mitigation in the sector. Promising new approaches need to be supported through policy development and support. It is likely that some approaches to emissions reduction will require significant financial investments. Although there is an urgent need to quantify the lowest expected emissions when multiple abatement strategies are combined, the vast majority of agri-food greenhouse gas emissions experts agree that there is also a timely requirement to reduce livestock product intake (in other words, avoid over-consumption) in individuals/countries where it is currently high, in line with the most reasonable contemporary dietary recommendations, meaning a societal behaviour shift toward reduced consumption of livestock foods is crucial for minimising food-related greenhouse gas emissions. There will also be a requirement for education, training and skills development, as well as practical demonstration of new technologies for farmers to be able to see them working and adopt them effectively. Lastly, whilst environmental burdens are quite rightly receiving intensive attention at present, complementary economic analyses are also required, and urgently at that, to determine the combined consequences of implementing multiple mitigation/abatement technologies simultaneously on farmers and other persons whose livelihoods are either directly or indirectly dependent on the livestock sector.



NET ZERO CARBON
& UK LIVESTOCK

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

09. Recommendations

In order to harness the opportunities identified above, this report makes recommendations under three key headings below:

Investment

The application of current technologies will not achieve net zero, but new solutions continue to emerge. In order for the UK to minimise its greenhouse gas emissions, significant investment will be needed to advance the development of innovation in terms of both mitigations and carbon capture technologies.

The impact of many mitigations and carbon capture technologies is currently based on a number of assumptions linked with scientific investigations. As such, investment is also required to refine and quantify the impact of some key mitigations and carbon capture technologies, individually and collectively, to better inform accounting practices and decision support tools.

In order to inform investment decisions on a national and regional scale, significant modelling is required at macro and micro levels to test the economic and environmental impact of a large range of scenarios while considering the diversity of livestock farming across the UK. This modelling will be key to put in place informed action plans aligned with the opportunities and constraints of regional areas. Ideally, this modelling also needs to be cognisant of wider sustainability issues.

"Significant investment will be needed to advance the development of innovation"

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

Carbon accounting

Accounting for greenhouse gases from agriculture at national and international level is complicated and overall can confuse the achievement of goals. This report recommends that improved transparency in the way we report the emissions of greenhouse gases from agriculture and livestock products is needed. Reporting must fully consider on-farm mitigation and carbon off-setting to produce that product (i.e. interventions on farm/sector to mitigate and off-set are fully considered to reduce the farm/sector's carbon cost). To achieve this there needs to be an improved representation of farm management interventions in space and time in order to provide a better representation of mitigation opportunities.

"Improved transparency in the way we report the emissions of greenhouse gases from agriculture and livestock products is needed"

Carbon accounting tools for use by the industry are effective but further improvements are required to achieve the transparency noted above, as well as levels of accuracy required. Furthermore, linked with knowledge exchange above, the widespread adoption and uptake of state-of-the-art carbon accounting tools on farms is needed to enable farmers to track and reduce on-farm emissions including both carbon reduction and potential.

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

Education, knowledge exchange and adoption

Education programmes and knowledge exchange need to accelerate and increase adoption of mitigation technologies with immediate effect, since significant opportunity exists to reduce greenhouse gas emissions through the implementation of currently available and proven approaches, which also align to win-win improvements in efficiency and profitability on-farm. The knowledge to be exchanged needs to be consistent and far reaching with the audiences spanning both farming and society to ensure the effective roll out of new technologies, as well as evidence based advice surrounding the benefits of responsible consumption of high-quality animal-based products to align with public health advice and the new National Food Strategy. Scientists, technical support organisations and government need to play a key role in realising effective knowledge exchange.

In order to maximise the impact of knowledge exchange across all farming systems and individuals involved, barriers to adoption need to be addressed. A wide range of methodologies and incentives, including financial, will be required with flexibility to encourage and reward through multi-sector approaches.

“Significant opportunity exists to reduce greenhouse gas emissions through the implementation of currently available and proven approaches”

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

10. Conclusion

The UK livestock industry has a complex carbon footprint, but due to its important role in the UK economy and fabric of rural life, as well as what it provides to sustain human and environmental wellbeing in many respects, efforts must be urgently applied to progressively and aggressively delivering livestock's contribution to our net zero carbon goal.

However, net zero will be a major challenge. Using all known cost effective greenhouse gas mitigation options, at a high rate of adoption, the UK farming sector could achieve approximately 19% of the greenhouse gas reductions required by the agriculture and land use sector by 2035, against the 2050 target of 64% reduction within the agricultural sector.

However, significant investments in time, strategising and finances are required to achieve even this. Even more significant investment in research, innovation and subsequently effective implementation is required to achieve net zero by 2050 through both mitigation and carbon capture. As such the recommendations and key steps noted above need urgent attention and should be addressed with efficacy, through co-design and co-implementation of partnership between science, industry, government and society.

Finally, it is vital to remember that achieving net zero does not equate to achieving sustainability. Reducing carbon emissions is a vital component of achieving sustainable livestock systems as already indicated – climate change is the greatest global challenge – however, it is not the sole challenge. A single focus on carbon may result in a system which is skewed, under-delivering in other vital sustainability metrics such as nitrogen and phosphorus pollution, animal behaviour (positive welfare), and rural communities; social wellbeing and the economy. These aspects must be considered in concert to achieve a truly sustainable livestock industry which delivers to both human and planetary health.

"Significant investment in research, innovation and subsequently effective implementation is required to achieve net zero by 2050"

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

11. GLOSSARY

Abatement
The reduction or removal of a detrimental effect (e.g. pollution)

Afforestation
The introduction of trees to an area where there previously were none

Agroforestry
The introduction of trees alongside crops and pasture-based land uses

Anthropogenic
Environmental impact originating in human activity

CO_2–eq
A unit of greenhouse gas expressed as a carbon dioxide equivalent

Carbon capture and storage
The removal and permanent storage of carbon dioxide from the atmosphere

Embedded emissions
Emissions associated with products that fall outside UK inventory reporting boundaries (e.g. imported goods from another country)

Eutrophication
Excessive richness of nutrients in waterways causing dense growth of plant life. Often caused by run-off from the land

Global Warming Potential
A measure of the warming potential of a greenhouse gas relative to that of carbon dioxide

Greenhouse gas
A gas produced by human activity that contributes to warming of the atmosphere

Intergovernmental Panel on Climate Change (IPCC)
An intergovernmental body of the United Nations

Mt
Megatonnes (1 million metric tonnes)

Methane
A greenhouse gas produced by ruminant livestock by fermentation in the gut and during manure storage

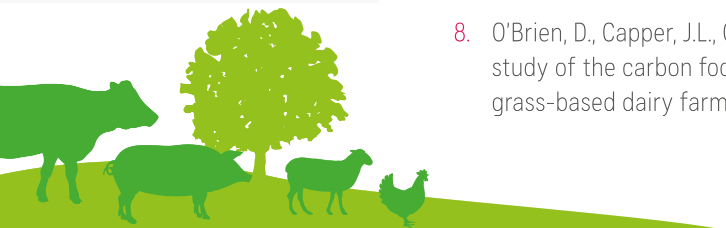
Negative emissions
Removal of greenhouse gases from the atmosphere

Net Zero Carbon
A situation where anthropogenic emissions of greenhouse gas to the atmosphere are balanced by anthropogenic removals over a specified period

Nitrous oxide
A greenhouse gas produced largely as a result of the use of nitrogen fertilisers and manures

Silvopastoral
Integration of trees with grazing animal systems

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS



12. References

1. Committee on Climate Change (2020). Reducing UK emissions: 2020 progress report to parliament, June 2020. Available: www.theccc.org.uk/publication/reducing-uk-emissions-2020-progress-report-to-parliament/
2. IPCC (2019). 2019 Refinement to the 2006 IPCC guidelines for national greenhouse gas inventories. Intergovernmental panel on climate change: Japan. Available: www.ipcc.ch/report/2019-refinement-to-the-2006-ipcc-guidelines-for-national-greenhouse-gas-inventories/
3. Committee on Climate Change (2019). Net Zero: The UK's contribution to stopping global warming, May 2019. Available: www.theccc.org.uk/publication/net-zero-the-uks-contribution-to-stopping-global-warming/
4. Williams, A.G., Audsley, E., Sandars, D.L. (2006). Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities. Main Report. Defra Research Project IS0205. Cranfield University and Defra, Bedford. Available: randd.defra.gov.uk/Default.aspx?Module=More&Location=None&ProjectID=11442
5. Poore, J., Nemecek, T. (2018). Full excel model: Life-cycle environmental impacts of food and drink products. University of Oxford, Oxford. Available: http://doi.org/10.5287/bodleian:0z9MYbMyZ
6. Garnsworthy, P.C., Gregson, E., Margerison, J.K., Wilson, P., Goodman, J.R., Gibbons, J., Dorigo, M., Topliff, M. (2019). Whole-farm feed efficiency on British dairy farms. Advances in Animal Biosciences 10(1), 193.
7. Balmford, A., Amano, T., Bartlett, H., Chadwick, D., Collins, A., Edwards, D., Field, R., Garnsworthy, P., Green, R., Smith, P., Waters, H., Whitmore, A., Broom, D.M., Chara, J., Finch, T., Garnett, E., Gathorne-Hardy, A., Hernandez-Medrano, J., Herrero, M., Hua, F., Latawiec, A., Misselbrook, T., Phalan, B., Simmons, B.I., Takahashi, T., Vause, J., Ermgassen, E.Z., Eisner, R. (2019). Author correction: The environmental costs and benefits of high-yield farming. Nature Sustainability 2, 339-341.
8. O'Brien, D., Capper, J.L., Garnsworthy, P.C., Grainger, C., Shalloo, L. (2014). A case study of the carbon footprint of milk from high-performing confinement and grass-based dairy farms. Journal of Dairy Science 97, 1835-1851.
9. Mackenzie, S.G., Kyriazakis, I. (2020). Quantifying the contribution of livestock health issues to the environmental impact of their production systems. Reducing greenhouse gas emissions from livestock production (ed. R. Baines). Burleigh Dodds Science Publishing (in press).
10. Leinonen, I., Williams, A.G., Wiseman, J., Guy, J., Kyriazakis, I. (2012)(a). Predicting the environmental impacts of chicken systems in the United Kingdom through a life cycle assessment: Broiler production systems. Poultry Science 91, 8-25.
11. Leinonen, I., Williams, A.G., Wiseman, J., Guy, J., Kyriazakis, I. (2012)(b). Predicting the environmental impacts of chicken systems in the United Kingdom through a life cycle assessment: Egg production systems. Poultry Science 91, 26-40.
12. Ottosen, M., Mackenzie, S.G., Filipe, J., Misiura, M.M., Kyriazakis, I. (2020). Substantial progress has been achieved in reducing the environmental impacts of pig production in Great Britain over the last 18 years. Agricultural Systems (In press).
13. DECC (2015). The UK's second biennial report under the United Nations Framework Convention on Climate Change Department of Energy and Climate Change, London.
14. Jones, A.K., Jones, D.L., Cross, P. (2014). The carbon footprint of lamb: Sources of variation and opportunities for mitigation. Agricultural Systems 123, 97-107.
15. McAuliffe, G.A., Takahashi, T., Orr, R.J., Harris, P., Lee, M.R.F. (2018)(a). Distributions of emissions intensity for individual beef cattle reared on pasture-based production systems. Journal of Cleaner Production 171, 1672-1680.
16. Wilkinson, J.M., Lee, M.R.F. (2018). Review: Use of human-edible animal feeds by ruminant livestock. Animal, 1-9.
17. McAuliffe, G.A., Takahashi, T., Lee, M.R.F. (2018)(b). Framework for life cycle assessment of livestock production systems to account for the nutritional quality of final products. Food and Energy Security 7, e00143.
18. Weiss, F., Leip, A. (2012). Greenhouse gas emissions from the EU livestock sector: A life cycle assessment carried out with the CAPRI model. Agriculture, Ecosystems and Environment 149, 124-134.

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

19. Wilkinson, J.M., Garnsworthy, P.C. (2017). Dietary options to reduce the environmental impact of milk production. The Journal of Agricultural Science 155, 334-347.

20. IPCC (2006). International Panel for Climate Change guidelines for national greenhouse gas inventories, prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). IGES, Japan.

21. Taft, H., Chadwick, D., Styles, D., Kipling, R., Newbold, J., Moorby, J. (2018). A review of greenhouse gas calculators for use in the Welsh agricultural sector. A Climate Smart Agriculture (Wales) Report. 20th August 2018.

22. National Farmers Union, NFU (2020). Carbon calculator review, January 2020. Available: www.nfuonline.com/nfu-online/environment/carbon-calculators-review-member-briefing-14012020/

23. Leinonen, I., Eory, V., MacLeod, M., Sykes, A., Glenk, K., Rees, R. (2019) Comparative analysis of farm-based carbon audits. Report for ClimateXChange, February 2019. Available: www.climatexchange.org.uk/research/projects/comparative-analysis-of-farm-based-carbon-audits/

24. PEFCR (2018). Feed for food producing animals first public version April 2018. Available: ec.europa.eu/environment/eussd/smgp/pdf/PEFCR_feed.pdf

25. Eory, V., MacLeod, M., Topp, C.F.E., Rees, R.M., Webb, J., McVittie, A., Wall, E., Borthwick, F., Watson, C., Waterhouse, A., Wiltshire, J., Bell, H., Moran, D., Dewhurst, R. (2015). Review and update the UK agriculture marginal abatement cost curve to assess the greenhouse gas abatement potential for the 5th carbon budget period and to 2050. Prepared for the Committee on Climate Change. Available: www.theccc.org.uk/wp-content/uploads/2015/11/Scotland%E2%80%99s-Rural-Collage-SRUC-Ricardo-Energy-and-Environment-2015-Review-and-update-of-the-UK-agriculture-MACC-to-assess-abatement-potential-for-the-fifth-carbon-budget-period-and-to-2050.pdf

26. Rees, R. M., Eory, V., Bell, J., Topp, C.F.E., Sykes, A., MacLeod, M., Misselbrook, T., Cardenas, L., Chadwick, D. R., Sohi, S., Manning, A., and Smith, P. How far can greenhouse gas mitigation take us towards net zero emissions in agriculture? Chistensen, C.L., Home, D.J., and Singh, R. (2020). Palmerston North, New Zealand, Massey University. Farm Landscapes Research Centre Conference.

27. Smith, P., Davis, S.J., Creutzig, F., Fuss, S., Minx, J., Gabrielle, B., Kato, E., Jackson, R.B., Cowie, A., Kriegler, E., van Vuuren, D.P., Rogelj, J., Ciais, P., Milne, J., Canadell, J.G., McCollum, D., Peters, G., Andrew, R., Krey, V., Shrestha, G., Friedlingstein, P., Gasser, T., Grübler, A., Heidug, W.K., Jonas, M., Jones, C.D., Kraxner, F., Littleton, E, Jason Lowe, J, Moreira, J.R., Nakicenovic, N., Obersteiner, M., Patwardhan, A., Rogner, M., Rubin,E., Sharifi, A., Torvanger, A., Yamagata, Y., Edmonds, J. and Yongsung, C. (2015). Biophysical and economic limits to negative CO_2 emissions. Nature Climate Change 6, 42-50.

28. Bealey, W.J., Dorea. A.J., Dragositsa, U., Reis, S., Reay, D.S., Sutton, M.A. (2016). The potential for tree planting strategies to reduce local and regional ecosystem impacts of agricultural ammonia emissions. Journal of Environmental Management 165, 106-116.

29. Ralph (2019). Review of new planting under the South West forest scheme and notes on publicly funded new planting schemes for the future. Devon County Council, the Forestry Commission and the Diverse Regeneration Company CIC. Available: www.drcompany.co.uk/wp-content/uploads/2020/06/SW-Forest-Review-2020-minus-appendices-1.pdf

CIEL

NET ZERO CARBON
& UK LIVESTOCK

01. PREFACE

02. EXECUTIVE SUMMARY

03. BACKGROUND

04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK

05. COMPARISON OF PRODUCTION SYSTEMS

06. CARBON ACCOUNTING AND REPORTING

07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS

08. WHERE TO FROM HERE?

09. RECOMMENDATIONS

10. CONCLUSION

11. GLOSSARY

12. REFERENCES

13. ACKNOWLEDGEMENTS

13. Acknowledgements

CIEL is gratefully acknowledged for having the foresight and leading on the commissioning and funding of the delivery of this important report, which focuses on the livestock industry within the UK and its challenges and opportunities to achieve a net zero carbon status against policy targets over the coming decades.

To maximise coverage of all potential eventualities in terms of the impact of livestock on climate change (and vice versa), this report has been compiled by a cohort of world leading, interdisciplinary academics covering, but not limited to, the fields of environmental science, nutrition and soil science from all corners of the UK.

As chair of the consortium which delivered this report, I wish to acknowledge the immense efforts invested by Dr Sarah Buckingham, from Scotland's Rural College, and Dr Graham McAuliffe, from Rothamsted Research, as the main authors of this report, under the expert supervision of Prof Bob Rees (Scotland's Rural College) and Prof Michael Lee (Rothamsted Research).

Key inputs were also provided by Prof Phil Garnsworthy (The University of Nottingham), Prof Ilias Kyriazakis (Queen's University Belfast), Prof Dave Chadwick (Bangor University), Dr Amanda Thomson (UK Centre of Ecology & Hydrology), Dr Steven Morrison (Agri-Food and Biosciences Institute) and Ms Becky Willson (Duchy College).

We are also extremely grateful to many others within these organisations and across the wider CIEL family of academics for their input, comments and guidance as the report developed. The list following demonstrates the wide range of individuals contributing, at various stages, to the report. I am very grateful for the challenges these individuals presented as well as their understanding of the complexity of delivering a report such as this and one which aimed to have wide spread agreement across a large and significant body of livestock and environmental scientists across the whole of the UK.

Dr Elizabeth Magowan
Director of Sustainable Agri-Food Sciences, Agri-Food and Biosciences Institute
Chair of the consortium to deliver the 'Net Zero Carbon & UK Livestock' report

01. PREFACE
02. EXECUTIVE SUMMARY
03. BACKGROUND
04. CURRENT CARBON BENCHMARKS FOR LIVESTOCK
05. COMPARISON OF PRODUCTION SYSTEMS
06. CARBON ACCOUNTING AND REPORTING
07. OPTIONS FOR ACHIEVING CARBON NET ZERO GOALS
08. WHERE TO FROM HERE?
09. RECOMMENDATIONS
10. CONCLUSION
11. GLOSSARY
12. REFERENCES
13. ACKNOWLEDGEMENTS

Aberystwyth University:
Prof Alison Kingston-Smith, Dr Christine Marley, and Dr Ruth Wonfor

Agri-food and Biosciences Institute:
Dr Elizabeth Magowan, Dr Steven Morrison, Dr Dario Fornara, Mr Chris Johnston

Bangor University:
Prof Dave Chadwick

Duchy College:
Ms Becky Willson

Harper Adams University:
Prof Liam Sinclair

University of Leeds, SMART Agri-food Systems, School of Biology:
Dr Gesa Reiss

Newcastle University, School of Natural and Environmental Sciences:
Prof Lucy Asher, Ms Hannah Davis, Dr Abdul Chaudhry, Mr James Standen

Queen's University Belfast; Institute for Global Food Security:
Prof Ilias Kyriazakis, Prof Nigel Scollan

Rothamsted Research:
Dr Graham A McAuliffe, Prof Michael R F Lee, Dr Taro Takahashi

Scotland's Rural College:
Prof Bob Rees, Dr Sarah Buckingham, Dr Alasdair Sykes

University of Nottingham:
Prof Phil Garnsworthy

UK Centre for Ecology & Hydrology:
Dr Amanda Thomson

University of Edinburgh, Global Academy of Agriculture and Food Security:
Prof Geoff Simm, Dr Jon Hillier

University of Bristol, Bristol Veterinary School:
Dr Sarah Lambton, Prof Mark Eisler

Collectively, the body of scientists noted to the left, who have delivered and endorsed this report and its recommendations, offer a significant breadth and depth of knowledge surrounding the global 'livestock carbon debate'. As a consortium we trust the information reported here provides an authoritative overview of evidence and guidance for policy makers, industry, NGOs and scientists to design effective roadmaps for the UK livestock sector.

Dr Elizabeth Magowan

Director of Sustainable Agri-Food Sciences, Agri-Food and Biosciences Institute

Chair of the consortium to deliver the 'Net Zero Carbon & UK Livestock' report.