Barriers and incentives to the uptake of GHG emission reducing technologies in the global dairy sector: the UK case study.

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Print publication: 01/08/2023

Document Version
Publisher's PDF, also known as Version of record

Barriers and incentives to the uptake of GHG emission reducing technologies in the global dairy sector: the UK case study.

Report for the Global Dairy Platform, August 2023

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Acknowledgements and Citation

The Incentives to the uptake of GHG emission reducing technologies in the global dairy sector: the UK case study was commissioned by the Global Dairy Platform through the New Zealand Agricultural Greenhouse Gas Research Centre (NZAGRC). We thank the following for their helpful advice and input into the report Claudia Arndt, Richard Dewhurst and Michael Macleod (SRUC), Nick Wheelhouse (Napier University), Timothy Robinson and the members of the Global Dairy Platform steering group.

Suggested Citation: *Barnes, A.P. (2023). Incentives to the uptake of GHG emission reducing technologies in the global dairy sector: the UK case study. Report for the Global Dairy Platform, Illinois, US.*

Executive Summary

- The UK Government have ambitious plans for its transition to decarbonise the agricultural sector whilst balancing the requirement for output growth. Numerous solutions and pathways exist for reducing greenhouse gas footprints on dairy farms. We explore those mitigation measures which have been identified to have the highest current potential for mitigating emissions.
- The dairy sector is one of the most technically advanced of all farming sectors in the UK. However, there are great variances between best performers in both resource use and greenhouse gas footprints.
- We identify a range of technologies and practices that could improve efficiency, prove cost effective and support goals for improving emissions intensities. These cover uptake of sexed semen and genetic improvement, improving animal health, improving feed practices and supplements, land, and nutrient management as well as renewable energy.
- A range of barriers are identified that tend to limit uptake of these approaches which covers both economic issues, around cost and risk-aversion, but also behavioural nuances around the perception of their efficacy.
- A significant driver of uptake is the institutional environment which is undergoing a change since the UK left the European Union in 2020. The subsidy system and the underpinning regulatory base is proposed to change in different countries of the UK. New schemes aim to embed climate goals within support payments, and these include encouraging more climate smart approaches, as well as capital support for larger investments and concerted efforts to integrate woodlands onto farm.
- We outline the different mitigation measures, their main barriers, and incentives in the following tables.

Table A1. Improving productivity per animal

Mitigation Category	Practice	Description	Current Uptake	Barriers	Incentives	Uptake Potential: ***Housed high input***	***Mixed Housed/ grazing***	***High use of grazed grass***	***Time Frame***
Improve productivity per animal	*Uptake of Sexed Semen*	Sexed semen aims to increase the proportion of female to male calves and thus reduce the need for replacements from outside the herd. Optimal results require heat detection monitors to ensure greater efficacy.	In 2020 around half the sales of semen are sexed. This has risen from 12% in 2012, with more rapid rises in 2018-2020.	Major barriers around lower conception rates, lower availability, and higher costs. Economies of scale may inhibit smaller enterprises from adopting sexed semen strategies. There may be some understanding needed of indexes and particular traits and how they relate to the herd dynamics.	Technological improvements have led to better success rates, relative reductions in prices compared to conventional semen but also regulatory changes around bull calves have encouraged more adoption.	High	High	Medium	5-10yrs

Table A1 (cont). Improving productivity per animal

Mitigation Category	Practice	Description	Current Uptake	Barriers	Incentives	Uptake Potential *Housed high input*	*Mixed Housed/ grazing*	*High use of grazed grass*	*Time Frame*
Improve productivity per animal	*Animal Health Management*	A variety of endemic diseases pervade UK dairy cattle, with the main being Bovine Viral Diarrhoea (BVD) and mastitis, but also bovine TB. Welfare problems will also impact productivity negatively. Better hygiene, housing and active management of infected cows reduces the incidence of disease.	BVD has been estimated at 20% prevalence, though in some UK countries, notably Scotland there is a government eradication programme which reduces incidence to around 5% (Defra, 2023-forthcoming). Around 61% of dairy holdings completed a written health plan in 2023, with 58% claiming they used the plan routinely. Around a quarter of all dairy cows in the UK are experiencing lameness at some point in time, which will lead to losses in the productive life of the animal and prevention includes a range of measures, such as foot trimming, improving flooring and nutrition	An animal health and welfare plan (AHWP) require management time and relies on a larger labour structure to manage aspects of the dairy herd. An AHWP also employs a preventative approach which, again, may not be visible in terms of profit gains and is a potential barrier to adoption.	The main influence on adoption of animal health planning is the role of the veterinarian and their advice has been ranked higher than other referents or advisors. Institutional change around eradication plans has been found to reduce the incidence of disease. Government and supply chains are supporting improved animal welfare targets for the sector.	High	High	Medium	10-20yrs

Table A2. Improving animal genetics

						Uptake Potential			
Mitigation Category	**Practice**	**Description**		**Barriers**	**incentives**	*Housed high input*	*Mixed Housed/ grazing*	*High use of grazed grass*	**Time Frame**
Animal breeding, genetics and herd structure	*Genetic improveme nt:*	Higher performance breeding and genomic selection can be assessed through Economic Breeding Values and a profitable lifetime index (PLI) provides a metric to impose on genetic selection, these provide weighted indexes around yield increases and emphasising fertility, as well as others such as improving calving performance and udder health.	It was recently found that high PLIs are considered by around 90% of UK dairy farmers, with 72% saying they only use bulls with high PLIs.	The main financial barrier seems to be around returning a profit under a breeding strategy and calculation of long-term gains for desirable traits. Lack of trust in fertility rates, difficulty in interpretation of indexes and changes in bull prices have all been found to influence non adoption of high-performance traits.	There is a financial return to optimising traits against farmer motivates. Supply chain drivers will also influence uptake, as will rising input costs to influence efficient traits.	High	High	High	1-5yrs

Table A3. Improving feed practices

Mitigation Category	Practice	Description	Current Uptake	Barriers	incentives	Uptake Potential: *Housed high input*	*Mixed Housed /grazing*	*High use of grazed grass*	Time Frame
Improving feed practices and supplements	Precision feeding	Feed mixtures that are deliver nutrients to reflect the needs of the cow, e.g., during lactation, can be supported through monitoring the individual cow's needs. Optimising feed mixtures and feed quality to requires continual monitoring between performance and dry matter intake and PF is better suited to housed systems.	Precision livestock farming is composed of multiple technologies, such as sensing equipment, software and related housing. Few dairy farms have invested in the whole kit but there have been increases in the adoption of sensing equipment, though this is still small.	Capital is needed to adopt precision feeding techniques, but also software to analyse these data for decision-making. This implies some level of additional management time to respond to these metrics. This implies the motivation of the farmer is key to their adoption, and the more innovative, younger cohorts may find these more attractive. Moreover, size and intensity to justify paybacks are also required.	Rewards, through the subsidy system, have been proposed to support capital purchasing of precision feeds.	*High*	*High*	*Low*	*10-20yrs*

Table A3 (cont). Improving feed practices

Mitigation Category	Practice	Description	Current Uptake	Barriers	incentives	Uptake Potential			
						Housed high input	***Mixed Housed/ grazing***	***High use of grazed grass***	**Time Frame**
Improving feed practices and supplements	Methane inhibiting supplements	Multiple dairy cow supplements are available with a range of additives both newly introduced or in development that can inhibit methane production in the rumen.	A multitude of supplements are available or undergoing regulatory approval. They are usually offered as mixes with forages and therefore uptake is harder to measure.	The main influence on adoption of supplements will be development of viable supply chains. There may be insufficient proof of efficacy of these supplements to assure adoption and lack of data on interactions between supplements and the environment in which they will be used.	Additional supply chain incentives may lead to greater uptake, e.g. through inclusion in overall carbon footprint of the dairy farm. These offer a change to off-set carbon and therefore may incentives uptake.	High	High	Low	5-10yrs

Table A4. Improving land and nutrient management

Mitigation Category	Practice	Description	Current Uptake	Barriers	incentives	Uptake Potential			Time Line
						Housed high input	*Mixed Housed/ grazing*	*High use of graze d grass*	
Land and Nutrient Mgnt.	Adoption of inhibitors	Inhibitors are injected into the ground to capture nitrogen and urease from dairy cows. These are then slow released to provide nutrients for grass growth.	Nitrogen inhibitors have been available in the UK for some decades but their uptake has been limited by their costs. Only recently has there been an increased interest in their use but their application to dairy farming would support progress to carbon reduction strategies.	nitrogen inhibitors have proven popular with intensive dairy farmers elsewhere and their costs are reducing, though additional equipment is needed to inject these into the soil. This requires relating grass yield benefits to overall costs of adoption.	The sale and marketing of nitrification inhibitors has been delayed through regulatory process around food safety and only recently have new inhibitors been introduced to the market which claim greater veracity.	*Low*	*High*	*High*	5-10 yrs

Table A4(cont). Improving land and nutrient management

Mitigation Category	Practice	Description	Current Uptake	Barriers	incentives	Uptake Potential: *Housed high input*	Uptake Potential: *Mixed Housed/ grazing*	Uptake Potential: *High use of grazed grass*	Time Line
Land and Nutrient Mgnt	Nutrient management planning and storage of slurry to manage the wastes from the dairy sector.	A housed system can use integrated nutrient management to ensure collection and storage of waste, based on investment in housing structures. A grazed system will lead to nutrient losses and urease and nitrification inhibitors may be an option which mitigates nutrient loss in the soil for improved grass yield and reducing bought in fertiliser. Nutrient management planning gives farmers the ability to map their resources and plan for any excess storage.	Around 78% of dairy holdings have a nutrient management plan and around 60% produce a plan with some advisory input.	The main issues with NMPs are the management time needed to develop a plan or the cost of employing an environmental consultant to undertake the review. Various options exist for slurry storage but covering slurry captures additional nutrients and reduces leaking of ammonia. These require capital investment which may be prohibitive and require longer-term pay offs, from the additional nutrient recovery. N	Regulation has been the main driver of uptake of nutrient management in the UK and this may tighten under post-EU withdrawal environmental policy. A growing number of retailers are requiring their suppliers to be accredited through ecological labelling which may include nutrient management practices to reduce water pollution.	High	High	Low	1-5yrs

Table A5. Renewable energy

Mitigation Category	Practice	Description	Current Uptake	Barriers	incentives	Uptake Potential			
						Housed high input	*Mixed Housed/ grazing*	*High use of grazed grass*	Time Line
Renewable Energy	Adoption of solar/wind/an a-erobic digestors etc to reduce dependence on fossil fuels.	Switching from fossil fuel-based systems to use of renewables, such as solar/wind power, anaerobic digestion, heat pumps and energy storage require infrastructure investments but will reduce greenhouse gas footprints, stabilise farm energy prices but also offer diverse income if excess energy were supplied back to the grid.	Anaerobic digestion plants: the number of farms processing their slurry or manures by anaerobic digestion on farm or elsewhere increased from 2 to 5% from 2015-2022. Solar panels experience high uptake due to feed-in tariffs, this has slowed recently, but integrated systems including solar panels may become popular	Renewable technologies require a large infrastructure cost and a longer payback period. Support for 'feed-in' tariffs have now been dropped which may make it uneconomic. Motivations of the farmer to diversify income streams. Access to and capacity of the main energy grid will dictate demand for supply of energy.	Most studies highlight government support as the key driver for their adoption and may be led by subsidy. Higher fuel prices may lead to greater investment for better pay off. Supply chain requirements and carbon-offsetting reward schemes may lead to an incentive to adopt.	High	High	Medium	5-10 yrs

Contents

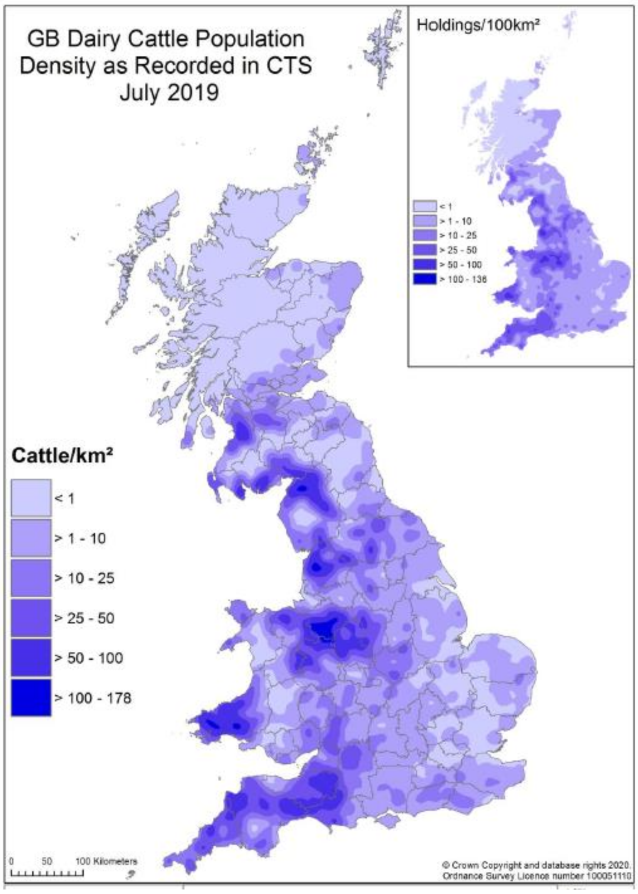
The UK Dairy Sector

Background

The UK is the thirteenth-largest milk producer in the world, with just less than 2 million dairy cows. Dairy provides around 16% of total UK agricultural output and has a value of around £4.4 Billion to the UK economy (Uberoi, 2020). The Dairy sector is considered the most progressive sector in the UK livestock economy and tends to be characterised by high levels of technology uptake, but also tight margins. As such it is operating at a high level of efficiency relative to other ruminant sectors (Gonzalez-Mejia et al., 2018).

Figure 1 shows the intensity of dairy production within Great Britain, with the majority of dairying focused on the West. Density ranges from quite extensive, and mixed systems in the Northwest of Scotland, to high stocking densities in Wales and the Western Coast of England and Scotland.

Figure 1. Dairy Intensity within Great Britain



Source: APHA (2020)

A range of systems are being implemented within the UK. These will have different economic effects and also, potential impacts on the type of measures that will be adopted by these farmers. These systems can be summarised as:

- *Housed high input:* A small but growing number of dairy herds may spend most of their time indoors in modern, well-ventilated and light cattle sheds. This is referred to as 'continuous', or 'year-round' housing[1]
- *Mixed Housed/grazing:* The majority of cows in the UK are extensively grazed on grass, predominantly due to the climate. Most British dairy herds will graze during

[1] See: https://www.thedairysite.com/articles/2549/dairy-farming-systems-in-great-britain

the spring and summer months and be housed for up to six months of the year, usually from late autumn through to the end of winter, when the weather is wet and cold and grass stops growing. This practice can vary depending on weather conditions, availability of feed and stage of lactation.

- *High use of grazed grass:* Outwintering of cattle may occur, which reflects a more extensively managed system. Again, whilst this is a small segment it may be growing as the general trend towards warmer winters and thus reduces costs of housing.

GHG emissions from UK dairy systems

Macleod (2022) estimates the total emissions for UK dairy in 2015 using the FAO GLEAM model which itemises the source of emissions. Enteric fermentation tends to lead to the highest source of emissions and mixed systems generating a higher proportion of Methane and Nitrous Oxide compared to pure grassland systems. These are shown in Figure 2.

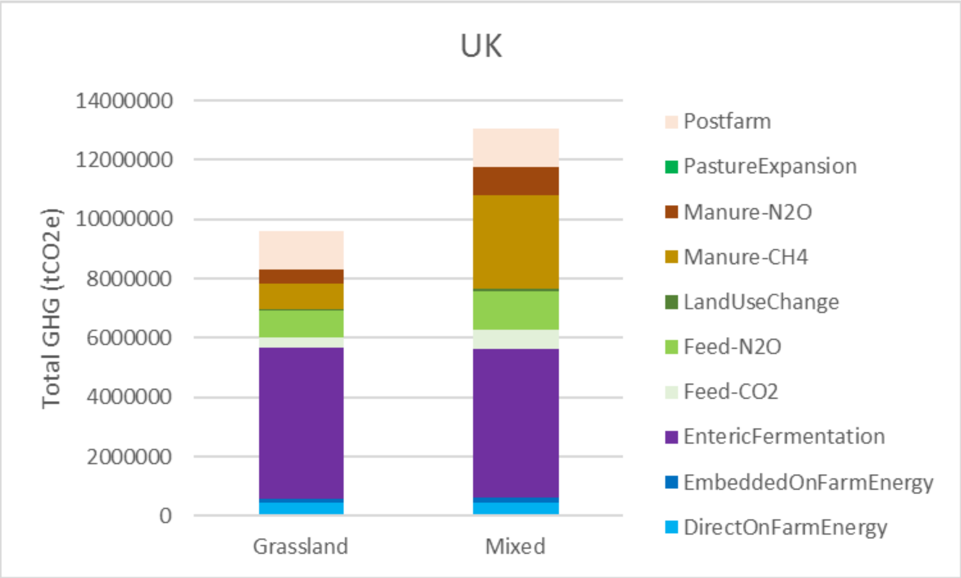


Figure 2. Total GHG from UK dairy production, 2015 (FAO 2022)

Policy towards dairying

Agricultural policy is applied at administrative levels across the UK. This means that the UK, under the EU Common Agricultural Policy, and post-EU withdrawal, have employed their own incentive structures across the countries of the UK. Since 2020 and up to 2027 UK agriculture is undergoing a transition towards a UK agricultural policy. This means that basic payments, offered under the CAP, will be phased out and replaced by payments with a different rationale. Most developed, at time of writing, is the English Administration of the Environmental Land Management System. At the purest this offers support for employing standards that achieve win-win outcomes. Embedded within these standards are aims to decarbonise the sector. In addition, an Animal health and welfare pathway is being developed to support minimising disease from cattle, sheep and pigs. Most administrations though support options, shown in Table X below, which identify both the emissions and potential cost of application.

Table 1. Cost Effectiveness Ranking of Technologies Applicable to UK Dairy

Mitigation Measure	Abatement kt CO2e y-1 (2050)	Cost-effectiveness £ (t CO2e)-1
Analyse manure prior to application	4.1	-2,126.6
GM Cattle	34.9	-1,931.5
Biological N fixation (grass-legume mixtures)	207.2	-1,896.6
Increased milking frequency via robotic milking	43.7	-1,882.0
Precision Farming	127.3	-1,716.1
Breeding for reduced methanogenesis with genomics	101.3	-1,690.8
Use of current breeding practices to reduce emission intensity	162.5	-1,620.3
Higher sugar content grasses	33.5	-801.2
Breeding Genomics – current breeding goal	480.0	-784.1
Anaerobic Digestion (AD) of livestock excreta: Cattle	418.6	-187.0
Better health planning: cattle	372.3	-88.3
Reducing soil compaction	311.0	-21.0
Multi use of cows (milk, calves and meat)	1,349.8	-10.0
High Starch Diet	4.8	0.0
Biorefinery (as nutrient recovery)	265.0	0.0
Covering slurry with impermeable cover	143.3	22.9
Nitrate as feed additive	359.2	79.9
Agroforestry	1,793.0	87.0
Integrating grass/herbal leys in rotation	73.9	107.4
3NOP	1,074.0	111.4
Precision Feeding (+ feed analysis)	4.1	162.2
New low-emission livestock and poultry housing systems: wider BAT uptake	7.0	283.0
Methanisation, methane capture and combustion	105.5	648.2
New low-emission livestock and poultry housing systems: ammonia scrubbing	14.0	2,099.0
Take stock off from wet ground	13.9	5,334.5
Slurry Acidification	4.3	6,584.9
Covering slurry with permeable cover	0.0	36,931.8

Source: Barnes et al (2022)

On-farm adaptation measures

Adaptation measures within the UK can be characterised as both cutting edge technology, such as precision feeding or closed shed systems, the promotion of niche products with potential, and the reintroduction of nature-based methods. The latter includes a systems-based approach which involves rotation of grazing or shifting away from more specialised enterprises. Hence adaptation can involve short term fixes or longer-term investment. This may require system change or large multiyear investments.

A range of measures have been assessed for their cost-effectiveness and feasibility for the UK dairy industry, based on a number of assessments (Eory et al. 2020; Defra 2022; CIEL, 2022a). Table 2 summarises the likely maximum uptake and reduction in emissions intensity that could be achieved (Macleod, 2022). These roughly estimate total mitigation could be achieved with four of the more promising measures for UK dairy would deliver a reduction of around 19%. Moreover, intensification of activity could further free up land for afforestation and sequester carbon.

Table 2. Preliminary list of mitigation measures *where expected uptake 0: Negligible uptake/AP. 1: Low uptake/AP. 2: Medium uptake/AP. 3 High uptake/AP.*

	Maximum uptake		**Maximum reduction in total EI**		**Significant AP identified**	
	Part grazing	Fully housed	Part grazing	Fully housed	CIEL (2022)	Eory et al (2020), Defra (2022)
Improve feed quality	1	1	1	0	No	No
Improve productivity per animal	3	3	3	3	**Yes**	**Yes**
Methane inhibiting feed additives	2	3	2	3	**Yes**	**Yes**
Breeding for low CH4 emitting animals	*2*	*2*	*2*	*2*	*No*	*Yes*
Methane vaccine	*3*	*3*	0	0	No	No
Manure storage, treatment and gas capture	**2**	**3**	**1**	**2**	**Yes**	**Yes**
Optimise feed mix	2	2	1	1	No	No
Urease and nitrification inhibitors	**3**	**3**	**2**	**2**	**Yes**	**Yes**
Reduced land area used for feed, afforestation.	*2*	*2*	*2*	*2*	*Yes*	*No*
Reduce over grazing and nutrient depleting forage	1	0	1	0	No	No
Reduced fertiliser use	**2**	**2**	**2**	**2**	**Yes**	**Yes**
Reduced on-farm fossils fuel use	2	2	1	1	No	No
Electricity from renewable sources	**2**	**2**	**2**	**2**	**Yes**	**Yes**

Source: Review by Macleod (2022)

Main Barriers

A number of factors have been identified which may drive uptake.

Farmer Related Factors: These focus on the drivers of decision making within the farming household and proxied by the current age of the decision maker, the farm family life cycle but also the ability of new entrants to join the industry and for current farmers to retire to allow a transition of perspectives towards environmental planning approaches. The average age of UK farmers is around 58 years, and most studies find a negative relationship between age and the adoption of new farm management practices. Thus, succession and succession planning are critical for the dynamics of farming decision making as this is a key point in which management approaches may change and farm trajectories may adopt either a more productivitist or climate smart approach. This also includes new entrants and their perspectives who generally have wider social networks than the current farming population and have been found to bring more innovative approaches to farming.

Education and Knowledge Accumulation: The education level of a farmer is usually assumed to positively influence adoption decisions. More specifically, education can increase an individuals' understanding of complex issues and is believed to increase efficacy of farm management though enhancement of technical skills and familiarity required to adopt new innovations. Accordingly, adaptation approaches require an understanding of this complexity of the technology and a more 'systems based' view of how measures fit within farm planning and create benefits for the farm as a whole. Similarly, more innovative farmers have been found to actively seek information through traditional routes, e.g., advisors, than other farmers, but also non-traditional routes, in terms of visits to other countries to examine farming systems. Again, the options require more information as the level of complexity increases of the practice to be adopted. Support and trust in the information source has been found to be critical in uptake of environmental measures.

Farm and Economic Factors: Income from farming and wealth accumulation is positively associated with the adoption of environmental farm management practices. Adoption requires sufficient financial wellbeing, especially if changes to management strategies or the use of equipment are required. Accordingly, mitigation measures which save labour, such as precision feeding, may be viewed more positively within dairy farms, whereas those which require more time, such as nutrient management planning, may be resisted. In addition to income is the risk aversion of most farmers but that is negated by Government support payments. Risks are negated to some extent by subsidies and uncertainties in the policy landscape which may lead to stasis in decision making and adoption.

It is commonly hypothesised across the literature larger farms are more likely to invest in environmental management practices. Larger farms can spread fixed costs and labour costs over a larger area, thus allowing some flexibility in practices adopted and therefore give 'room' to experiment within fields new approaches or adoption of technologies with a longer-term payoff, such as anaerobic digestion. Conversely, for smaller or medium sized farms there may be 'lock in' effects due to the assets owned which limit a change in trajectory of that farm to more environmental management. This includes not only current machinery, which may have a life of 10 years, but also buildings and land improvements which will lock in the farm for longer. Small scale machinery improvements may resolve this, with some manufacturers offering add on equipment, e.g., for seed drilling, to perform tasks more efficiently and in a more sustainable manner.

Institutional conditions: The role of policy makers, supply chains, information and advisory bodies and regulators are important in determining the capability to innovate and switching to more environmental approaches. These include the relationship with regulation, with policy support and reporting requirements, but also memberships of organisations promoting particular perspectives. In addition, more informal conditions, around social networks are also seen as influential on promoting peer pressure to change practices towards less common approaches.

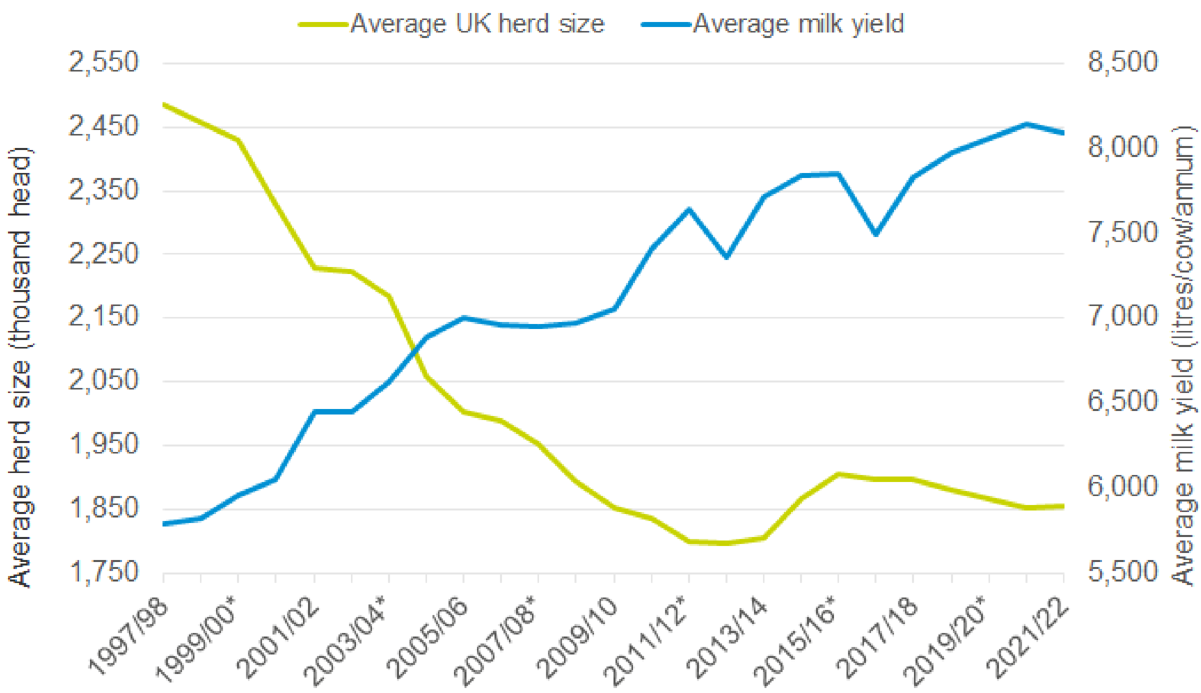
Generally, reluctance or acceptance to adopt climate smart approaches are a composite of these factors which may be compounded by the particular measures that may require a significant system change compared to small term fixes at the farm level.

Key practices and constraints

Improve productivity per animal

Practice: Improving productivity per animal mostly involves approaches which support yield improvement and efficiency of resource use. Figure 3 shows the milk yield has, on average, improved over the last 15 years or so. This figure also shows the reduction in herd size over this time, inferring rising technical change driven by adoption of new technologies. However, it must be noted there are large ranges of performance recorded across the UK of between 5 to 10 thousand litres of milk per cow per year which will be dependent on system, breed and management approaches.

Figure 3. Average UK dairy herd size and milk yield



Source AHDB (2023)[2]

Improving productivity will involve a number of approaches. For the purposes of this report we focus on the adoption of sexed semen - which reduces the number of male calves produced from the dairy sector - and animal health management – which supports resource use efficiency - are two prominent measures within UK dairying which will both improve productivity and emissions intensity.

Current Adoption:

Uptake of Sexed Semen: Recent estimates (2020) show that around half (51%) of the sales of semen are sexed[3]. This has risen from 12% in 2012, with more rapid rises in 2018-2020. According to the AHDB this growth was led by improvements in success rates, relative reductions in prices compared to conventional semen but also regulatory changes around bull calves have encouraged more adoption.

Animal Health Management: A variety of endemic diseases pervade UK dairy cattle, with the main being Bovine Viral Diarrhoea (BVD) and mastitis. Farmers in Southern England and Wales are also exposed to BovineTb outbreaks. The former diseases tend to be

[2] Available at: https://ahdb.org.uk/dairy/uk-milk-yield
[3] Available at: https://ahdb.org.uk/news/jump-in-use-of-sexed-dairy-semen

managed through testing and removal of persistently infected cows, alongside vaccination and hygiene measures as part of biosecurity to reduce risk. The latter requires more severe restrictions on movement and tends to lead to culling of infected cows with repeated testing.

BVD has been estimated at 20% prevalence, though in some UK countries, notably Scotland there is a government eradication programme which reduces incidence to around 5% (Barnes et al., 2023). The Defra Farm Practices Survey (2023) finds around 61% of livestock holdings completed a written health plan in 2023, with 58% claiming they used the plan routinely. In addition, welfare issues may occur, which could be proxied by a range of indicators, predominantly lameness. The AHDB estimate around a quarter of all dairy cows in the UK are experiencing lameness at some point in time, which will lead to losses in the productive life of the animal and prevention includes a range of measures, such as foot trimming, improving flooring and nutrition.

Main Barriers:

Economic and Farm barriers: There are additional costs to operationalise a productivity improvement plan, and these are seen as a barrier (Balzani et al., 2021) but also the economic gains are not immediate for this investment (Borthwick et al., 2014). In sexed semen, for instance, observed lower conception rates, compared to traditional breeding approaches, has been found to limit adoption but recent increases in success rates may have driven recent uptake. Moreover, economies of scale may inhibit smaller enterprises from operationalising sexed semen and this may be more attractive to larger more intense dairy herds. Similarly, animal health and welfare planning (AHWP) require management time and relies on a larger labour structure to manage aspects of the dairy herd. An AHWP also employs a preventative approach which, again, may not be visible in terms of profit gains and is a potential barrier to adoption.

Personal and Social-psychological barriers: The dairy sector, relative to other livestock sectors in the UK, is generally regarded as more technologically advanced farmers are more business-oriented (Noordhuizen et al., 2008) therefore they are more receptive to technical change than other livestock sectors. A number of studies find the major barriers to be perceived and actual lower conception rates relative to conventional semen, lower availability of sexed semen and higher costs relative to alternatives (Balzani et al., 2021; Telford et al., 2005). These studies argued that motivations for the future of the herd may drive intentions to adopt sexed semen.

A series of studies have identified major barriers to adoption of animal health planning, and predominantly revolve around their efficacy in preventing disease outbreaks. Moreover, the influence of veterinarians on shaping attitudes towards animal health have been found to be key. Notably, there is limited evidence available to establish the effectiveness of both health and welfare plans and further demonstration may be needed to support voluntary uptake (Tremetsberger & Winckler, 2015).

Environment, physical and ecological barriers: There are regional differences in dairy farming and health status. Most dairy farming is situated in the western part of Great Britain and Northern Ireland, which is generally wetter but may increase the risk of infection if there is a general trend to warming. Further, bovineTB tends to centre on the South-West of England and Wales and interventions, such as compensation schemes and targeted disease vectors, are local influences on behaviour and attitudes (Broughan et al., 2016: Barnes et al., 2022). Pregnancy rates are often reduced with sexed semen so a number of authors have argued that adoption will be influenced by current fertility states (Walsh et al., 2021).

Institutional barriers:

Sexed semen is commercially driven and supplied by a number of agents. Further regulation, which aim to address issues around dairy bull calves, have been identified as a driver to uptake sexed semen further.

The main influence on adoption of animal health planning is the role of veterinarian and their advice has been ranked higher than other referents or advisors (Borelli et al., 2023). Accordingly, access to vets, and the subsequent training of these vets to manage a range of issues, will be key to meeting reductions in carbon footprints. A large proportion of livestock holdings who complete an animal health plan do so with a veterinary specialist (Defra, 2023b). Moreover, in Scotland a BVD eradication programme has been in place for a number of years, and this has reduced prevalence of the disease.

Animal breeding, genetics and herd structure

Practice:

Genetic improvement: Improvements in animal breeding relate to adoption of higher performance breeding and genomic selection. To assess the potential against a farmer's goals a profitable lifetime index (PLI) provides a metric to impose on genetic selection, these provide weighted indexes around yield increases and emphasising fertility, as well as others such as improving calving performance and udder health. As methane emitted from cows vary across animal levels integrating methane reduction within genetic breeding goals is being actively explored and this may offer potential to reduce emissions.

Current Adoption:

It was recently found that high PLIs are considered by around 90% of UK dairy farmers, with 72% saying they only use bulls with high PLIs (AHDB, 2023; British Dairying, 2022)

Main Barriers:

Economic and Farm barriers: The main financial barrier seems to be around returning a profit under a breeding strategy and calculation of long-term gains for desirable traits (Esselmont et al., 2001). Costs identified must be weighted against the costs of delays on conception per cow which includes veterinary costs and AI services.

Personal and Social-psychological barriers: A range of perceived barriers have been identified for adoption of high-performance traits through breeding values[4]. Ooi et al (2021) found for Australian farmers a lack of trust in the fertility EBV, difficulty in interpreting international proofs, information overload, semen prices, low bull reliability, and difficulty in understanding bull catalogues.

Institutional barriers: The main issues for genetic improvement emerge around the ownership of data and assurance of their quality. In the UK the AHDB, a levy funded body, provides some assurance on their validity and detailed information on performance. For dual purpose breeds there is a financial incentive to sell on calf bulls to new markets, but these have the potential to reduce a farm's overall carbon footprint and there may be opportunities for sell carbon off-sets on newly established carbon markets. Moreover, an increasing awareness from the consumer in terms of the treatment of dairy bull calves may influence a change towards sexed semen, or through demands set by the retailer.

Improving feed practices and supplements

Practice:

Precision Feeding: Optimising feed mixtures and feed quality to requires continual monitoring between performance and dry matter intake. Dairy farmers need to provide

[4] See: https://ahdb.org.uk/gb-dairy-calf-strategy-2020-2023

feed mixtures that are deliver nutrients to reflect needs of the cow, e.g., during lactation. Monitoring individual cow needs through sensors allows for particular nutrient needs to be met[5]. This requires associated software and monitoring to provide the basis for decision-making, alongside capital equipment to regular monitor and dynamically provide nutrients. It therefore works at an optimum in intensively housed systems[6].

Methane-Inhibiting Supplements: Dairy cow supplements are available and offer a range of options to augment forage dependant on cow's needs. These now include a range of additives both newly introduced or in development that can inhibit methane production in the rumen. A popular example of this is seaweed-based feeds, but these could also be mixed with biochar, but also 3NOP. Moreover, single cell proteins, reduced through recycling wastewater and biorefining are available in high value sectors such as fish farming and pigs. Single cell proteins may offer an alternative to soya-based imported meal and therefore improve the climate footprint of the dairy sector.

Current Uptake:

A survey of farmers in the UK found that whilst around 40% of all livestock holdings frequently used a ration formulation programme or nutritional advice from an expert when planning livestock feeding regimes, a significantly higher proportion were dairy farmers (Defra, 2023a). There are no estimates of current precision feeding uptake within UK dairy industry, but this is relatively new technology. There is also less evidence to support current uptake of methane reducing supplements, ostensibly as these are relatively new on the market but may also be sold as overall mixtures and therefore principally not sold as methane reducing[7].

Main Barriers

Economic and Farm: Precision feeding will require a high capital cost, though mobile monitoring is available. There will be increases in stockworker's time to deploy sensors for the appropriate time, as well as software costs – which usually relies on subscription – to analyse data and provide support for decision making. Nevertheless, feed mixer wagons, which offer some ability to control nutrients on farm have proven popular in UK dairy and this may convince farmers to invest more in monitoring technology.

As supplements may be sold as part of overall rations there may be few economic barriers to their adoption. The main influence on adoption will be development of viable supply chains. Rewards, through the subsidy system, have been proposed and additional supply chain incentives may lead to greater uptake, e.g. through inclusion in overall carbon footprint of the dairy farm.

Personal and Social-psychological barriers: For both these approaches there may be insufficient proof of efficacy to generate a return. In terms of precision feeding an increasing number of demonstration sites are available which may convince more farmers to adopt the technology. There is a wide and active market for supplements which provide a range of benefits that must be matched to farmer motivates and needs. There is also lack of demonstration of interactions between supplements and the environment in which they will be used that could affect efficacy and lead to negative.

Institutional: The role that supplements and precision feeding play in reducing emissions will depend on a range of institutional factors. Riddoutt et al. (2022) highlight the choice of climate metric, which would affect market incentives to adopt supplements. Moreover,

[5] See:https://www.dairyglobal.net/industry-and-markets/smart-farming/precision-feeding-and-dynamic-nutrients-in-dairy-cows/

[6] See: https://ahdb.org.uk/news/maximising-forage-feed-and-performance-in-your-dairy-herd-with-jimmy-goldie

[7] See: https://www.nfuonline.com/updates-and-information/methane-reducing-feed-additives-the-story-so-far/

whilst numerous options are available, there may be a lack of viable supply chains to ensure availability and prove cost-effective and lack of financial reward to end-users. There are also challenges in the regulatory pathways to gain approval for use of supplements but also to promote the benefits of supplements, (EFSA, 2022) Adoption of low methane feed practices will be driven by supply chain demands. A number of UK supply chains require farmers to undertake a carbon audit, and this may lead to growing desire to reduce footprints.

Land and Nutrient Management

Practice: Reduction of nutrient loss is critical to sustainable development and dependant on the system as different practices are needed. A housed system can use integrated nutrient management to ensure collection and storage of waste, based on investment in housing structures. A grazed system will lead to nutrient losses and urease and nitrification inhibitors may be an option which mitigates nutrient loss in the soil which can be used for improved grass yield and reducing bought in fertiliser usage. Nutrient management planning gives farmers the ability to map their resources and plan for any excess storage.

Current Adoption: According to a recent farm practices survey, around 78% of dairy holdings have a nutrient management plan and around 60% produce a plan with some advisory input (Defra, 2023a). Nitrogen inhibitors have been available in the UK for some decades but there uptake has been limited by their costs. Only recently has there been an increased interest in their use, predominantly in cropping sectors, but their application to dairy farming would support progress to carbon reduction strategies.

Economic and Farm factors: The main issues with NMPs are the management time needed to develop a plan or the cost of employing an environmental consultant to undertake the review. However, software and decision-making tools are now more popular to support these planning and provide useable platforms to compare performance with other farms and over time. Various options exist for slurry storage but covering slurry will also capture additional nutrients and reduces leaking of ammonia. These require capital investment which may be prohibitive and require longer-term pay offs, from the additional nutrient recovery.

Nitrogen inhibitors have proven popular with intensive dairy farmers in New Zealand and whilst initially expensive are reducing in cost leading to their popularity. Moreover, some require equipment to inject these into the soil which, again, adds to the overall cost of adoption. This therefore requires cost-accounting to measure the increased return on grass yield from captured nutrients. Other approaches, such as remote sensing techniques to map nitrogen use may be more attractive to cropping farmer, though there are examples of innovative dairy farmers adopting these to understand a viable return.

Personal and social-psychological barriers: A range of studies have explored the attitudinal and motivational drivers behind nutrient management, finding that motivations for both efficiency or environmental management drive uptake (Buckley et al., 2015). Moreover, the influence of other farmers has been found to drive thinking towards nutrient management practices (Bechini, et al., 2020; Daxini et al. ,2018).

Institutional issues: Regulation has been a key driver of uptake of nutrient management practices in the UK for around three decades (Barnes, 2010). As all farmers must follow regulations regarding nitrogen use and storage, NMPs should be considered basic practice and several supply chains require this as a standard. These require compulsory nutrient management practices, particular regulatory zones to be established and an associated environmental monitoring programme. The sale and marketing of nitrification inhibitors has been delayed through regulatory process around food safety and only recently have new inhibitors been introduced to the market which claim greater veracity. Moreover, the commercial sector is an active market and there is potential for excessive synthetic fertiliser use due to the influence of private sellers (Sheriff, 2005*)*. Conversely, a growing number of retailers are requiring their suppliers to be accredited through ecological labelling which may include nutrient management practices to reduce water pollutions.

Environment, physical and ecological barriers: The dairy sector mostly operates on the Western part of the UK which has higher levels of rainfall and therefore is more susceptible to run-off risks. Dairy farming tends to be more intensive, than beef or sheep farming, and on the whole the management of slurry may be most cost-effective. The efficacy of nitrification and urease inhibitors are influenced by soil type and pH, as well as temperature and moisture content (de la Pasture, 2020). These may be outside the control of dairy farmers but will influence returns and, ultimately, adoption.

Renewable Energy

Practice: Switching from fossil fuel-based systems to use of renewables, such as solar/wind power, anaerobic digestion, heat pumps and energy storage require infrastructure investments but will reduce greenhouse gas footprints, stabilise farm energy prices but also offer diverse income if excess energy were supplied back to the grid.

Current Adoption: Anaerobic digestion plants have proven popular with dairy farmers due to their requirement for high throughput of materials. Defra (2023a) the number of farms processing their slurry or manures by anaerobic digestion on farm or elsewhere increased from 2 to 5% from 2015-2022. An estimate of 32% of farms have renewables, with 22% of farmers in England having solar power, though this is not split into enterprises[8], however an estimate from Ireland found 2% of dairy farms were using solar energy[9].

Economic and Farm: Renewable technologies require a large infrastructure cost and a longer payback period. More established technologies, such as solar photovoltaics (PV) was supported by a tariff mechanism between 2008-2018. This encouraged farmers to adopt this technology. Most studies highlight government support as the key driver for their adoption (Morris and Bowen, 2020). The removal of the tariff, however, may limit future adoption, although the cost the equipment and installation has fallen over a similar period[10]. However, recent rises in the cost of fossil fuel, and potential regulations against older machinery and vehicles, may encourage a switch to renewables.

Personal and Social-psychological barriers: Few studies have examined drivers beyond economic barriers behind the adoption of renewables. These find motivations around diversification of income streams and spreading of risk (Morris and Bowen, 2020). Moreover, adopters were more likely to have higher educational attainments and were more likely to operate within limited companies or family partnerships than non-adopters.

Institutional: Overall, the UK is decarbonising its energy supply. Investment in renewables was driven by attractive rates in feed-in tariffs which has subsequently been dropped, affecting the incentive to further decarbonise. On farm AD is a potential investment choice but, cattle slurry, compared to other feedstocks, is not as effective in generating output. For on-site renewables local planning applications are needed, and these add cost but may also be rejected due to local concerns. Moreover, there are reviews on the type of

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8 See:https://www.solarpowerportal.co.uk/news/farmers_without_solar_missing_out_on_up_to_1_billion_over_two_year_says_eci#:~:text=Around%2032%25%20of%20farms%20had,Climate%20Intelligence%20Unit%20(ECIU).

9 See: https://www.irishexaminer.com/farming/arid-40875386.html#:~:text=The%20way%20the%20agriculture%20industry,country%20in%20the%20next%20years.

10 See: https://ahdb.org.uk/knowledge-library/solar-pv

land available for renewable developments in England and this may limit opportunities to farmers with better grade land to turn over to solar (Morris and Bowen, 2020).

Environment, physical and ecological barriers: The opportunity for income diversification is based on selling excess energy to the grid. Accordingly, the physical connection and the capacity of the grid itself limits the attraction of their adoption to farmers. Moreover, on-farm fossil fuel use is not a major source of emissions. The UK electricity mix is decarbonising (and may become 100% low carbon by 2030). Hence, this may dampen the attraction of generating an alternative income stream for investment.

Main Incentives for Increasing Uptake

Subsidy Change: A key driver for uptake is the change in subsidy system. These plan to offer a range of measures to support environmental practices that could be considered climate smart, whilst also reducing payment for income support. Hence, the intention is to incentivise farmers towards adoption of climate smart practices or, if these farmers do not wish to participate, to either follow routes with little or no support, or decide to exit from the industry. This is in addition to other measures, most prominently the Animal Health and Welfare Scheme in England, which supports development of a health plan with a vet visit and aims to tackle, amongst others, priority diseases such as BVD, or more support for an eradication scheme such as those imposed in Scotland.

Further to this capital payment support is directed at farmers, and these offer part payment for large scale investments in, for example slurry storage facilities, or anaerobic digestors. The latter of which may also be driven by energy policies as much as those for food. Wider farmer innovation grants are available for the sector, with the aim of encouraging collaboration between farmers with agri-businesses and researchers.

Increased Competition and Exports: Another tranche of post-EU withdrawal related measures will focus on trade, especially entry from newer trading agreements, e.g. new Zealand and Australia, with additional measures based in East Asia. Whilst these imports may reduce prices, they also offer opportunities for export growth. This may incentivise producers to invest in increased efficiencies to service these markets or further reduce cost structures to compete internationally.

Regulation: The UK has carried over EU regulation in a period of transition but have announced new regulations which will come into force later in 2023 (Defra, 2023). The aim is to improve transparency and fairness across the supply chain for pricing contracts and notice periods. The expectation that an assured price would reduce some of the risk in production and increase investment. Underlying ambitions for reduced emissions would be increased regulations for environmental standards and this may incentivise investment in more nutrient recovery as well as storage which, whilst considered a high capital investment, may pay off compared to regulatory penalties for non-compliance.

Supply Chain: Whilst the supply chain is occupied by some large players who can agree prices, there has been a push to require dairy farmers to adopt carbon accounting and measure their greenhouse gas footprint. This should embed an awareness of the GHG impact of practices and provide benchmarks with which to improve emissions intensity. Moreover, for those supplying to a large retailer, there is an expectation that these farmers will sign up to ecological commitments[11].

Rewards for Carbon and Biodiversity: New markets are emerging around carbon and biodiversity, in the form of offsets which can reward or be traded on the market, or in partnership with corporations. This should incentivise the adoption of low carbon approaches but also planting and management of farm woodland.

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[11] See: https://www.tescoplc.com/tesco-completes-most-significant-roll-out-of-environmental-standards-in-uk-with-leaf-marque-certification-for-all-fruit-and-veg-growers/

Harmonising carbon accounting: For ensuring behavioural change accurate monitoring and verification are needed to measure progress in climate and a range of carbon accounting software is available for farmers, through support from extension agents. Agreement on the particular approach used, or at least transparency between measures, would seem critical when comparing progress and understanding how the above measures may lead actual reductions.

Implications for GLEAM

Increase levels of efficiency: The UK is undergoing a significant change in the rationale for support payments which would lead to structural changes throughout the UK. Dairy farming operates at tight margins and changes to the relative input costs to output prices will have impacts on the survival of the industry. Unknowns around future trading relations with competing and new markets may lead to the trend towards higher efficiency levels to increase.

Structural change: Given the proposed changes in support, regulation and trade within the industry there will be some expectation that structural changes will occur. Potentially, one scenario would lead to greater intensification and more housing of larger units, at the cost of smaller units. This may reduce the amount of land needed for dairy farming and be turned over to other activities. Underlying this the removal of income support which would be expected to remove less efficient farmers from the industry leading to a smaller more intense sector.

Reductions in Animal Health and Welfare Prevalence: Management of disease, disease reporting through regular vet visits and concerted eradication programmes would be expected to reduce the prevalence of disease within the national dairy herd which in terms improves resource use efficiency. Moreover, rigorous standards on welfare have This has benefits on

Changing systems. There may be growing pressures on grasslands to support not only dairy but other land use demands, including woodland planting. Moreover, higher regulatory baselines on nutrient use, the declining cost of new technology, such as precision milking and feeding may lead to a shift towards more housed cattle. Hence, whilst GLEAM explores grazing and housed systems, there may be an expected shift between them as we progress to 2050.

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