Farming and Food Analysis
RESAS
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Evidence for the Dairy Farmer-Led Climate Change Group

This report highlights evidence on Scotland's dairy sector for the dairy climate group, covering the context and structure of the industry, greenhouse gas emissions, biodiversity, performance and productivity.

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Executive Summary

This report highlights evidence on the dairy sector in Scotland and its contribution to Green House Gas (GHG) emissions. The main findings from this report are:

Context and structure:

- In 2019, milk and milk products accounted for 11% of agricultural output from 265,000 dairy cattle, mostly in southern Scotland, with a value of £377 million. Further value is also added by beef from the dairy herd which contributed around 13% of finished cattle in 2019.
- In 2018-19, the average Scottish farm had a farm business income (incl. support payments and diversification) of around £38,700. On average, specialist dairy farms had a farm business income of £66,000 including income from support payments and diversification, rising to £241,000 for the best performing 25% of associated farms.
- Over 60% of specialist dairy farms are profitable including support payments. When excluding support, over 50% are profitable – the highest of all livestock sectors.
- 8% of all specialist dairy farms made more than 10% of their turnover from diversified activities in 2016, up from 4% in 2012. The remaining 92% make between 0-10%. 21% of farmers in 2018 indicated intentions to increase renewable energy production.
- In 2018/19, Scottish consumers spent 9.5% of their in-home food and non-alcoholic drink expenditure on milk, milk products and cheese (£2.73 per person per week). Since 2001, UK milk and milk product consumption has been falling while cheese consumption has steadily increased.

Greenhouse gas emissions and biodiversity:

- Large reductions in emissions are required from all sectors of the Scottish economy to meet Scotland's legally binding 2045 Net Zero target, and the target of a 75% reduction from 1990 levels by 2030.
- Agriculture represented 18% of Scotland's emissions, or 7.5 MtCO2e, in 2018. The Scottish Government's Climate Change Plan update requires the equivalent of a 31% reduction in agricultural emissions by 2032, from 2018 levels, a pace nearly four times faster than historic declines.
- The dairy herd accounts for 1.17 MtCO2e[1], or 16% of total agricultural emissions. Emissions per dairy cow are significantly higher than other livestock in Scotland, though emissions per kilogramme of output are lower.

[1] Some cattle associated with the industry and milk production are classed as non-dairy cattle in the GHG inventory. Further work is needed to clarify and allocate these emissions, which are likely to be in the region of 0.25 – 0.37 MtCO2e.

This highlights the imperative for the group to consider practical measures for reducing emissions.

- Evidence on technically feasible mitigation specific to the dairy sector covers feed additives, selective breeding, precision feeding, improved health, slurry storage and high starch diets, of which feed additives provide significant potential.
- Evidence suggests these measures could deliver reductions in the region of 0.27 MtCO2e, if applied to their maximum technical capacity based on current levels. This scale of reduction would not be sufficient to meet agriculture's envelopes by 2032, even if matched with equivalent reductions across all sectors. In fact, it would fall short of targets by nearly a third.
- The Climate Change Committee states changes in farming practices, woodland planting and reductions in livestock numbers are all required to achieve net zero. Their advice also highlights three key changes required to reduce agricultural emissions:

  1 - diet change with their main pathway to net-zero assuming a 20% reduction in UK consumption of dairy products by 2030
  2 – low-carbon farming practices, similar to those outlined above
  3 – productivity measures to improve yields and reduce stocking rates

- The Climate Change Committee have also stressed that not only are the changes outlined critical for agriculture to reduce its emissions but also critical to free up the land required for other sectors to achieve the emissions reductions needed.
- In recent years, the evidence suggests that agricultural intensification has negatively impacted biodiversity, particularly due to a trend towards homogeneity leading to fragmentation and loss of habitats. There is evidence that this is particularly evident in the dairy sector. Overall biodiversity benefits from a mix of land use intensities as well as a mix of habitats.

Performance and productivity:

- Evidence suggests that Scotland is mid-table in international comparisons when it comes to agricultural productivity growth. This report sets out some potential options for increasing agricultural productivity in Scotland.
- Dairy farms typically have higher profitability and efficiency than the average farm in Scotland, with a relatively smaller proportion of their output coming from support payments.

Contents

1 Context and Structure

1.1 Composition of the Dairy Sector

1.1.1 Definition

Data on farms that specialise in dairy, and data on the total dairy holdings, are both important to understanding the overall Scottish dairy sector. Farms where more than two-thirds of output comes from dairy are categorised as dairy farms. A glossary and definitions of these categories and other terms can be found in Annex A.

Unless otherwise stated, data in this chapter are drawn from the June Agricultural Census, Total Income from Farming (TIFF), and the Farm Business Survey (FBS), with further detail available in Annex B.

1.1.2 Outputs and Value

In 2019, Scottish farmers produced about 1.3 billion litres of milk and milk products, accounting for around 9% of the UK's total milk production. Typically ranging between 1.2 billion to 1.4 billion litres per year, production levels in Scotland have remained fairly stable since 2003. Despite this the value of output does fluctuate, driven by changes in price per litre.[2]

In 2019, the value of Scotland's milk production was around £377 million. This was down £23 million on the previous year and £77 million less than the sector's recent peak in 2014. Milk and milk products account for around 11% of total Scottish agriculture output by value, roughly equivalent to the combined output associated with Scottish wheat and barley in 2019.

At the same time, Scotland's dairy farmers are responsible for a proportion of output associated with finished cattle – referred to as dairy beef. While providing a precise monetary value is complex, analysis carried out by the SRUC suggests that, in 2019, around 13% of Scotland's finishing herd was kept on specialist dairy holdings.

Data for the Scottish dairy sector is often reported in one of two ways:

- 'Specialist dairy' holdings, where two-thirds or more of output are from dairy.
- Output from all holdings with dairy cows (which accounts for smaller dairy producers and/or farms with a third or less of their total output from dairy)

[2] Source: the Economic Report on Scottish Agriculture for 2019, and DEFRA's Agriculture in the United Kingdom 2019

Milk production in Scotland comes from both 'specialist dairy' farms and from farms holding any number of dairy cows (even if that is not their primary output). Both types of data are valuable to understanding the overall Scottish dairy sector. The Economic Report on Scottish Agriculture's figures for 2019 primarily show the latter – data on farms with any number of dairy cows. The Farm Business Survey shows farm income for specialist dairy farms in Scotland. The specialist dairy sector's output, input, and income for 2018/2019 is shown in Section 1.2.1.

1.1.3 Scottish Dairy Herds

176,000	89,000	56,000
Female dairy cows[3] in Scotland in 2019	Other adult female dairy cattle in Scotland in 2019	Female dairy calves in Scotland in 2019

In Scotland in 2019, there were 265,000 female dairy cattle (aged one year or over) and 56,000 female dairy calves (aged less than one year), over two-thirds of which were located in Southern Scotland. This includes 176,000 dairy cows (aged two years or over with offspring), of which 78% were located in Southern Scotland.

Within the South West, Dumfries & Galloway had the highest concentration of both dairy cattle and calves. For example, holdings in Dumfries & Galloway held 82,000 dairy cows, nearly half of all dairy cows in Scotland.

Table 1. Female dairy calves and cattle by NUTS2 region, 2019

NUTS2 Region	Female Dairy Calves (000's) Aged < 1 year	Female Dairy Cattle (000's) Dairy cows*	Other female dairy cattle**	Total
North Eastern Scotland	**2**	6	3	**9**
Eastern Scotland	**6**	16	8	**24**
Southern Scotland	**43**	137	69	**206**
Highlands and Islands	**3**	10	5	**15**
West Central Scotland	**2**	7	4	**11**
Total	**56**	176	89	**265**

* Female dairy cattle aged 2+ years, with offspring. ** Female dairy cattle aged 1-2 years or aged 2+ years without offspring. Source: ERSA 2020, Table C10 (ii), provisional figures. Available at: https://www.gov.scot/publications/economic-report-on-scottish-agriculture-tables-2020-edition/

[3] Female dairy cattle aged 2+ years, with offspring

More than two thirds of Scotland's dairy cows, and nearly three quarters of holdings with dairy cows, are located on LFA land.

Table 2. Dairy cows by LFA and non-LFA land, 2019

	LFA		Non-LFA		Total	
	Holdings	Number	Holdings	Number	Holdings	Number
Dairy Cows	1,204	120,580	423	55,240	1,627	175,820
Dairy Cows - Proportions	74%	69%	26%	31%	100%	100%

Dairy cows made up 10% of all cattle in Scotland in 2019 (including beef), roughly half the proportion when looking at the UK total: 19% of all cattle in the UK were dairy cows. England, Wales, and Northern Ireland all had higher proportions of dairy cows to all cattle – which highlights Scotland's relatively higher proportion of beef cattle.

Table 3. Female dairy cows by country, 2019

	Female Dairy Cattle (000's)		**Total Cattle (000's)**	Dairy Cow Proportion (%)
Country	Dairy cows*	Other female dairy cattle**		
Scotland	176	89	**1,728**	10.2
England	1,131	476	**5,280**	21.4
Wales	252	118	**1,120**	22.5
Northern Ireland	314	145	**1,612**	19.5
Total	**1,871**	**829**	**9,739**	**19.2**

* Female dairy cattle aged 2+ years, with offspring. ** Female dairy cattle aged 1-2 years or aged 2+ years without offspring. Source: ERSA 2020, Table C8, provisional figures. Available at: https://www.gov.scot/publications/economic-report-on-scottish-agriculture-tables-2020-edition/

1.1.4 **Farm Size**

The Economic Report on Scottish Agriculture's figures for 2019 show that the 27% (434) of holdings with the largest dairy herd hold 73% of the total dairy herd in Scotland.

- A large proportion of holdings with dairy cows (621 holdings or 38% of all holdings with dairy cows) have a herd size of 1-4 dairy cows.
- Herd sizes between 5-149 dairy cows are less common (572 or 35%), while 434 holdings (27%) held 150 dairy cows or more.

Of these, only 651 holdings were specialist dairy farms, while the remaining 976 were classed as a different farm type.

Table 4. Dairy cow herd size, 2019

Dairy cow herd size	Holdings	Proportion of holdings (%)	Dairy cows*	Proportion of dairy cows (%)
1-4	621	38.2	950	0.5
5-19	105	6.5	970	0.6
20-49	58	3.6	1,850	1.1
50-74	80	4.9	5,010	2.8
75-99	92	5.7	8,140	4.6
100-149	237	14.6	29,780	16.9
150 -299	313	19.2	64,420	36.6
300-499	79	4.9	30,110	17.1
500-799	24	1.5	14,830	8.4
800-999	8	0.5	6,900	3.9
Over 1000	10	0.6	12,870	7.3
Total	1,627	100.0	175,820	100.0

* Female dairy cattle aged 2+ years, with offspring. Source: ERSA 2020, Table C11, provisional figures. Available at: https://www.gov.scot/publications/economic-report-on-scottish-agriculture-tables-2020-edition/

1.1.5 Workforce

Figures from the 2019 June Agricultural Census show the distinction between specialist dairy holdings and holdings with any number of dairy cows (as mentioned in Section 1.1.2) in terms of workforce.

Table 5. Agricultural workforce in the dairy sector, 2019

Category	Specialist Dairy Holdings	Specialist Dairy Workforce	All Holdings with Dairy* Holdings	All Holdings with Dairy* Workforce
Occupiers and spouses working more than half time	577	766	1,305	1,706
Occupiers and spouses working less than half time	209	217	522	571
Full-time employees	499	1,369	952	2,367
Part-time employees	267	429	529	834
Casual and seasonal workers	113	175	237	369
Total workforce	**634****	**2,956**	**1,494****	**5,847**

* Female dairy cattle aged 2+ years, with offspring. ** Labour data was not available for all 651 specialist dairy farms.
Source: June Agricultural Census 2019, via RESAS Agricultural Analysis Unit

Specialist dairy farms had an average workforce of 4.7 employees (including owner-occupiers), while holdings with any number of dairy cows had an average of 3.9 employees.

Specialist dairy holdings were also more likely to have full-time employees: 499 specialist dairy holdings out of 634 had full-time employees (79%), making for a total of 1,369 full-time employees or around 2.7 employees per holding on average. When looking at all holdings with dairy cattle, only 64% had full-time employees, averaging 2.5 employees per holding.

1.2 Profitability and Turnover

1.2.1 Estimated Farm Business Incomes and Profit

Farm Business Income (FBI) statistics are estimated from a sample of nearly 500 farms with a standard output (the average monetary value of the agricultural output at farm-gate price) over €25,000. The FBS does not collect information on non-supported sectors, which include farms predominantly engaged in horticulture, pigs, poultry and some fruit production. A large number of part-time and small Scottish farms with low output are also not included[4].

Farms with more than two thirds of their output from dairy are categorised by the FBS as specialist dairy farms. A glossary and definitions of these and other terms is in Annex A.

[4] Farms with Standard Labour Requirements (SLR) more than 0.5. Standard Labour Requirements represent the approximate average labour requirement for a livestock or crop enterprise. The annual hours of a full-time worker is 1,900 hours.

Table 6 below shows estimated FBI by upper and lower performance band, based on income with and without support payments. FBI figures measure profitability from agricultural activity and includes income from non-agricultural activities using farm resources. For example, tourism, renewables or processing and sale of farm products. There are wide variations in performance across farm types.

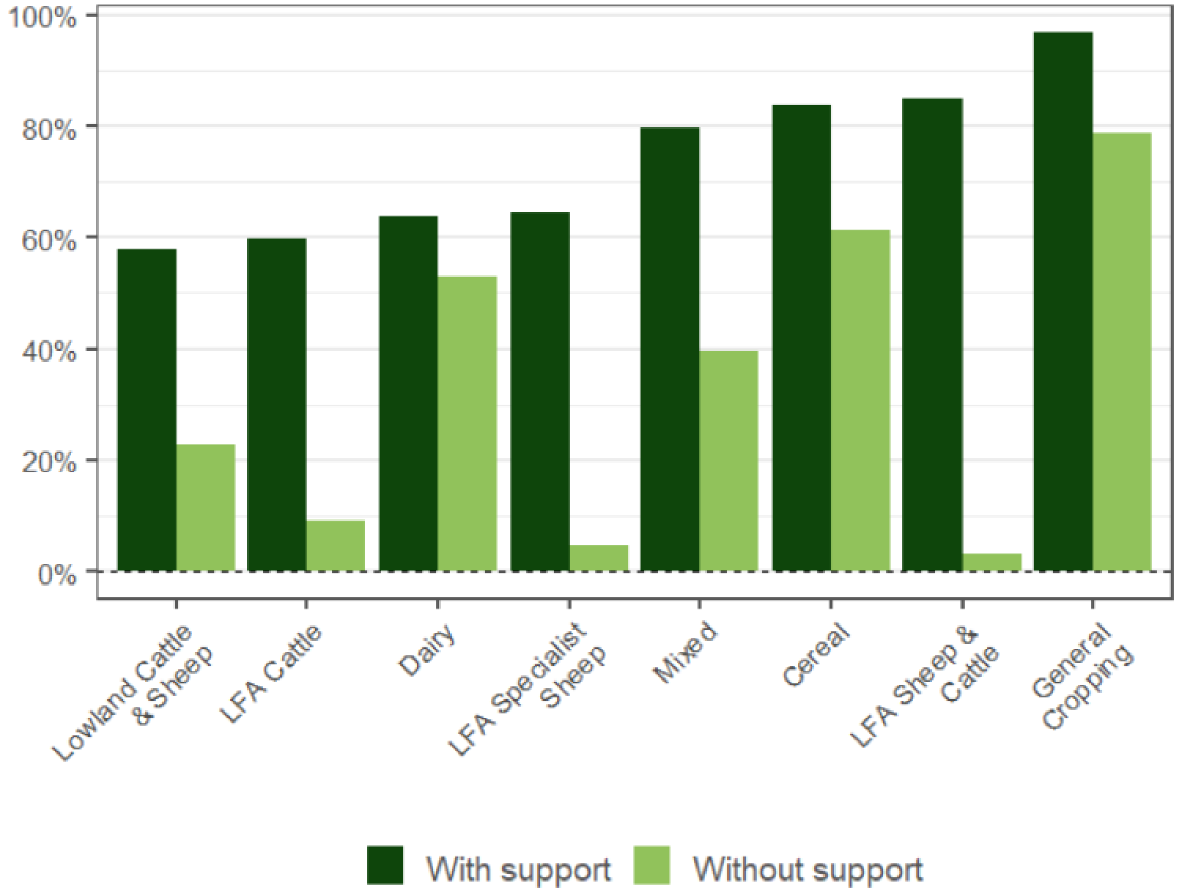
In 2018-19, the average Farm Business Income (FBI) in Scotland was around £38,700. Excluding support payments, this figure falls to around -£4,700, suggesting that for many Scottish farms CAP support plays an important role. On average, specialist dairy farms show higher profitability with an FBI of around £66,000, falling to £26,400 when support payments are excluded.

Table 6. Specialist dairy farm business income

	Farm business income by performance band – dairy farms					
	Lower 25%		**Average**		**Upper 25%**	
	Including Support	Excluding Support	Including Support	Excluding Support	Including Support	Excluding Support
Specialist Dairy	-£50,600	-£104,800	£66,000	£26,400	£241,000	£191,400
All Farms	**-£15,500**	**-£53,800**	**£38,700**	**-£4,700**	**£159,800**	**£100,800**

The figure below shows profitability by farm type, represented by the proportion of farms with income from farming greater than zero (i.e. agricultural output is greater than input). Over 60% of dairy farms were profitable with support payments and, in comparison to other farm types, this drops relatively little when support payments are removed.

Proportion of farms with agricultural output greater than input, 2018-19



Scottish Government analysis shows that across all farm types, 28% of farm businesses turn a profit without support, and 72% turn a profit when support is included.

On average, specialist dairy farms have an output of around £590,000, and receive around a further £40,000 from subsidies and payments. Inputs are around £560,000 a year, with the largest part associated with livestock expenses. The economic efficiency is calculated as a ratio of outputs to inputs. Therefore, the average dairy farm has an economic efficiency of around 108%.

1.2.2 **Diversification**

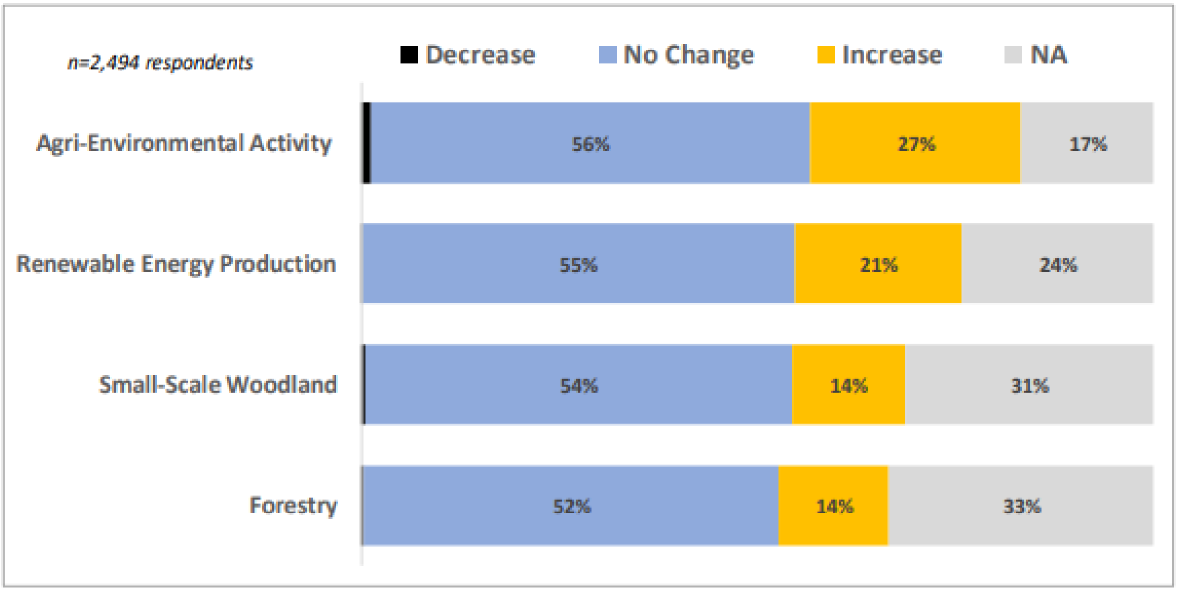
Data on diversification and investment in renewable energies on dairy farms in Scotland is scarce. The Farm Structure Survey 2016 found that across all farming around 9% of farms made more than 50% of their turnover from diversified activities and 16% made more than 10%. 92% of dairy farms made between zero and ten per cent of their turnover from diversified activities. Between 2013 and 2016 the number of dairy farms making more than 10% of their turnover from diversification increased from 4% to 8%.

The Farmers' Intention Survey 2018, summarised by SRUC in their October 2019 briefing, revealed that over 50% of (Scottish) farmers (from all sectors) plan no changes to the levels of agri-environmental provision on their holding in the succeeding five years. Between approximately 14% and 27% of farmers plan to increase provision of "public goods" through increased agri-environmental, forestry, small-scale woodland and renewable energy production.

Of those who did signal intentions to increase these activities, identification of a successor, status as a new entrant, tenure, gender and land type were the most significant characteristics of those intending to increase public good based activities. Lower productivity of land appears to be a factor which positively influences the decision of farmers to increase the level of forestry and small-scale woodland on their farm or holding.

The figure below shows the overall intentions of the farmers, crofters and smallholders surveyed to change the level of activities on their farm or holding that may enhance 'public good' provision in the next five years (2018-2023). Over 50% of respondents planned no changes to the level of each of the activities and for many the question was not applicable as they currently don't engage in that activity. The type of public good provision that most respondents planned to increase is agri-environmental activity, at 27%.

Intentions to change level of 'public good-type' activities by 2023



1.3 Future Trends

1.3.1 Impacts of Brexit

In late 2020, the Anderson Centre produced a report for Scottish Government, assessing the impacts on Scottish agriculture of a UK-EU Free-Trade Agreement (FTA), and a No-Deal Brexit.

Overall, the modelled impacts of an FTA were projected to result in relatively small changes in Scottish agricultural output over the longer term. This is because agricultural trade, with the exception of seed potatoes, can continue effectively tariff-free, aside from additional non-tariff measures (NTM). Indeed, the modelling suggests that increased demand from the rest of the UK could actually increase Scottish agricultural output in some cases.

Specifically for dairy, output was projected to increase by around 0.6%. It should also be noted that this kind of modelling is not suitable for capturing the initial disruption being experienced in the very near term by individual businesses in the early stages of the deal.

Trade between the UK and EU, however, is no longer frictionless with new non-tariff measures (NTM) – additional certifications, enhanced border checks, etc. – now in place. As a result, the costs of such trade are set to increaseFor most dairy products the NTM costs are estimated between 0.8% and 1.7% of their price (also referred to as ad-valorem equivalent ,AVE[5]). EU importers are also subject to higher costs due to NTMs so some Scottish producers may see increased domestic demand from relative price improvements in their produce compared to EU imports.

The study states that added friction will support domestic prices, if key export markets for cheddar are safeguarded and enough processing capacity exists for increased milk volumes. This is crucial as Scotland does not have capacity to process all the milk it produces.

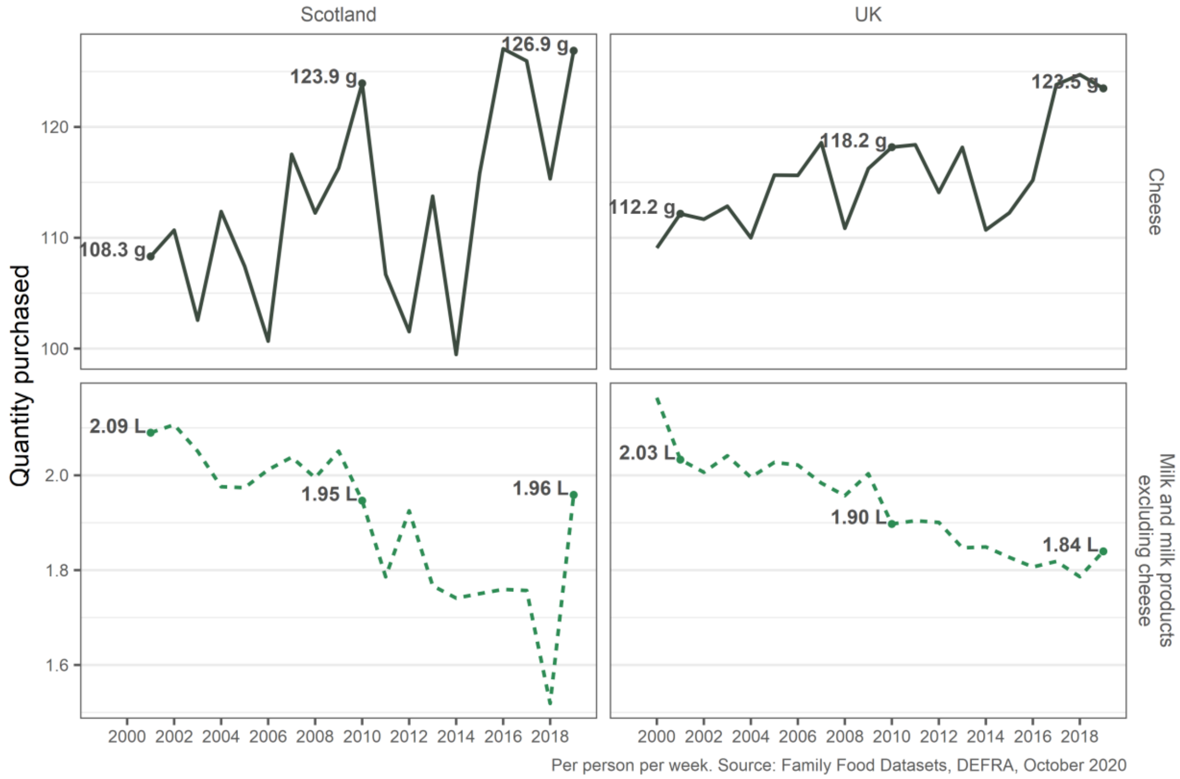
1.3.2 Changing Dietary Demands

DEFRA's Family Food datasets, based partly on ONS' Living Costs and Food Survey, provide an overview of UK and Scottish household purchases and expenditure of food and drink. The latest release, showing data up to 2018/2019, shows that the volume of milk and milk products (excl. cheese) purchased in the UK has declined (the volume of cheese purchased, however, has increased by c.a. 13% since 2000). Generally, Scottish households have seen a similar decrease in the volume of milk and milk products (excl. cheese) purchased between 2000-2017 (-

[5] The % equivalent of the value of the commodity in question

16%). However, the large decrease and subsequent increase in 2018 and 2019 do not reflect wider UK household consumption.

Quantity of dairy products purchased, 2000-2019



In 2018/2019, Scottish households purchased on average 1.96 litres of milk per week, and 127g of cheese per week for in-home consumption. In terms of expenditure, this totalled £2.73 total per week, or 9.5% of total weekly expenditure on food and drink for in-home consumption (for UK households, this totalled 9.9%)

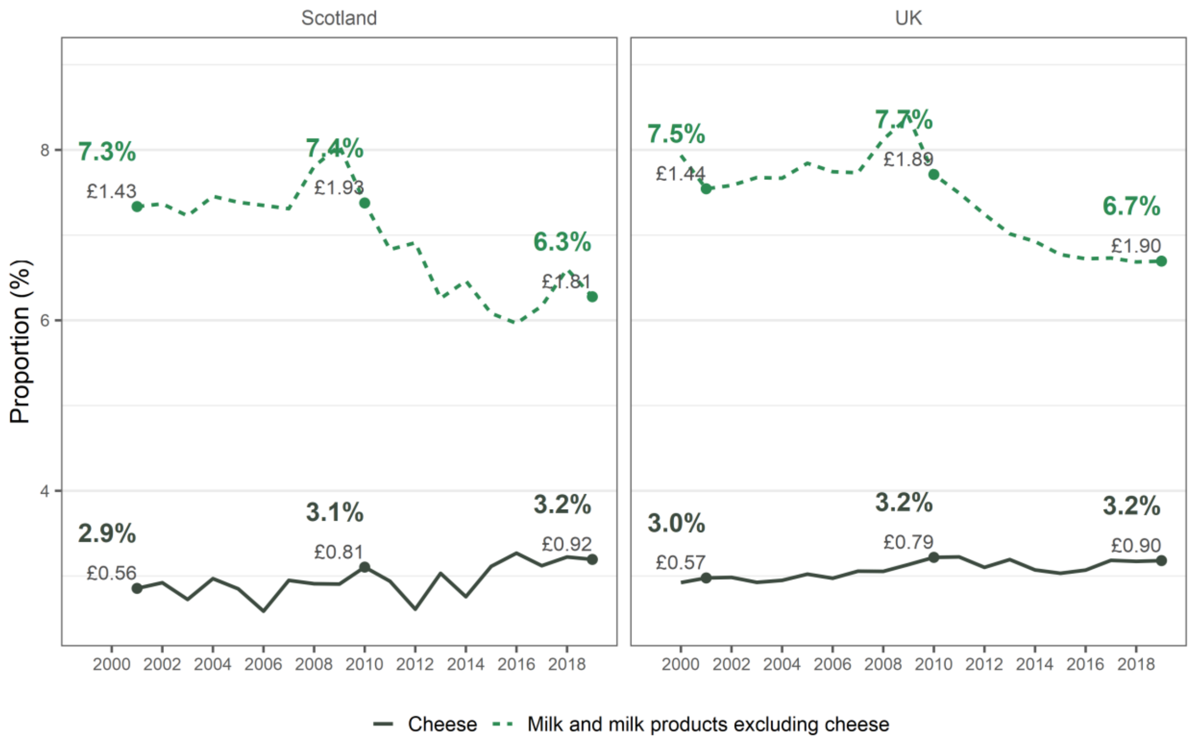
Table 7. Average expenditure on dairy per person per week, 2018/2019

Category	**UK**		**Scotland**	
	Purchase	Expenditure	Purchase	Expenditure
Milk and milk products, excl. cheese	1,840 ml	£1.90	1,960 ml	£1.81
Cheese	123 g	£0.90	127 g	£0.92
Food and Non-Alcoholic Drinks	**..**	**£28.32**	**..**	**£28.85**

Source: Family Food 2018/2019, October 2020

While expenditure has remained broadly stable for cheese (2.9% in 2000, 3.2% in 2018/2019), expenditure on other milk products has decreased since the financial crisis of 2008/2009 (which saw a peak of 7.4% of food and drink expenditure or £1.93 pppw).

Expenditure on dairy products, 2000-2019



Per person per week. Source: Family Food Datasets, DEFRA, October 2020

A number of key reports have discussed changes to red meat consumption. The UK Climate Assembly[6] – a citizens' assembly on climate change – discussed their preferred future for food, farming and land use on the path to net zero in the UK. This included 20-40% voluntary and education driven reductions in red meat and dairy consumption.

The Climate Change Committee[7] have also formally modelled these reductions in their 6th Carbon Budget report in order to determine their pathways for the UK, including Scotland, to reach net-zero by 2050.

Their advice also highlights three key changes required to reduce agricultural emissions:

i. diet change with their main pathway to net-zero assuming a 20% reduction in UK consumption of dairy by 2030;
ii. low-carbon farming practices;
iii. productivity measures to improve crop yields and reduce stocking rates.

The sectoral pathway for Scottish agriculture in the CCC report requires an emissions reduction of 23% by 2030 and the CCC state changes in farming practices, woodland planting and reductions in livestock numbers are all required to achieve net zero.

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[6] https://www.climateassembly.uk/report/read/final-report-exec-summary.pdf
[7] Sixth Carbon Budget - Climate Change Committee (theccc.org.uk)

The Ambition 2030 delivery programme sets out a structure for the Scottish farming, fishing, food, and drink sectors’ development and growth up to 2030. This was jointly funded by Scottish Government and industry, and has introduced programmes such as a co-op sector development programme and a regional and island food development.

2 Greenhouse Gas Emissions and Biodiversity

2.1 Sector Emissions

The Scottish Government has committed to reaching net zero emissions by 2045, including a reduction, from 1990 levels, of 75% by 2030. Whilst a number of countries have adopted net zero targets by on or around 2045, Scotland's 2030 target is particularly ambitious and requires quick action.

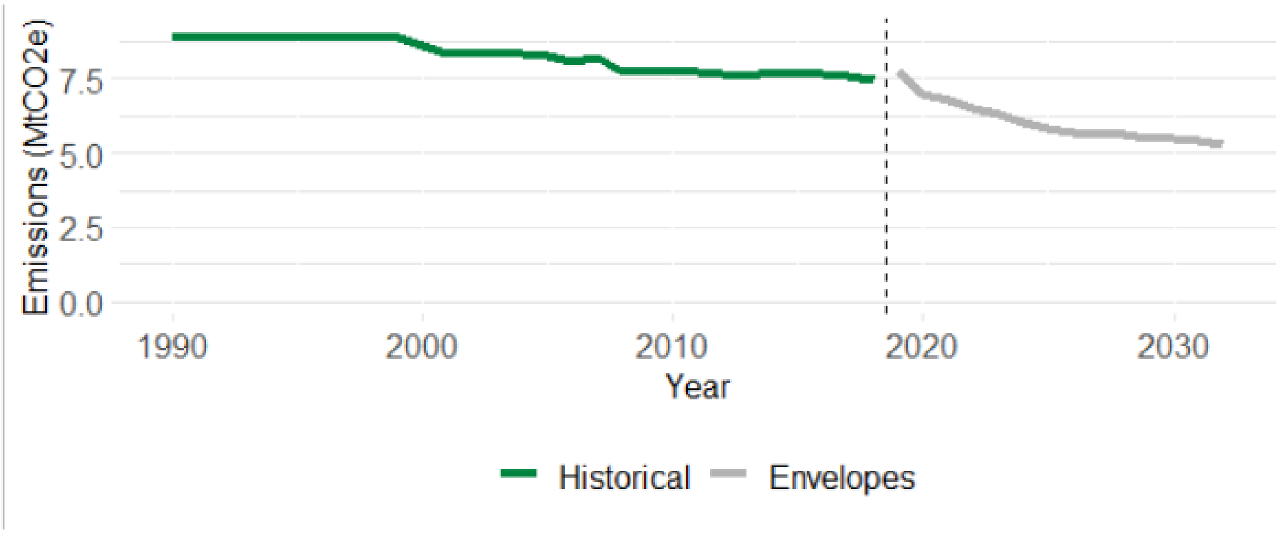
Scotland has a legal requirement to meet these goals, and every industry must adjust to contribute to reducing emissions. The Greenhouse Gas (GHG) inventory measures the domestic emissions, i.e. those produced in Scotland. It is the key data source against which Scottish Government measures its progress against its net zero targets. Emissions arising from goods produced in Scotland and exported overseas for consumption are counted in the Scottish GHG inventory. Emissions arising from goods produced overseas and imported into Scotland for consumption are not counted in the Scottish GHG inventory.

In 2018 total Scottish emissions were 41.6 million tonnes of carbon dioxide equivalent (MtCO2e). The 2019 figures are scheduled to be published in summer 2021.

In 2018 emissions from agriculture were 7.5 MtCO2e, or 18% of Scottish emissions. The sectoral envelope for agriculture as set out in the Climate Change Plan update requires a reduction, from current levels, of agricultural emissions of 2.4 MtCO2e to 5.3 MtCO2e[8] by 2032, the equivalent of a 31% reduction from 2018 levels. As shown in the chart below this requires agriculture to reduce emissions at a pace nearly four times faster than historic reductions. Progress towards delivering the plan will be part of statutory annual reporting at a sector by sector level, to the Scottish Parliament from May 2021 onwards.

[8] The Climate Change Plan update incorporates some likely methodological changes not yet included in GHG inventory figures resulting in 7.7 MtCO2e in 2018 rather than 7.5.

Scottish GHG Emissions from Agriculture



Source: Scottish Greenhouse Gas Emissions 2018 - gov.scot (www.gov.scot), Securing a green recovery on a path to net zero: climate change plan 2018–2032 - update - gov.scot (www.gov.scot)

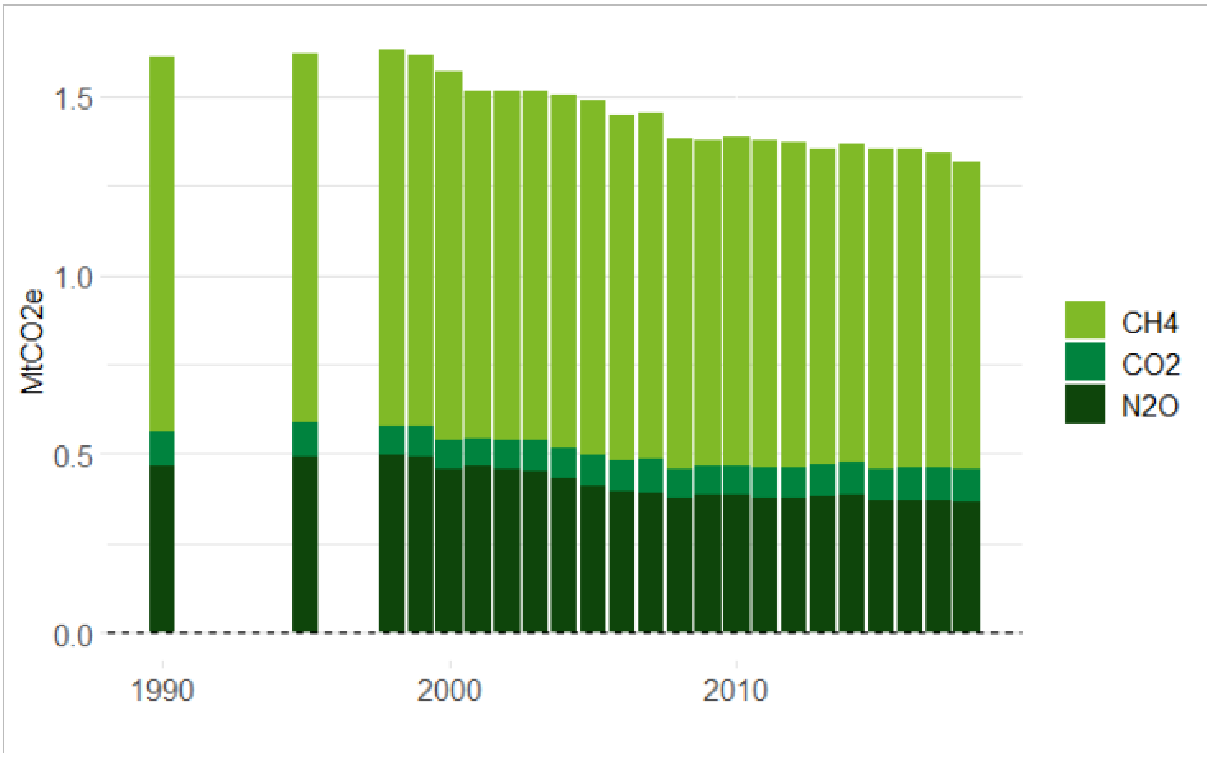
Note: there is a small break in the series due to a slight mismatch in the historic data and the forecast envelopes

2.1.1 Emissions from Dairy farms

As shown in the chart below dairy cattle contributed 1.17 MtCO2e in 2018, or 16% of agricultural emissions. This is a 0.12 MtCO2e fall since 1990, or 9% driven by a decline in dairy cattle numbers. These figures relate to the 176,000 female dairy cows aged two years plus with offspring. However, a further 0.25 – 0.37 MtCO2 of emissions are likely associated with the 89,000 other dairy cows and 56,000 dairy calves aged one year and under in section one. This level of detail on the inventory methodology is not yet available.

Milk output in Scotland has remained broadly steady with little change in the last 10 years. Between 1990 and 2018, there was an increase of around 6%. (Milk Production Survey, published in ERSA 2020 and 1991). Since cattle numbers have fallen, this suggests a significant increase in efficiency. Increased emissions efficiency support reduction of overall emissions, but only as long as the total level of production remains stable or decreases.

Total emissions from Dairy, 1990-2018



Source: Scottish Greenhouse Gas Emissions 2018 - gov.scot (www.gov.scot)

Of the 1.17 MtCO2e in 2018, 0.86 MtCO2e are directly attributable to dairy cattle in the inventory. This suggests annual emissions per dairy cow in the region of 4,900 kgCO2e per year – substantially higher on a per cow basis than cattle raised for beef which is in the region of 2,600 kgCO2e per year. The inventory estimates direct emissions from the dairy herd, which do not reflect the dual purpose nature of dairy cows as they provide both milk and beef, with the largest part of their output being milk. Therefore, emissions per kilogramme of protein are lower for the dairy herd than for the suckler beef herd.[9]

According to analysis carried out by SRUC and ClimateXChange on Scottish data, beef from the dairy herd has an emissions intensity less than half of beef from the suckler herd (9.2 kgCO2e/kg and 21.2 kgCO2e/kg carcass weight, respectively). This is because most of the emissions from dairy systems are allocated to milk. Comparatively, milk has very low emissions intensity, at 1.2 kgCO2e/kg of milk.

The remaining 0.31 MtCO2e are sources such as crop residues, liming and inorganic fertilisers. These are covered in aggregate in the inventory and not listed specifically by sector. Based on discussions with experts we have attributed these as shown in Annex B.

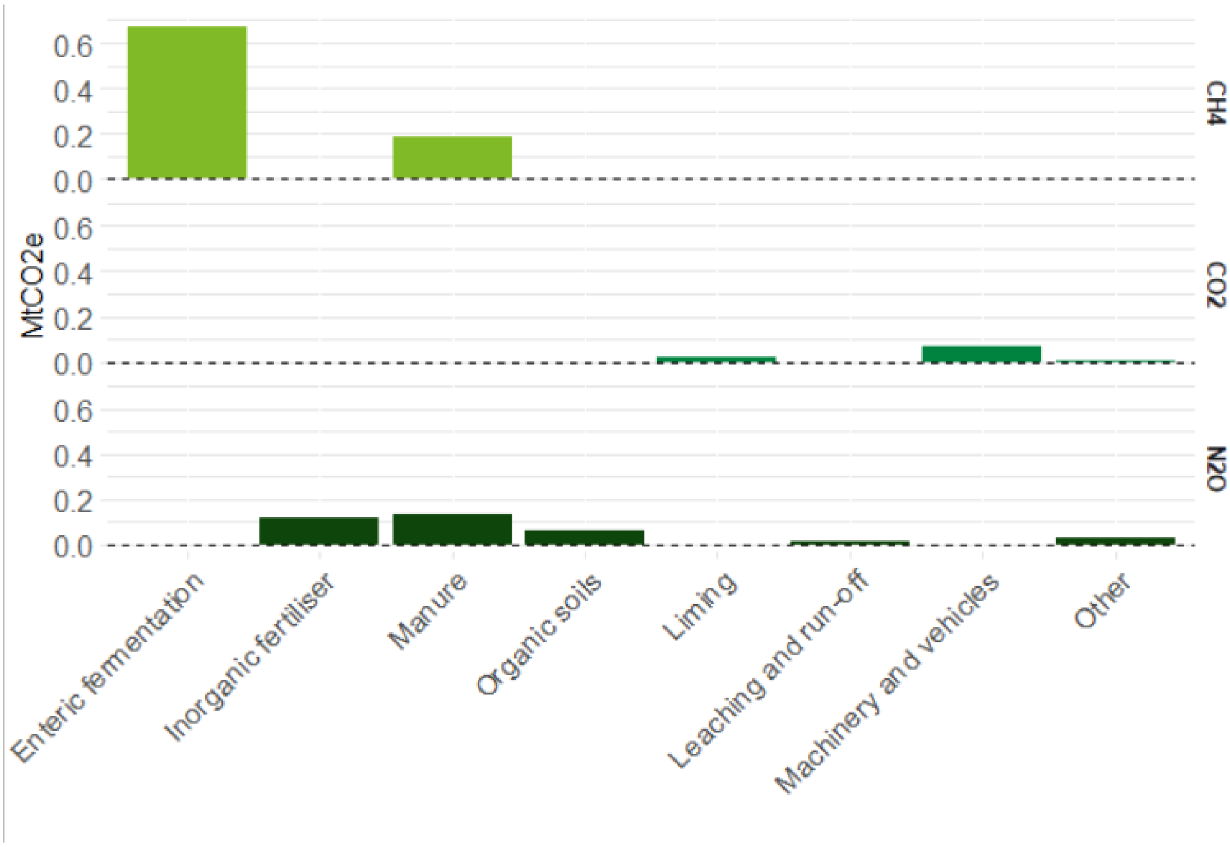
2.1.2 Sources

The chart below shows how the 2018 emissions from dairy break down by source and pollutant. Enteric fermentation is the largest source contributing 45% of dairy

[9] MacLeod et al. 2018, SAEM

emissions. The next largest source, contributing a further 14%, is manure management.

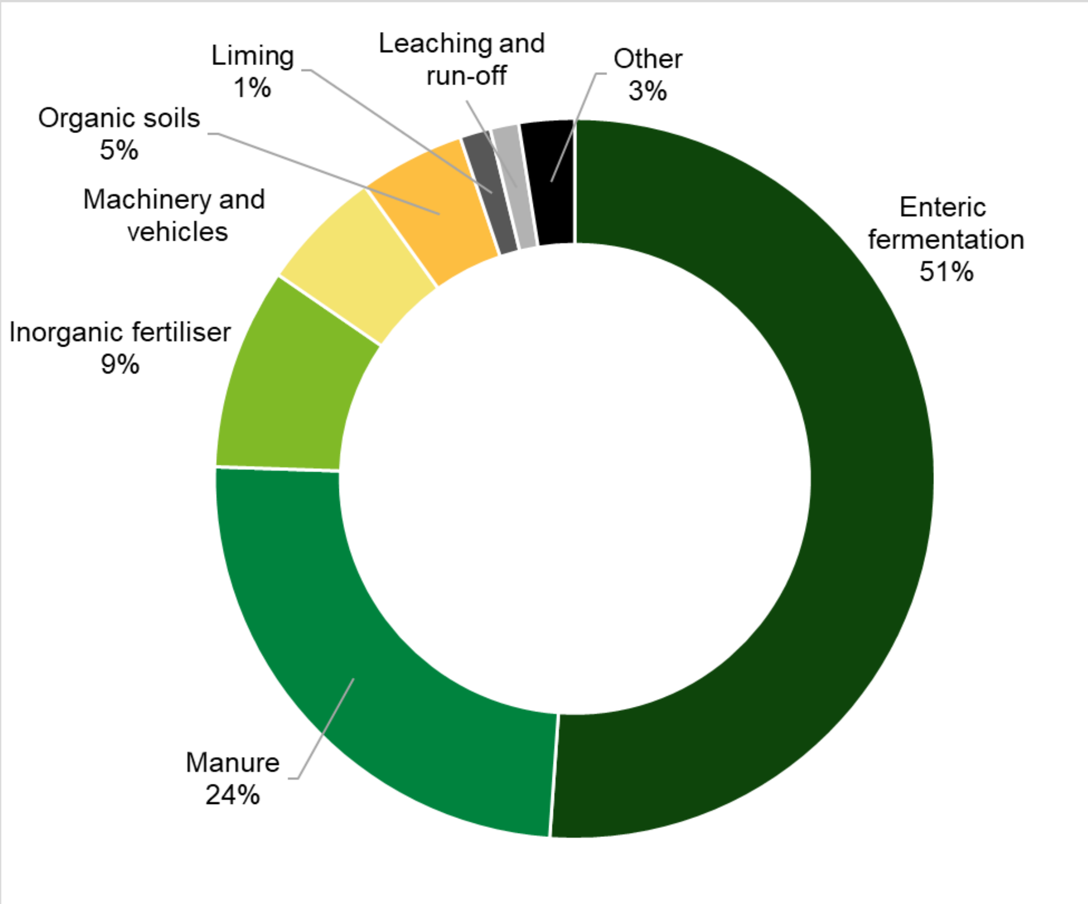
Emissions from Dairy by source and pollutant (2018)



Source: Scottish Greenhouse Gas Emissions 2018 - gov.scot (www.gov.scot)

Alternatively, this can be viewed as a pie chart. Due to multiple sources, the smallest sources (urea application, managed manure, atmospheric deposition, nitrogen leaching, and urine and dung from grazing) have been grouped under “Other”.

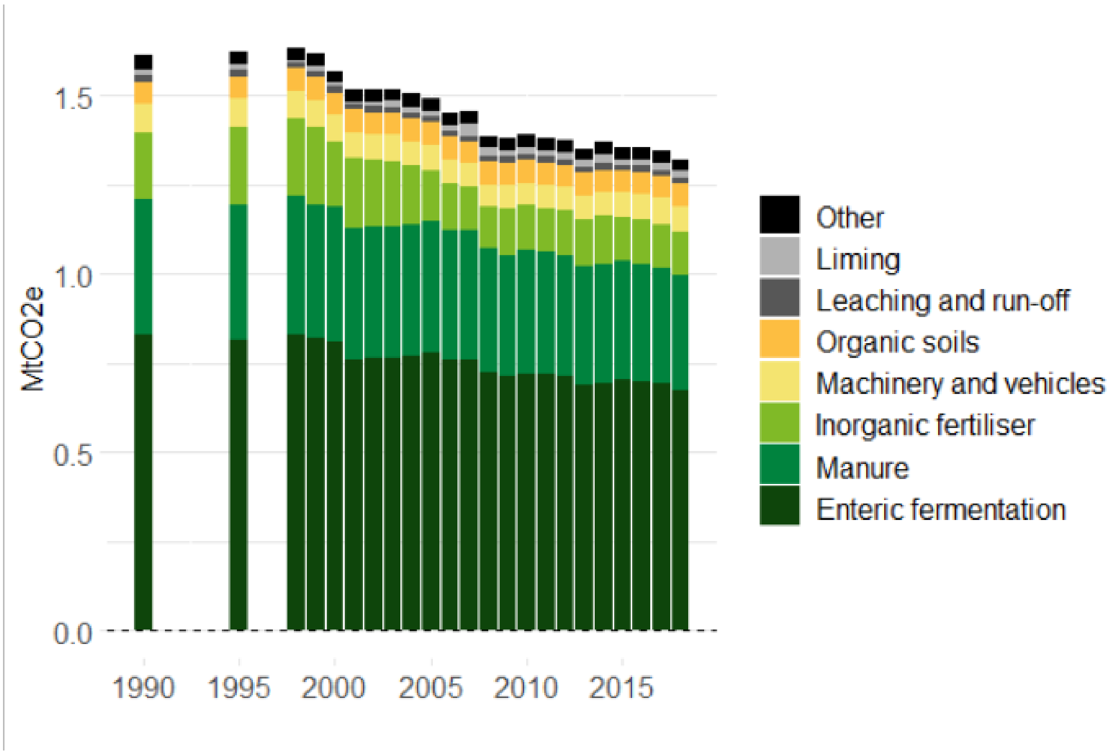
Emissions from Dairy by source and pollutant (2018)



Source: Scottish Greenhouse Gas Emissions 2018 - gov.scot (www.gov.scot)

Over time, the largest reduction by source has come from a reduction in total emissions from non-organic fertilisers. Most other sources have shown only small change since 1990, though in some cases, such as manure management, there has been an increase. The increase in emissions from manure management is offset by the decrease in emissions from non-organic fertilisers.

Emissions from Dairy by source, 1990-2018



Source: Scottish Greenhouse Gas Emissions 2018 - gov.scot (www.gov.scot)

2.2 Options for Reducing Emissions

2.2.1 Potential Savings

Research undertaken by CXC and SRUC on behalf of Scottish Government assessed the potential savings from a range of mitigation measures that could be applied in Scotland and the likely maximum uptake that could be achieved. The report did not assess timescales for uptake of these measures, which will be influenced heavily by factors such as behaviour change and policies. Table 8 below summarises the measures that could be applied in the dairy sector. Estimates of the aggregate emissions savings have been added based on most recent data on levels of dairy cattle. There will be some overlap with potential reductions in beef emissions with the SBCS.

Table 8. Potential emissions savings in the dairy sector

Mitigation measure	Dairy Cattle 2020	Maximum Uptake 2050	Per unit mitigation (kg CO2e)	Aggregate Mitigation (MtCO2e)
3NOP feed additive	321,000	53%	860	0.15
Breeding low methane cattle		19%	630	0.04
Slurry cover - impermanent		31%	530	0.05
Improved health		75%	60	0.01
High starch diet		5%	160	0.003
Precision diet		26%	100	0.009
Additive Total				**0.27**

Source: Marginal abatement cost curve for Scottish agriculture (climatexchange.org.uk)

Strictly speaking the 'additive totals' overstate the savings as some measures may interact and reduce the impact of other measures. However these interactions were assessed to be relatively low for dairy and these interactions could mainly happen between 3NOP feed additive for dairy and dairy breeding for low methane emissions.

If each of these measures were applied to their maximum potential as identified in the report, estimated reductions from dairy emissions based on current levels of dairy cattle would be in the region of 0.27 MtCO2e.

This would be around a 22% reduction in terms of 2018 emissions from the dairy sector it would still only be 11% of the 2.4 MtCO2e reductions required by agriculture by 2032 with the remaining 89% needed to come from elsewhere in the sector. A reduction of 2.4 MtCO2e is equivalent to a 31% reduction from 2018 levels. Therefore, even if all agricultural sectors were to achieve an equivalent 22% reduction in their emissions this would not be sufficient, by nearly a third, for the agriculture sector to meet its envelope by 2032.

The Climate Change Committee states changes in farming practices, woodland planting and reductions in livestock numbers are all required to achieve net zero. Their advice also highlights three key changes required to reduce agricultural emissions:

1 - Diet change with their main pathway to net-zero assuming a 20% reduction in UK consumption of red meat by 2030, rising to 35% by 2050
2 – Low-carbon farming practices, similar to those outlined above
3 – Productivity measures to improve crop yields and reduce stocking rates

It is important to note that the figures above are average estimates that were provided for Scotland as a whole and may not reflect issues specific to dairy cattle. Further, on an individual farm basis, both the mitigation and the net costs (below) can be very different and some measures above cover a wide range of possible actions which would be demanding to assess individually. Therefore the GHG benefits achieved and costs could vary widely.

Further details on each of these measures, such as costs, underpinning assumptions, constraints and potential uptake can be found on pages 12-13 of the CXC report and in the Annexes on pages 43-53. They have also been collated into Annex C for ease.

Other sources of evidence on mitigation measures are available, including reports by the WWF, CCC, and Defra. These are based on (or heavily influenced by) the work carried out by the same team at SRUC as the measures included here.

As set out within the CXC report, there is scope for Scottish dairy farmers – as with all sectors in agriculture – to mitigate their operational GHG emissions through other practises and alternative land use such as those to encourage carbon sequestration.

2.2.2 **Costs**

Some of these measures would involve the purchase of capital equipment with upfront costs. The table below shows the net costs to farmers including capital costs on an average annual basis. These do not include any wider costs such as those to Government or Research and Development from developing measures. Negative figures above indicate a net saving to the farmer, i.e. if implemented they would provide a financial saving to the farmer, as well as a reduction in emissions. Based on current levels the average potential net saving to the sector is around £26 million which – to put this in context – is 7% of the value of output from milk production in 2019.

Table 9. Potential costs of emissions savings in the dairy sector

Mitigation measure	Dairy Cattle 2020	Maximum Uptake 2050	Per Unit Annualised Cost (£)	Aggregate Cost (£m)
3NOP feed additive	321,000	53%	17.78	3
Breeding low methane cattle		19%	-359.15	-22
Slurry cover - impermanent		31%	2.56	0.2
Improved health		75%	-26.89	-6
High starch diet		5%	0.00	0.0
Precision diet		26%	-18.22	-1.5
Additive Total				**-26**

Source: Marginal abatement cost curve for Scottish agriculture (climatexchange.org.uk)

2.2.3 **Current Uptake & Implementation Constraints**

This section contains a brief summary of some of the key issues relating to each of the measures outlined in Tables 7 and 8 above drawing heavily on the CXC report.

2.2.3.1 3NOP feed additive for cattle

Feed additives are not yet available on the market for the purposes of reducing methane. However some products have already sought regulatory approval and are expected to be approved this year for dairy, with other sectors likely to follow.

Current uptake is effectively zero. Practically feed additives will be easier to provide to housed cattle where potential uptake at least is 100%. National inventories and monitoring programs will need to be adjusted to track, record and measure the reductions from such additives.

2.2.3.2 Cattle breeding for low-methane emissions

The measure requires enteric methane emissions to be included in breeding goals with low emission animals selected for breeding. It requires farmers buying (semen from) breeding animals, which have a high score of this breeding index (i.e. lower methane emissions). If genomic tools are used in the selection then the genetic improvement can be sped up, meaning that the methane emissions reduce at a faster rate.

The CXC study estimated improvements could be applied to around 45% of the dairy herd.
There would be upfront research costs estimated in the region of £2.5m across the UK and ongoing research costs as well. The farmers are not likely to experience costs beyond the costs of their current breeding practices (like artificial insemination). Moreover, they can expect improvements in productivity and therefore achieving a better gross margin.

In terms of current uptake the option of low-methane breeding does not exist in Scotland or the UK, as a low emission breeding index is not in use yet.

2.2.3.3 Covering slurry stores with impermeable cover

A review of experimental results showed that impermeable plastic covers have the potential to reduce ammonia and GHG emissions in parallel. However, there can be feasibility problems with floating covers if applied on slurry tanks or larger lagoons and their durability is not yet well tested. Furthermore, the presence of a slurry cover increases the ammonia concentration of the slurry and hence its nitrogen content and fertiliser value, but also the potential subsequent ammonia and nitrous oxide losses when the slurry is applied to the soil, unless low ammonia emission spreading techniques are implemented.

Impermeable covers do not inhibit methane formation, so gas built up under the cover needs to be managed to avoid an explosion risk. The report states that all slurry tanks could be covered. The Survey of Agricultural Production Methods[10] (2016) shows that nine per cent of all holdings had storage facilities for slurry, with 62 per cent of these having covered storage.

2.2.3.4 Improved health of ruminants

Animal health is a complex topic, influenced by numerous diseases. The emissions intensity of ruminant meat and milk production is sensitive to changes in key production aspects, such as maternal fertility rates, mortality rates, milk yield, growth rates and feed conversion ratios - all of which are influenced by the health status of the animal. The CXC study estimated 80% of the herd could have improved health and estimated the cost-effectiveness to the farmer from productive gains.

A simplistic approach was taken; rather than estimating the GHG effects of the prevention and control of individual diseases, a general improvement in the health status was assumed, without reference to specific management options.

2.2.3.5 High-starch diet for dairy cattle

Higher inclusion of high-starch feed components like grain, whole-crop cereal or maize silage, lowers enteric methane emissions. However, this requires a change in land use from grass to cereal which is likely to induce the release of carbon from the soil. The CXC work assumes maize is grown on temporary grass.

Maize needs to be grown in warm areas on medium soils so it is not cultivated on a significant proportion of dairy farms in Scotland. This is reflected in published data: the production in Scotland in 2018 was only 13,500t Dry Matter (DM); about 0.8% of the Scottish dairy feed DM intake.

The CXC report infers that maize is fed to 1-3% of Scottish dairy cows, similar to around 1% in North East England. The current uptake rate in the whole of England (11%) is an indication of a conservative maximum uptake rate of 10%. The measure is assumed to be cost-neutral to farmers.

2.2.3.6 Precision feeding of livestock

Precision feeding allows feed to be tailored to individual animals, increasing the efficiency with which nutrients are utilized, using less feed and lowering emissions from feed production. It is applicable primarily to housed animals that can be monitored regularly. For ruminants, emissions could be reduced through improved characterisation of forages.

Accurate analysis of feed composition is the first step in the precision-feeding process. Feed analysers based on near-infrared reflectance spectroscopy (NIRS)

[10] Survey of Agricultural Production Methods, 2016

technology can measure the nutritional content and automatically adjust the ration composition. However evidence shows that it is a complex process and responses are likely to be farm-specific.

Precision-feeding opportunities offer individually tailored supplements to cows in out-of-parlour feeders which have been available for over 30 years using neck-based transponders, to individual cows in standard milking parlours, or through milking robots.

The CXC report highlights evidence that tailoring feeding led to a 10% increase in profit margins by increasing concentrate supplementation and milk yields. Based on industry feedback a 5% reduction in feed cost is assumed and, without exact information on investment costs, based on anecdotal industry information, a four-year payback time is assumed. The applicability for dairy cows was assumed to be 50%, as an approximation of the time cows and heifer spend housed.

2.2.4 **Evidence from the Climate Change Committee**

Agriculture, and land-use, feature prominently in the Climate Change Committee's sixth Carbon Report, which expresses the need to reduce red meat and dairy intake, via behavioural change, and transform farmland.

The sectoral pathway for Scottish agriculture in the CCC report requires an emissions reduction of 23% by 2030. The CCC state changes in farming practices, woodland planting and reductions in livestock numbers are all required to achieve net zero. Their advice also highlights three key changes required to reduce agricultural emissions: 1 - diet change with their main pathway to net-zero assuming a 20% reduction in UK consumption of red meat by 2030, rising to 35% by 2050. 2 – low-carbon farming practices, similar to those outlined above. 3 – productivity measures to improve crop yields and reduce stocking rates.
The CCC and its key speakers have stressed that not only are the changes outlined critical for agriculture to reduce its emissions but also critical to free up the land required for other sectors to achieve what they need.

The CCC recommend the following policies are implemented in fair way to farmers; a strengthened regulatory baseline, incentive schemes such as auctioned contracts and measures to address skills issues, supply chains and barriers for tenant farmers. The CCC state that policies are also needed to cut food waste and encourage a reduction in consumption of meat and dairy.

A number of farm-level challenges were highlighted including uptake of measures, particularly cost-incurring measures, lack of knowledge, skills and experience to transition to low carbon farming, contractual issues and incentives around tenancies and common-land. Wider barriers on dietary change were around lack of awareness, metrics, labelling issues and lack of public sector leadership.

2.3 Biodiversity

2.3.1 What do we know about biodiversity

The Convention on Biological Diversity defines biodiversity as the variability among living organisms from all sources including within and between species and of ecosystems. It is vital to supporting humans by contributing to food production, manufacturing supplies, recreation, soil quality, and climate stabilisation. In December 2020 the Scottish Government published a Biodiversity Statement of Intent which includes proposals in relation to land use.

The Dasgupta Review of the Economics of Biodiversity commissioned by HM Treasury highlights that we are demanding more goods and services than nature can sustainably supply. This means global stocks of natural assets have been depleted. The review makes clear that increased biodiversity helps mitigate risks to economic prosperity and climate change. Acting immediately on biodiversity loss is significantly more cost effective than delaying action. We can respond by reducing our use of natural resources, increasing the efficiency with which we use them or increasing them through conservation and rebuilding.

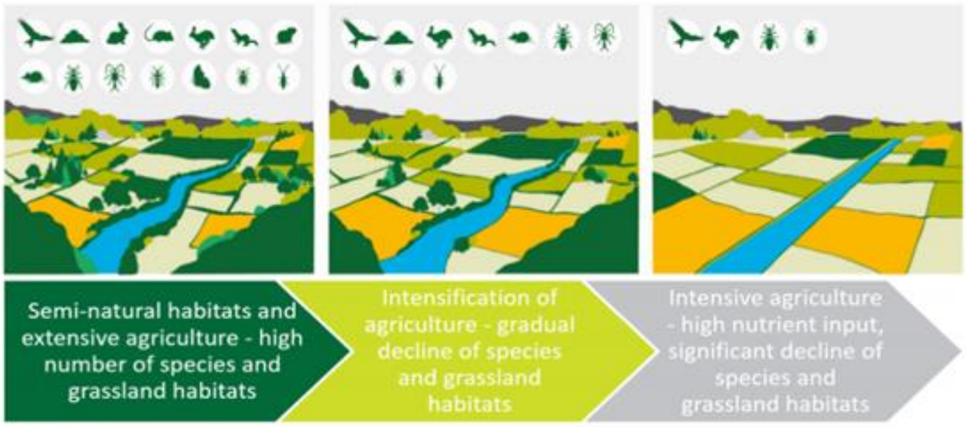
2.3.1.1 What is the relationship between farming and biodiversity?

The UKG review states the relationship between farming and biodiversity is complex. Biodiversity can benefit farmers by improving productivity including soil health, and farming approaches can be tailored to benefit wildlife and biodiversity[11]. However, this is not always true: for example, an area of farmland may have high biomass, but low biodiversity[12].

In recent years, agricultural intensification has negatively impacted biodiversity, particularly due to a trend towards homogeneity leading to fragmentation and loss of habitats. This is particularly evident in the dairy sector[13]. Overall diversity benefits from a mix of land use intensities as well as a mix of habitats[14] as shown below.[15]

[11] The importance of biodiversity and wildlife on farmland | Business Wales (gov.wales)
[12] Final Report - The Economics of Biodiversity: The Dasgupta Review - GOV.UK (www.gov.uk)
[13] Dairy Sub Group Report Green Food Project (publishing.service.gov.uk)
[14] James Hutton Institute. Briefing for RESAS.
[15] https://www.eca.europa.eu/Lists/ECADocuments/SR20_13/SR_Biodiversity_on_farmland_EN.pdf

Figure 1 – Decline in farmland biodiversity due to intensification of land use

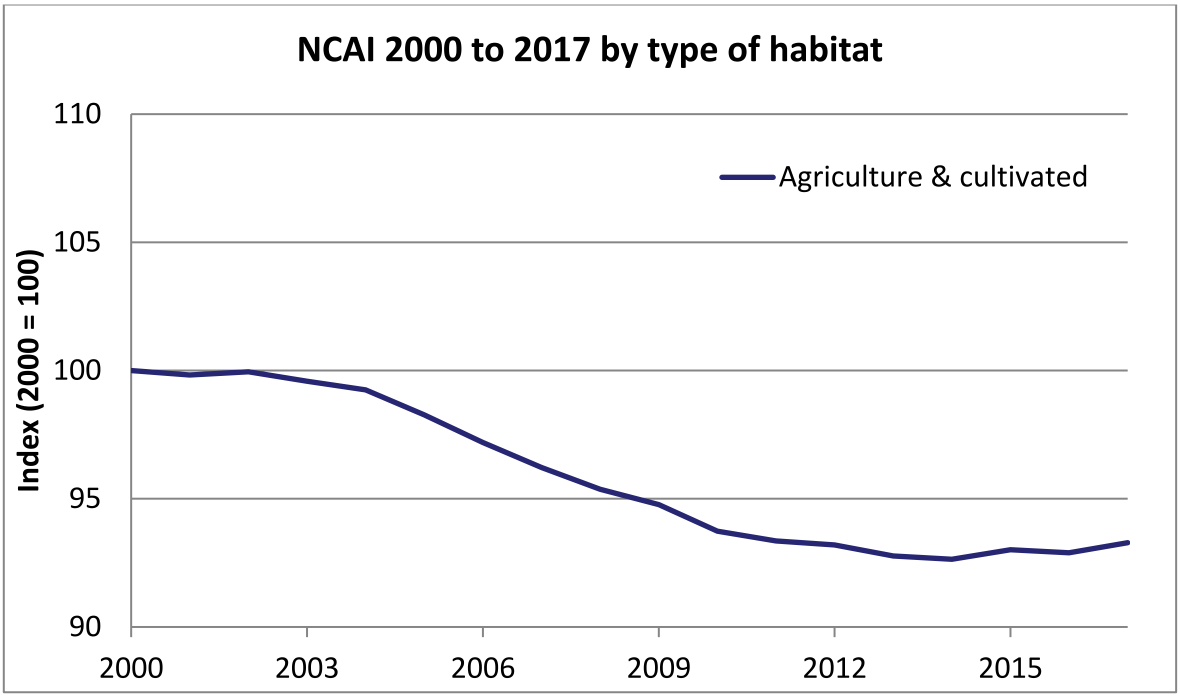


Source: ECA.

A change of land use can result in various impacts on biodiversity: for example, conversion from semi-natural grazing to forestry may be detrimental, as the diversity and richness of wildlife associated with the former can be considerable, whereas conversion from improved grassland (which can be poor for wildlife) to forestry is likely to make little difference[16].

Farmland is particularly able to deliver services such as energy sources, food production and recreation. However, the Natural Capital Asset Index shows that the natural capital[17] asset value of agricultural and cultivated land has been reducing over recent years. The Index is made up of quality (38) x quantity indicators (ie area) and the recent agriculture decline seems to be driven by a reduction in land designated arable land and market gardens[18].

[16] Does plantation forestry restore biodiversity or create green deserts? - Bremer, L., Farley, K.
[17] “Natural capital is the part of nature which directly or indirectly underpins value to people including ecosystems, species, freshwater, soils, minerals, the air and oceans, as well as natural processes and functions. … In combination with other types of capital, natural capital forms part of our wealth; that is, our ability to produce actual or potential goods and services into the future to support our wellbeing.” Natural Capital Terminology (publishing.service.gov.uk)
[18] Scotland's Natural Capital Asset Index - 2019 Update summary.pdf (nature.scot)



Source: Natural Capital Asset Index

Biodiversity varies across regions, land uses and species. A commonly used indicator for biodiversity is bird populations. Research by Nature.Scot shows that most wader species have seen significant declines while seed-eaters show stable or increasing long-term trends.

Summary of long and short term trends for bird species on farmland in Scotland

Species	Long-term trend	Short-term trend
Common snipe	Increase	Increase
Curlew	Decrease	Decrease
Lapwing	Decrease	Decrease
Oystercatcher	Decrease	Decrease (slowing)
Redshank	Decrease	Decrease (slowing)
Linnet	Increase	Stable
Skylark	Stable	Decrease (accelerating)
Tree sparrow	Increase	Increase
Yellowhammer	Stable	Increase
Corn bunting	Decrease	Increase

Long-term changes in Scottish and UK farmland bird populations have been driven by many factors including agricultural intensification, reduced diversity of crop types within farms and reductions in spring-sown crops[19]. Agri-environment schemes have

[19] https://www.nature.scot/official-statistics-terrestrial-breeding-birds-1994-2019

been in place in Scotland for around two decades, helping reverse impacts with results varying between different species.

Pollinators play an essential role in plant reproduction and ecosystem functions, and there are currently large worrying declines in their populations. The European Court of Auditors on Pollinators have found that EU measures did not ensure the protection of wild pollinators, and that key EU policies, including the Common Agricultural Policy, do not include specific requirements for the protection of wild pollinators.

2.3.1.2 What is the relationship between dairy farming and biodiversity?

It is difficult to ascribe biodiversity impacts to particular farming sectors, as biodiversity data are collected on the basis of habitat rather than sector. Some land types, particularly machair, rely on grazing to maintain species richness and hold very high populations of breeding waders. Equally, a substantial proportion of the High Nature Value farming in Scotland is associated with extensive grazing of cattle[20].

Improved grassland is one of the most species poor habitats in Scotland, with typically about half as many species as more semi-natural vegetation[21]. While the benefits for wildlife from improved grassland are limited, according to NatureScot, some bird species such as curlew (number precariously low in many parts), oystercatcher, and redshank can benefit from it, with the right management in place. On the other hand, intensively grazed fields have relatively little habitat value for many farmland birds, and local extinctions are more common in grass-dominated areas compared to arable areas[22].

NatureScot has a project[23] testing an outcome based approach to supporting biodiversity on farms and crofts in Scotland and is beginning a new pilot with dairy farms in South West Scotland, based on the example of the BRIDE project[24] in Southern Ireland.

[20] (PDF) The effects of cattle on the natural heritage of Scotland : Scottish Natural Heritage Commissioned Report No. 203 (ROAME No. F04AA103) (researchgate.net)
[21] British Plant Communities, Volume 3: Grasslands & Montane Communities | NHBS Academic & Professional Books
[22] Dairy Sub Group Report Green Food Project (publishing.service.gov.uk)
[23] Piloting an Outcomes Based Approach in Scotland (POBAS) project | NatureScot
[24] The Bride Project: Biodiversity Regeneration in a Dairying Environment

3 Performance and Productivity

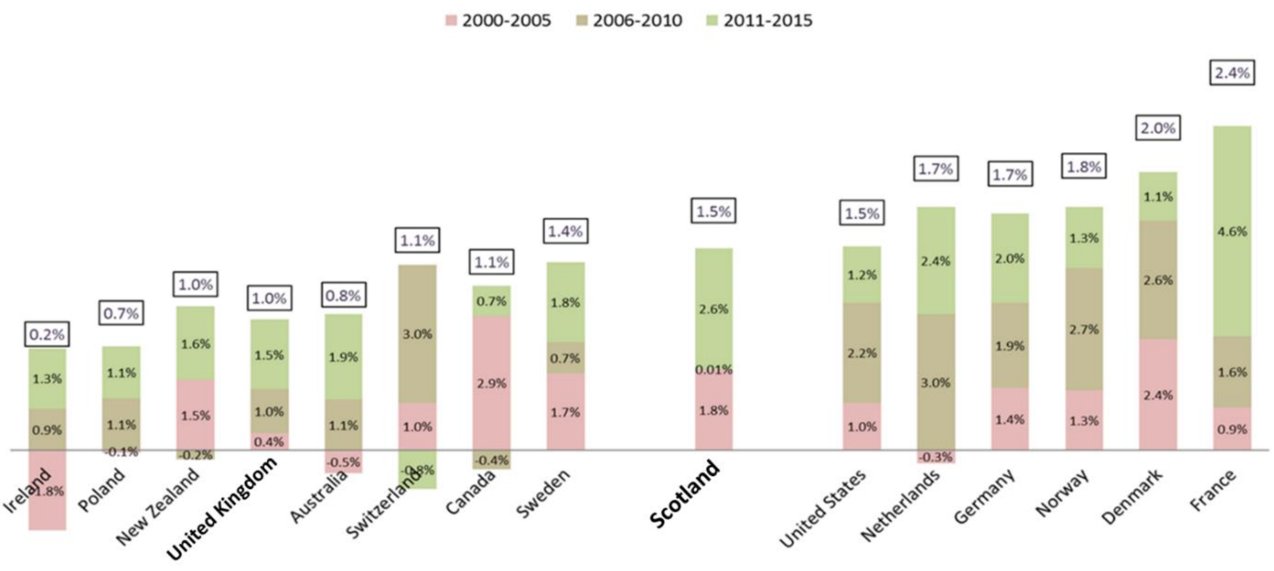
3.1 Key Metrics for Performance and Productivity

Productivity refers to the efficiency of production. One method of quantifying productivity commonly used is Total Factor Productivity (TFP). This looks at an industry's overall efficiency in converting all of its inputs into all of its outputs, and is usually presented in terms of TFP growth over time. Scottish dairy sector specific estimates for TFP are not available.

Productivity is a key measure of sustainable growth, and growth in productivity is usually assumed to be related to the increase and adoption of new technology and farm management techniques. In the case of agriculture, low productivity means more inputs per unit of output, which may lead to higher pollution, lower wages and lower farm incomes.

SRUC's Boosting Productivity Growth in Scottish Agriculture report compares productivity of agriculture in Scotland with other countries. Since 2000, agricultural productivity has been growing, with average annual growth of 1.5%. Scottish agricultural productivity appears to have had stronger growth than UK agricultural productivity overall. However, it is important to note that this is from a fairly low base.

Average annual growth in agricultural productivity by selected countries, 2000 to 2015



Source: Boosting Productivity Growth in Scottish Agriculture

The chart above shows international estimates of agricultural productivity growth, with variation over time. Scotland appears to sit around the middle of international rankings of agricultural productivity growth. It is important to note that the Scottish

Government uses data from the census to calculate agricultural TFP internally, whereas TFP growth for the other countries is based on data published by the United States Department of Agriculture (USDA). Therefore, this comparison should be viewed with some caution.

In the case of agriculture, productivity can be heavily impacted by factors such as land quality, weather conditions and outbreaks of crop and livestock diseases. There are challenges to supporting agricultural productivity in Scotland, particularly around land and weather disadvantages, and lack of adoption of new and existing technologies.

There is wide variation in performance between farm types and within farms types in Scotland, as shown below. There are clear differences in growth[25] between farm type and between time periods, with cereals showing the strongest growth in recent years.

Table 10. Total Factor Productivity Growth by Sector

Years	Cereals	LFA Cattle and Sheep	General Cropping	LFA Sheep	LFA Cattle	Dairy
2000-05	-0.2%	-0.2%	-0.7%	0.4%	0.1%	-0.1%
2006-10	-1.4%	0.9%	1.0%	0.6%	0.1%	1.3%
2011-17	1.2%	-0.3%	0.7%	-0.1%	-0.8%	-2.1%

Source: SRUC, Boosting Productivity Growth in Scottish Agriculture, April 2020

There are multiple factors which impact on agricultural productivity. Various studies, summarised by SRUC, suggest that dairy farming are particularly likely to see a positive impact from policy change, and other factors such as subsidy, age, and quality of land have less impact.

3.2 Options for Improving Performance

3.2.1 Measures

3.2.1.1 Implementing Established Technologies

SRUC's Boosting Productivity Growth in Scottish Agriculture report provides a high level summary of a long list of measures which would potentially increase productivity in Scottish farming broadly covering approaches to information sharing, financial schemes and management changes. Information sharing covers, for example, knowledge exchange, education and implementation. Financial schemes covers positive and negative effects of support and grant schemes. Further details

[25] In this SRUC report growth is assessed as a combination of different efficiency metrics. Whilst analogous to TFP they cannot be compared directly with the earlier TFP figures.

on these can be found in Annex D. It should be noted that there are limits and caveats to both uptake and effectiveness of these measures and the report was not specifically targeted at the dairy sector.

The SRUC report highlights that in Scotland there is generally a low uptake of current, mainstream technologies and techniques. For Scottish livestock farms, better use of well-established feeding, breeding, health, marketing and budgeting practices should lift productivity and profitability on most farms, e.g. low uptake of sexed semen in dairy, sheep and beef sectors, limited rotational grazing practices, progeny tested sires and benchmarking and budgeting skills.

In Scotland, some farm businesses have not adopted basic practices which are already existing and available. For example, practices such as variable liming, consistent weighing of livestock, and business planning are all likely to improve business productivity at low cost to the farmer; however, they have not been widely adopted. Increased adoption of existing, low cost and practical approaches such as these is likely to increase Scottish agricultural productivity.

Previous efforts to increase agricultural productivity through policy have sometimes been “over-successful”, leading to negative impacts from intensification such as biodiversity loss and the “lock-in” of farmers on a productivity-debt cycle.

3.2.2 **Current Uptake**

The Survey of Agricultural Production Methods (2016) collected information on the usage of genetic information on holdings reporting the breeding of dairy cattle. The results showed that 66% reported using genetic information such as PLIs, 47% reported using specific breeds or traits, whereas 18% reported not using information on genetics.

Discussions with researchers at SRUC also highlighted that at a UK level genomic testing in cows generally is around 1-2%. However, in the past 5-7 years the proportion of young genomically improved bulls, where scope for the greatest gains lies, being used has risen from around 25% to around 70% of inseminations and the benefits of that are starting to flow through to milk production.

Initiatives like the Farm Advisory Service (FAS) can provide a link between national policy and individual farmers, which can then translate the goals of policy into concrete actions.

The FAS One to Many service was procured by Scottish Government as part of the broader Scottish Rural Development Programme (SRDP) 2014-2020, and sought to improve the business and environmental performance of Scottish Agriculture through the provision of advice. There is clear evidence that the FAS One to Many delivered a wide-ranging programme, which appears to be well regarded by those who use it, as outlined in the recent “Farm Advisory Service - One to Many: evaluation”. However, this evaluation also demonstrated that FAS impacts are hard to measure. At present there is limited data about the extent of engagement with the programme, and limited monitoring of on-farm improvements resulting from that engagement. To ensure that the FAS can support policy delivery in the ways envisaged in this report, this gap will need to be addressed.

Annex A – Definitions and Classifications of Farms

Definitions

Farm Business Income (FBI)	The total income available to all unpaid labour (farmers and spouses, non-principal partners and directors and their spouses and family workers) and on their capital invested in the farm business, including land and buildings. Income from diversified activities are included in overall FBI.
Farm types	Farms are classified based on the how much of their standard output is from the crop and livestock enterprises on each farm.
Less Favoured Area (LFA)	Land where farming is more difficult due to natural constraints, such as hills and soil quality.
Standard Output	The standard output of an enterprise is an estimate of the average output value for every unit of production. It is defined as the estimated worth of crops and livestock without taking into account the costs incurred in the process.

Classification of Farms

The classification is based on detailed sub-types as defined in the European Commission (EC) farm typology 2, which have been grouped together where required to give the types shown below. The classification is based on the relative importance of the various crop and livestock enterprises on each farm assessed in terms of standard output. The method of classifying each farm is to multiply the area of each crop (other than forage) and the average number of each category of livestock by the appropriate standard output, with the largest source of output determining the type of farm. The list below defines the main types that are reported in the Farm Business Survey.

- **Specialist Sheep (LFA)** - Farms in the less-favoured areas with more than two thirds of the total standard output coming from sheep.
- **Specialist Beef (LFA)** - Farms in the less-favoured areas with more than two thirds of the total standard output coming from cattle.
- **Cattle and Sheep (LFA)** - Farms in the less-favoured areas with more than two thirds of the total standard output coming from sheep and beef cattle together.
- **Cereals** - Farms where more than two-thirds of the total standard output comes from cereals and oilseeds.

- **General Cropping** - Other farms where more than two-thirds of the total standard output comes from all crops.
- **Dairy** - Farms where more than two-thirds of the total standard output comes from dairy cows.
- **Lowground Cattle and Sheep** - Farms NOT in the less-favoured areas with more than two-thirds of the total standard output coming from sheep and beef cattle.
- **Mixed** - Farms where no enterprise contributes more than two-thirds of the total standard output

Annex B - GHG Inventory Assumptions

Estimates of emissions by broad sector have been derived in line with descriptions in the inventory. Not all sources are disaggregated into specific sectors therefore the following sources in the inventory have been attributed based on the following percentages.

Table B1. Emission sources attributed to sectors in the GHG inventory

IPCC	Source Name	Crops	Dairy	Deer	Goats	Horses	Beef	Pigs	Sheep
3H_Urea application	Fertiliser application	80%	20%				10%		
1A4cii_Agriculture/Forestry/Fishing:Off-road	Agriculture - mobile machinery	60%	30%				20%		
3A4_Enteric_Fermentation_other_livestock	Enteric			7%	1%	67%		25%	
3D11_Inorganic_nitrogen_fertilizers	Grass - Direct		30%				60%		10%
3D14_Crop_residues	Grass - Direct		30%				60%		10%
3G1_Liming - limestone	Liming	50%	15%				30%		5%
3G2_Liming - dolomite	Liming	50%	15%				30%		5%

Michael MacLeod, Ilkka Leinonen and Vera Eory (2018) Biotic material flows in Scottish cattle supply chains SRUC 10/4/18

This results in the following estimates of GHG emissions for agriculture in 2018:

Table B2. GHG Emission estimates for Scottish agriculture in 2018

	MtCO2e (2018)		
	Direct from inventory	Attributed based on expert input	% Attributed
Agriculture			
Beef	2.97	0.47	16%
Crops	1.02	0.59	58%
Dairy	0.86	0.31	36%
Sheep	0.99	0.05	5%
Other livestock	0.20	-	-
Uncategorised	0.02	-	-

Annex C– CXC Measures for Dairy

This annex contains an extract of mitigation measures from the CXC (2020) report that are specific to the dairy sector.

3NOP feed additive for cattle

3-Nitrooxypropanol (3NOP) is a chemical substance that reduces the emission of enteric methane by ruminants when added to their rations. It does so by reducing the rates at which rumen microbes convert the hydrogen in ingested feed into methane. Specifically, 3NOP inhibits the final step of methane synthesis by microbes. For housed animals, the 3NOP could be mixed in with the ration, while in grazing situations it may be possible to deliver the 3NOP via a bolus.

Overview

3NOP is a chemical that reduces the excretion of enteric methane by ruminants when added to their rations (or introduced via a bolus). It does so by reducing the rates at which rumen archaea convert the hydrogen in ingested feed into methane. Specifically, 3NOP inhibits methyl-coenzyme M reductase, the final step of methane synthesis by archaea (Duin et al. 2016).

The ingestion of a small amount of 3NOP each day is required, typically in the range of.0.05 to 0.2g NOP per kg of DMI (Javanegara et al. (2017), i.e. for cattle the effective dose is likely to be in the order of 2-3g of 3NOP/animal/day (Haisan et al. 2014, Martinez-Fernandez et al. 2018). For housed animals. the 3NOP could be mixed in with the ration. For grazing animals, it may be possible to deliver the 3NOP via a bolus (Rooke et al. 2016, p13).

Greenhouse gas mitigation summary

While 3NOP is a new mitigation measure (it was patented in 2012, Duval and Kindermann 2012) a range of experimental studies and meta-analyses have been undertaken. Most of the studies with 3NOP have focused on high quality concentrate-based diets. However Martinez-Fernandez et al (2018) found a reduction in enteric methane from beef cattle fed a roughage diet.

Table C1. Summary of studies of the mitigation effect of 3NOP

Livestock type	Parameter	Effect	Country	Year	Reference
Dairy cattle	Enteric methane yield Milk yield and fat Milk protein	-4 to -7% No effect Increase	UK	2014	Reynolds et al. (2014)

Livestock type	Parameter	Effect	Country	Year	Reference
Beef cattle	Enteric methane yield Daily weight gain DMI	-33% No effect Small decrease	Canada	2014	Romero-Perez et al., (2014)
Dairy cattle	Enteric methane yield DMI, milk yield Daily weight gain	-60% No effect Increased	Canada	2014	Haisan et al., (2014)
Dairy cattle	Enteric methane yield DMI, milk yield Daily weight gain	-30% No effect Increased	USA	2015	Hristov et al., (2015)
Beef cattle	Enteric methane yield Daily weight gain DMI	-7 to- 81% (varies with diet and dose) No effect High dose: reduced	Canada	2016	Vyas et al., (2016)
Beef and dairy cattle	Enteric methane yield	-30%	Canada	2016	Duin et al. (2016)
Ruminants	Enteric methane yield	-19 to -33%	Various	Various	Jayanegara et al., (2017)
Beef cattle	Enteric methane yield Daily weight gain	-38% Increase	Australia	2018	Martinez-Fernandez et al (2018)
Beef cattle	Enteric methane yield FCR	-37 to -42% -5%	Canada	2018	Vyas et al. (2018)
Beef cattle **Dairy cattle**	Enteric methane yield Enteric methane yield	-17.1% ±4.2% -38.8% ±5.5%	Various	Various	Dijkstra et al. (2018)

*methane yield: the kg of methane per kg of dry matter intake (DMI)

Jayanegara et al. (2017) undertook a meta-analysis of 3NOP based on 12 in vivo studies from 10 articles. Their results showed that increasing level of 3NOP addition in diets of ruminants decreased enteric methane emissions per unit of DMI, while having no effect on DMI and limited effects on the production performance of both dairy cows and beef cattle. They concluded that “3NOP is an effective feed additive to mitigate enteric methane emissions without compromising productive performance of ruminants”. Papers published since 2017 reinforce this conclusion. Based on the above-mentioned results, we assumed that 3NOP reduces the enteric methane yield by 30% and 20%, respectively, in dairy and beef.

In theory, the feed energy otherwise lost as methane will be transferred for animal functions; this will improve the animal performance. Assuming that 10% of the feed energy is consumed in generating methane, and that the methane reduction as a result of the use of 3NOP ranges from 20% (beef) to 30% (dairy), then the reduction of feed consumption when 3NOP is used would range from 2% (beef) to 3% (dairy). As a conservative estimate, we applied a 2% yield increase for both dairy and beef. It should be noted that changes in enteric methane conversion factor as a result of 3NOP are likely not to be additive with other methane mitigation methods, e.g. breeding and high-starch diet.

Costs

No one-off costs arising from the measure are predicted. The main recurring costs are likely to arise from the purchase and administering of 3NOP. It has been estimated that the cost of Mootral (an alternative to 3NOP) would be $50 per cow per year (Zwick 2017). i.e. £38.

Current uptake and maximum additional future uptake

In theory, 3NOP could be used with beef cattle, dairy cattle, and sheep. The current uptake of the measure is zero. The industry is seeking approval for commercial application of 3NOP by early 2021. If it is successful, the potential uptake rate from that date is 100% in Scotland - we assumed maximum uptake on all housed animals.

Assumptions used in the MACC

Table C2. Assumptions used in the modelling

Parameter	Change in value
Dairy	
Y_M	-30%
Milk yield	+2%
Cost	£38 animal^{-1}
Beef	
Y_M	-20%
Live weight	+2%
Cost	£38 animal^{-1}

Cattle breeding for low methane emissions

The composition of the micro-organisms present in the gut of mammals is influenced by the genetics of the host animal. Studies indicate that it is possible to select dairy cattle for low methane emission, as methane production is heritable to some extent. Inclusion of low enteric methane emission in the breeding goal could reduce methane emissions from cattle, though might limit the productivity and fitness improvements, as selection for low emission causes changes in the animal's nutritional physiology.

The measure assumes that enteric methane emission is introduced in the breeding goal and therefore animals are started to be selected considering their enteric methane emissions. The measure requires farmers buying (semen from) breeding animals with lower methane emissions. The improvements in emissions are cumulative over the years as the emissions from the individual animals get reduced by breeding. Genetic improvement in the national herd can be enhanced by using genomic tools, while farmers collect performance information on the individual animals and genetic testing, and feed this information back for breeding goal development. As well as the methane emission reductions, using genomics also means production traits can be improved.

Overview

The composition of the micro-organisms present in the gut of mammals is influenced by the genetics of the host animal (Hegarty and McEwan, 2010). It has been shown possible to select sheep for high or low methane emissions, as methane production is heritable to some extent (Pinares-Patiño et al. 2013). Studies indicate that dairy cattle have the potential for genetic selection for low methane emission too (de de Haas et al. 2011, Roehe et al. 2016). Inclusion of low enteric-methane emission in the breeding goal could reduce methane emissions from cattle, but might limit the productivity and fitness improvements to some extent, because selection for low emission causes changes in the animal's nutritional physiology.

The measure entails starting breeding for low enteric-methane emission in the national herd (via including the methane emissions in the breeding indices) and farmers buying the animals with lower methane emissions. The improvements in emissions are cumulative over the years as the emissions from the individual animals get reduced by breeding.

Genetic improvement in the national herd can be enhanced by using genomic tools. This entails farmers collecting performance information on the individual animals and genetic testing and feeding back this information to breeding goal development. By using these tools not only can the gains in methane emission reduction be achieved more quickly but production traits can also be improved.

Greenhouse gas mitigation summary

Dairy and beef production would increase (annual gain of 0.75% in milk yield, milk protein and fertility for dairy, and annual gain of 0.25% in live-weight, growth rate and fertility for beef cattle), reducing the emission intensity of products, and the enteric methane conversion factor would decrease by 0.15% of its value every year.

Costs

To realise the measure £2.5m in research investment would be needed in the UK for the dairy herd, of which 9% would be attributed to Scotland (based on dairy cow proportions between the four nations). The beef research would need another £2.5m in the UK, 21% of it falling to Scotland. Furthermore, in every five years £0.5m would be needed to fund both the dairy and the beef genomic tools in the UK. The genomic testing required on farms costs £20 for each bull (either dairy or beef). It is assumed a dairy bull would serve 500 cows while a beef bull would serve 100 cows. The productivity gains would translate into increased income from sales at the farm level.

Current uptake and maximum additional future uptake

The measure is assumed to be applicable to 45% of the dairy and 20% of the beef herd.

Assumptions used in the MACC

Table C3. Assumptions used in the modelling

Parameter	Change in value
Dairy	
Milk yield	0.75% $year^{-1}$
Milk protein content	0.75% $year^{-1}$
Cow fertility	0.75% $year^{-1}$
Methane conversion factor	-0.15% $year^{-1}$
R&D cost	£2.5M in every 5 years in the UK (9% of it in Scotland)
Genomic tool cost	£0.5M in every 5 years (9% of it in Scotland)
Genomic testing	£20 $bull^{-1}$ (serving 500 cows)
Beef	
Live-weight	0.25% $year^{-1}$
Growth rate	0.25% $year^{-1}$
Cow fertility	0.25% $year^{-1}$
Methane conversion factor	-0.15% $year^{-1}$
R&D cost	£2.5M in every 5 years in the UK (21% of it in Scotland)
Genomic tool cost	£0.5M in every 5 years (21% of it in Scotland)
Genomic testing	£20 $bull^{-1}$ (serving 100 cows)

Covering slurry stores with impermeable cover

Animal excreta stored in liquid systems is a source of substantial ammonia and methane emissions, as during the storage N and the volatile solids excreted turn into these gaseous compounds. Though nitrous oxide is not generated in large quantities in slurry stores, a small portion of the ammonia turns into nitrous oxide subsequently in the environment (the process is called indirect nitrous oxide emission). Several factors affect the rate of ammonia, methane and nitrous oxide emissions, including the airflow over the manure; by covering the stores these emissions can be reduced. The presence of a slurry cover increases the ammonia concentration of the slurry and hence its nitrogen content and fertiliser value, but also the potential subsequent ammonia and nitrous oxide losses when the slurry is applied to the soil, unless low ammonia emission spreading techniques are implemented. Cover technologies include floating covers, rigid covers, natural crust and suspended, tent-like structures, and their effects on the pollutant gases are very different.

A review of experimental results showed that impermeable plastic covers have the potential to reduce ammonia and GHG emissions in parallel. However, there can be feasibility problems with floating covers if applied on slurry tanks or larger lagoons and their durability is not yet well tested. Impermeable covers do not inhibit methane formation, so the gas built up under the cover needs to be managed to avoid an explosion risk (in this measure the flaring or purification of the methane is not assumed). Furthermore, depending on the structure, rainwater can accumulate on impermeable floating covers and needs to be removed via e.g. pumping.

Overview

Animal excreta stored in liquid systems is an important source of ammonia and methane emissions because, during the storage, N and the volatile solids excreted turn into these gaseous compounds. In these systems (unless the slurry is aerated), direct nitrous oxide formation is less important as the anaerobic environment blocks denitrification (Sommer et al. 2000). However, a small portion of ammonia emissions turns into nitrous oxide (indirect nitrous oxide emissions). Several factors affect the rate of ammonia, methane and nitrous oxide emissions, including the airflow over the manure. Thus, by covering the store, these emissions can be reduced (Hou et al. 2014; VanderZaag et al. 2015).

Cover technologies include floating covers, rigid covers, natural crust and suspended, tent-like structures (VanderZaag et al. 2015). Ammonia loss is a physiochemical process controlled by the ability of ammonia in the slurry to diffuse to the atmosphere; covers restrict diffusion by creating a physical barrier. With reduced ammonia emissions, indirect nitrous oxide emissions also reduce. The presence of a slurry cover increases the ammonia concentration of the slurry and hence its N content and fertiliser value, but also potential subsequent ammonia and nitrous oxide losses when the slurry is applied to the soil, unless low ammonia-emission spreading techniques are implemented.

The effects of cover solutions on direct GHG emissions are less explored however, with variable and inconclusive results (Hou et al. 2014; Montes et al. 2013; Sajeev et al. 2018; VanderZaag et al. 2008; VanderZaag et al. 2015). Crust formation, straw addition and the use of granules, in particular, tend to increase nitrous oxide emissions substantially, often overriding the emission savings in methane and indirect nitrous oxide emission reductions (Hou et al. 2014; Sajeev et al. 2018). The effects of these covers on methane emissions are variable, with high probability of increased emissions. A review of Hout et al. (2014) showed that impermeable plastic covers have the potential to reduce ammonia and GHG emissions in parallel.

However, there are feasibility problems with floating covers, in general, if applied on slurry tanks or larger lagoons (not on small earth-banked lagoons), and their durability is not yet well tested (Amon et al. 2014). When the slurry is covered by impermeable films, the formation of methane is not eliminated, and the gas builds up under the cover and in the liquid, creating an explosion risk and escaping when the cover is opened (Montes et al. 2013). With additional devices (gas pipes and pumping system) most of the methane can be captured and converted to CO2 either by direct flaring, reducing the GWP substantially, or by purification and use in electricity or heat generation. Furthermore, depending on the structure, rainwater can accumulate on impermeable floating covers and needs to be removed via e.g. pumping.

Greenhouse gas mitigation summary

Table C4. Data from literature on abatement

Abatement	Value	Country	Reference
Methane emissions	-47% (g methane–C (kg VS)$^{-1}$)	Sweden	(Rodhe et al. 2012)
Direct nitrous oxide emissions	-100% (g nitrous oxide–N m^{-2})	Sweden	(Rodhe et al. 2012)
Ammonia emissions	-80% (range: -59% - -95%)	Various	Review of four papers in (VanderZaag et al. 2015)

Costs

Cost information on slurry covers has been collated by VanderZaag et al. (2015) from North American and UK sources. They estimated the capital costs of floating impermeable covers to be in the range of €1.70 m-2 to €63 m-2 with a lifespan of 8-10 years and 2% annual maintenance costs for rainwater collection. The high cost solutions included negative pressure covers to keep the film tight on the slurry surface.

Current uptake and maximum additional future uptake

The slurry covers can be installed on all slurry tanks and lagoons.

Assumptions used in the MACC

Table C5. Assumptions used in the modelling

Parameter	Change in value
Methane conversion factor	-47%
Direct nitrous oxide emissions from storage	-100%
Ammonia emissions from storage	-80%

Improved health of ruminants

Endemic, production-limiting diseases are a major constraint on efficient livestock production, both nationally and internationally, and have an impact on the carbon footprint of livestock farming. UK systems are particularly vulnerable to endemic disease impacts because they are largely pasture-based. The emissions intensity of ruminant meat and milk production is sensitive to changes in key production aspects, such as maternal fertility rates, mortality rates, milk yield, growth rates and feed conversion ratios - all of which are influenced by the health status of the animal. Therefore, improving health status is expected to lead to reductions in emission intensity. Animal health is a complex topic, influenced by a plethora of diseases. It can be improved through preventative controls (such as changing housing and management to reduce stress and exposure to pathogens; vaccination; improved screening and biosecurity; disease vector control) and curative treatments such as antiparasitics and antibiotics. In this work a simplistic approach was chosen; rather than estimating the GHG effects of the prevention and control of individual diseases, a general improvement in the health status was assumed, without reference to specific management options.

Overview

Endemic, production-limiting diseases are a major constraint on efficient livestock production, both nationally and internationally, and have an impact on the carbon footprint of livestock farming (Elliott et al. 2014). UK systems are particularly vulnerable to endemic disease impacts because they are largely pasture based. The emissions intensity of ruminant meat and milk production is sensitive to changes in key production aspects, such as maternal fertility rates, mortality rates, milk yield, growth rates and feed conversion ratios. All of these parameters are influenced by health status, so improving health status is expected to lead to reductions in emission intensity (Skuce et al. 2014). However, there have been few empirical studies investigating the impact of any of the production diseases on GHG emissions intensity.

Health can be improved through preventative controls (such as changing housing and management to reduce stress and exposure to pathogens, vaccination, improved screening and biosecurity, disease vector control) and curative treatments such as antiparasitics and antibiotics.

Greenhouse gas mitigation summary

The impact of endemic disease is difficult to quantify, often relying on old data from experimental challenge studies, which do not reflect the natural presentation of many of these diseases. ADAS (2014) attempted to quantify the impact of the top cattle health ‘conditions’ on the carbon footprint of a litre of milk, and the reductions that could be made via veterinary and/or farm management interventions. The study concluded that a 50% movement from current health status to a healthy cattle population (assumed to be the maximum improvement achievable) would reduce the UK emissions by 1436 kt CO2e year-1, or 6%. Eory et al. (2015) used a similar approach to quantify the effect of improving sheep health, and estimated that a 50% movement from current health status to a healthy sheep population would reduce the UK emissions by 484 kt CO2e year-1 by 2035.

Several studies have been undertaken since the 2015 MACC (Eory et al. 2015), which are briefly summarised below.

UK cattle and sheep health

Skuce et al. (2016) reviewed the evidence on prevalence and impact for 12 key ruminant diseases. They identified potential GHG emissions savings for all twelve diseases evaluated, while noting that some diseases are more tractable than others. They concluded that emissions intensity could be reduced through control measures relating to:

- milk yield and cow fertility rates (dairy systems)
- cow/ewe fertility and abortion rates
- calf/lamb mortality and growth rates (beef and sheep systems), and
- feed conversion ratios (all systems).

Three diseases, one from each of the major livestock sectors, were considered more cost-effective and feasible to control: neosporosis (beef cattle), infectious bovine rhinotracheitis, IBR (dairy cattle) and parasitic gastroenteritis (sheep).

Worms in sheep

Houdijk et al. (2017) undertook experiments to determine the effect of parasitism on the emissions intensity (EI) of sheep and found that infection with Teladorsagia increased calculated global warming potential per kg of lamb weight gain by 16%. Fox et al. (2018) also undertook experiments infecting sheep with Teladorsagia and found that infection led to a 33% increase in methane yield and a significant decrease in lamb growth rates, which led the authors to conclude that “there is potential for parasitism to have an extensive impact on greenhouse gas emissions”.

Worms in beef cattle

Gut worms are the most important gastrointestinal nematode parasites of grazing cattle, responsible for considerable sub-clinical disease and production loss. Bellet et al. (2016) undertook an abattoir study of prevalence and production impacts in

England and Wales of Ostertagia spp. (the study also recorded the effects of rumen fluke and liver fluke). Based on this data set, MacLeod and Skuce (2019) estimated that the growth rates of cattle with a high Ostertagia burden were about 10% lower than those with a low burden. This translates into a difference in EI of 3.9%, i.e. the high-burden herd produced 3.9% more GHG for every kg of liveweight output. Assuming the overall burden could be halved with appropriate treatment implies that the EI could be reduced by 2%.

<u>Liver fluke in beef cattle</u>

Skuce et al. (2018) investigated the impact of liver fluke infection on cattle productivity and associated GHG emissions intensity (EI) using abattoir data from NE Scotland from 2014-2016. The study focused on a cohort of 22,349 Charolais males from a total dataset of ~250,000 cattle. Liver fluke infection resulted in a statistically significant reduction in liveweight gain of 0.023kg/day and an extra 21 days to slaughter. As a result, the EI of meat from a herd with no fluke is approximately 1% lower than the same herd with fluke. The study only focused on one impact of fasciolosis (reduced growth rates) - other effects include changes in feed conversion ratio, mortality and fertility, milk yields and quality of output (e.g. carcass conformation and rates of liver condemnation). These will have an additive effect on greenhouse gas EI, so removing fluke may have a much greater impact on EI in practice.

<u>Lameness in dairy cattle</u>

Lameness can reduce dairy cow milk yield, thereby increasing the EI of the milk produced. Chen et al. (2016) calculated the effect of lameness on EI, using the impacts of lameness reported in a series of studies undertaken in Europe and North America. They estimated that lameness can lead to an increase in emissions intensity of 1-8% compared to a baseline scenario, depending on the prevalence of the disease. Mostert et al. (2018) investigated the effects of three types of foot lesions in Dutch dairy cattle: digital dermatitis (DD), white line disease (WLD), and sole ulcer (SU). They found that the impacts of these lesions on milk yield and calving interval led to an average increase in milk emissions intensity of 1.5%.

<u>Conclusion</u>

The studies undertaken since 2015 indicate that the abatement potentials given for improved cattle and sheep health in Eory et al. (2015) are achievable (while bearing in mind that studies with negative findings are less likely to be submitted for publication). Furthermore, they provide specific examples of how the abatement potential might be achieved, i.e. by reducing the incidence of gastrointestinal parasites, liver fluke and lameness.

Costs

As improving livestock health is a very broad measure, encompassing a variety of livestock management, disease prevention and treatment options, this study, following previous studies, estimated the cost-effectiveness of the measures (based on earlier publications) and derived the costs from the cost-effectiveness.

Eory et al. (2015) estimated that improving cattle health could be achieved at an average of £-42 t CO2e-1, while the cost-effectiveness of improving sheep health would be £30 t CO2e-1. As there are many possible combinations of health challenges and treatments, the cost-effectiveness of achieving mitigation via improved health is likely to vary considerably; flocks and herds with below average health status are likely to provide scope for larger and more cost-effective reductions in greenhouse gas.

Current uptake and maximum additional future uptake

We assume that 80% of the herd could have improved animal health.

Assumptions used in the MACC

Table C6. Assumptions used in the modelling

Parameter	Change in value
Milk yield	+6.38%
Cost	£28 animal^{-1}

High starch diet for dairy cattle

The amount of enteric methane emission depends on the composition of the animal feed, amongst other things. The more starch the diet contains, as opposed to fibre, the lower the methane emissions. This is the result of the different chemical pathways in ruminal fermentation; fibre digestion generates more dihydrogen and subsequently more methane. Thus. higher inclusion of high-starch feed components, for example grain or whole-crop cereal or maize silage, lowers enteric methane emissions. However, the partial replacement of grass (as a fibre source) with starch necessitates a change in plant production and therefore land use from grass to cereal areas. This is likely to induce the release of carbon from the soil, depending on the details of previous and new cultivation practices and the soil type. In this report, we assumed maize would be grown on temporary grass areas.

Overview

A high starch diet increases the digestible energy (DE%) content of the diet by increasing the amount of starchy concentrates in the ration, while keeping the total crude protein content of the diet constant. This reduces the rate of enteric methane emissions. In practice, this can be achieved by replacing conserved grass with maize silage, to increase the digestibility of the ration. This will reduce enteric methane emissions and manure methane (as less volatile solids will be excreted). The starch content could also be increased by replacing grass silage with high starch concentrate. However, Moran et al (2008) found this to be a more expensive way of achieving mitigation.

Greenhouse gas mitigation summary

According to Hristov et al. (2013, p37) “it is generally believed that higher inclusion of grain (or feeding forages with higher starch content, such as whole-crop cereal silages) in ruminant diets lowers enteric methane production”. IBERS (2010, p3) concluded that “feeding more maize silage and less grass silage reduced methane production relative to feed intake and milk yield (13% and 6% reduction per unit of dry matter intake and per litre of milk output respectively when shifting from a 75:25 grass silage: maize silage ration to a 25:75 ration). Feeding less protein reduced nitrogen excretion in manure and increased the efficiency of dietary nitrogen utilization.” They assumed that this measure could be implemented year-round in 50% of the UK dairy sector and would lead to a 5% reduction in enteric methane emissions and a 20% reduction in N excretion. They assumed no impact on livestock performance. (IBERS 2010, p17). Doreau et al., (2012) reported similar results, i.e. a reduction in methane yield and N excretion.

According to Dewhurst (2013), reducing N intake by inclusion of maize silage in mixtures with legume silages leads to a marked reduction in urine N without loss of production potential. It is predicted, on the basis of their chemical composition and rumen kinetics, that legume silages and maize silages would reduce methane production relative to grass silage, though in vivo measurements are lacking.

In contrary, Wilkinson and Garnsworthy (2017) found that a maize silage diet could lead to higher methane emissions than a grass silage diet (although the overall effect on the carbon footprint of milk was modest, when other emission sources were included).
It should be noted that changes in enteric methane conversion factor as a result of high starch diet are likely not to be additive with other methane mitigation methods, e.g. breeding and 3NOP.

Costs

We assume that as grass silage and maize silage have the same production costs, and as grass silage will be replaced with maize silage, the net costs are zero.

Current uptake and maximum additional future uptake

Because maize needs to be grown in warm areas on medium soils (Morgan and Frater 2015), it will not be readily cultivated on a significant proportion of the grassland on dairy farms in Scotland. This is reflected by the current cultivation area (Scottish Government 2018b) and average yield: the production in Scotland in 2018 was only 13,500 t DM; this covers about 0.8% of the Scottish dairy feed DM intake.

Assuming that the maize inclusion rate in diets ranges from 25% to 75%, this would mean that maize is fed to 1-3% of Scottish dairy cows. This figure is comparable to North East England (1%) and much lower than the current uptake rate in the whole of England (11%). Therefore, a maximum uptake rate of 10% is assumed here as a conservative estimate. No changes are suggested to other assumptions of the earlier MACC.

Assumptions used in the MACC

Table C7. Assumptions used in the modelling

Parameter	Change in value
Methane conversion factor (Y_M)	-5%
Cost	0

Precision feeding of livestock

How well animals can utilise their feed depends on the individual animal and also on diet. Precision feeding allows for feed to be tailored to suit most of the needs of individual animals, increasing the efficiency with which nutrients in the feed are utilised. As less feed is used to achieve the same production, greenhouse gas emissions from feed production is reduced. This practice can also reduce the rate of nitrogen and volatile solid excretion and therefore the nitrous oxide and methane emissions arising from manure management. It is applicable primarily to housed animals that can be monitored at regular intervals, as such information is needed to adjust rations. For pigs, this may involve regular weighing of animals and adjustment of the ration protein content based on weight and growth rate, and supplementation of diets with synthetic amino acids. For ruminants, emissions could be reduced through improved characterisation of forages to enable appropriate supplementation.

Overview

Precision feeding provides opportunities for reducing the feed conversion ratio of animals, and, as less feed would be used, GHG emissions from feed production would fall. It can also reduce the rate of N (and volatile solid) excretion and therefore the nitrous oxide and methane emissions arising during manure management. It is applicable primarily to housed animals that can be monitored at regular intervals, and the information used to adjust rations, i.e. dairy cattle and pigs, and chicken. The measure requires technology to match the diet more closely to the animal's nutritional requirements. For pigs, this may involve regular weighing of animals and adjustment of the ration protein content based on weight and growth rate, and supplementation of diets with synthetic amino acids. For ruminants, emissions could be reduced through improved characterisation of forages to enable appropriate supplementation.

Accurate analysis of feed composition is the first step in the precision-feeding process. Feed analysers based on near-infrared reflectance spectroscopy (NIRS) technology can measure the nutritional content and automatically adjust the ration composition (Hristov et al. 2013).

Eory et al. (2015) stated that for dairy cattle, precision-feeding opportunities lie in the capacity to offer individually tailored supplements to cows in out-of-parlour feeders (which have been available for over 30 years using neck-based transponders); or to individual cows in standard milking parlours; or through automated milking systems (milking robots).

Combining milk recording and automated weighing systems with milking parlour visits provides good data on which to provide tailored supplement levels. Hills et al. (2015), in a comprehensive review of individual feeding of pasture-based dairy cows, however, highlight the complexity in determining responses to supplementary feeds and provided compelling evidence that both cow-level (e.g. genotype, parity, days in milk, cow body weight, condition score, feed intake) and system-level (e.g. pasture allowance and other grazing management strategies and climate) parameters can influence the marginal milk production response to supplementary feeding. Basically, the responses are likely to be system and farm specific.

Greenhouse gas mitigation summary

Pomar et al. (2011) found that growing pigs with daily tailored diets had nitrogen intake reduced by 25% and N excretion reduced by more than 38%. Cherubini et al. (2015) showed that pig diets low in protein had improved carbon footprints, principally through lower need for imported soya.

The 2015 UK MACC (Eory et al. 2015) had the measure “Improving beef and sheep nutrition”, which involved improving animal performance and reducing methane yield via improvement of ration nutritional values (i.e. digestibility of the ration). This was achieved by getting advice from an animal nutritionist to improve the composition of the diet, complemented with forage analysis and improved grazing management. Eory et al. (2015) assumed that improved diet formulation and grazing management increases the digestibility of the roughage and concentrate by 2% from their original values (i.e. from 70% to 71.4%), and results in a 2% improvement in growth rates.

The Farmscoper tool has three measures which relate to precision feeding. Their effect on pollution is presented in Table C8.

Table C8. Effect on pollutant flows of Farmscoper measures (ADAS 2017)

Farmscoper measure ID	Farmscoper measure	Methane	Direct nitrous oxide	Indirect nitrous oxide
331	**Reduce dietary N and P intakes: Dairy**	**-2%**	**-2%**	**-2%**
332	Reduce dietary N and P intakes: Pigs	-2%	-2%	-10%

Farmscoper measure ID	Farmscoper measure	Methane	Direct nitrous oxide	Indirect nitrous oxide
331	**Reduce dietary N and P intakes: Dairy**	**-2%**	**-2%**	**-2%**
333	Reduce dietary N and P intakes: Poultry	**-2%**	**-2%**	**-10%**
34	Adopt phase feeding of livestock	**-2%**	**-2%**	**-2%**

The measure was modelled assuming a 2% reduction in the gross energy needs of dairy cows and a 5% reduction in both the volatile solid and N excretion of pigs.

Costs

Pomar et al. (2011) found that feed cost was 10.5% lower for pigs fed daily tailored diets. Andre et al. (2010) found that tailoring feeding to the individual dairy cow led to a 10% increase in profit margins by increasing concentrate supplementation and milk yields. The costs estimated in the Farmscoper tool are presented in Table C9.

Table C9. Costs of Farmscoper measures (ADAS 2017)

Farmscoper measure ID	Farmscoper measure	Capital cost (£ animal^{-1})	Operational cost (£animal^{-1} y^{-1})	Cost (£ m^{-3} manure)
331	**Reduce dietary N and P intakes: Dairy**	**0.00**	**0.76**	**0.76**
332	Reduce dietary N and P intakes: Pigs	0.00	2.59	2.59
333	Reduce dietary N and P intakes: Poultry	0.00	6.39	6.39
34	Adopt phase feeding of livestock	0.94	-3.81	-2.87

Based on the information from the industry, a 5% reduction in feed cost is assumed. Without exact information on investment costs, based on anecdotal industry information a four-year payback time is assumed. Therefore, the capital cost is calculated as four times the annual feed cost savings. The lifetime of the investment is five years.

Current uptake and maximum additional future uptake

Pellerin et al. (2013) reported the maximum technical potential applicability: 52% of dairy cows, 20% additional uptake of biphase pig feeding and almost 100% pigs for multiphase feeding.

Martineau et al. (2016, p141) stated that "for pigs and poultry, phase feeding and the use of synthetic amino acids have been widely adopted by producers and future reductions in N excretion are likely to be at the lower end of the ranges cited (5 and 10% for pigs and poultry respectively)".

Adoption of phase feeding is believed to be implemented widely in the pig and poultry industry. Similarly, the current uptake of phytase supplements that increase the availability of dietary phosphorus is estimated to be already close to the potential as including the enzyme in the diet is cost neutral. Industry sources indicate that phytase is incorporated into approximately 90% of pig diets, 90% of hen feeds and 40% of broiler rations manufactured in the UK (Gooday & Anthony 2015).

The implementation rates estimated in the Farmscoper tool are presented in Table C10.

Table C10. Implementation rates of Farmscoper measures (ADAS 2017)

Farmscoper measure ID	Farmscoper measure	Prior	Maximum	Additional
331	**Reduce dietary N and P intakes: Dairy**	**10%**	**1100100%**	**90%**
332	Reduce dietary N and P intakes: Pigs	80%	100%	20%
333	Reduce dietary N and P intakes: Poultry	80%	100%	20%
34	Adopt phase feeding of livestock	80%	100%	20%

In pig production, nearly all farms in Scotland are expected to follow biphase or three-phase feeding already. This is because Scottish pig production is highly centralised and concentrated in large units. Therefore, the improvement in feeding is expected to be a shift to multiphase feeding. Technology for multiphase feeding already exists. However, the installation costs are high and, therefore, this is expected to applicable in large units only. Since Scottish pig production is concentrated in large units, a potential uptake rate of 90% is assumed, as a conservative estimate.

The applicability for dairy cows was assumed to be 50%, as an approximation of the time cows and heifer spend housed.

Assumptions used in the MACC

Table C11. Assumptions used in the modelling

Parameter	Change in value
Dairy	
Gross energy need	-2% (resulting in 2% methane and 3% nitrous oxide reduction)
Feed costs	-5%
Capital costs	Four times the savings in feed costs in every 5 years
Pig	
Volatile solid excretion rate	-5%
N excretion rate	-5%
Feed costs	-5%
Capital costs	Four times the savings in feed costs in every 5 years

Annex D - Productivity Measures – long list

Table D1. Measures for Improving Performance – Information Sharing

Measure	Logic behind intervention	Potential barriers	Feasibility in Scotland
Farm advisory service	Studies have found high rates of return on public investment in applied advice.		Existing in the SRDP - could be extended
Farmer discussion groups	Studies have found high rates of return on public investment in applied advice.	Lack of strong evidence; depends on method and context.	Can be encouraged
Support for farmer learning	Support for new entrants and for continued professional development likely to increase adoption of new technologies and management practices.	Low turnover in farming.	Can be implemented
Agriculture education	Apprenticeships, college and university courses have improved the level of specialist knowledge among farmers in other countries.	Low turnover in farming.	Can be implemented
Required qualifications	Some countries have created "license to farm" to ensure continuous improvement of current farming systems, including environmental goals.	May be politically unpopular.	Can be implemented
Support for Research and Development	Research suggests that reduction of government support for R&D in the 1980s had a negative impact on productivity.	Must be strategic, targeted, and adopted by farmers.	Can be implemented
Demonstration farms	Some evidence to support that farmers who attend improve practice on their own farms.	Unclear how it would impact farmers at scale.	Relatively untested
Smart farms	Have been used in Australia to implement cutting edge technologies.	Potential high costs.	None existing in Scotland
Monitor farms	Evaluation suggests the model has been effective in improving farming performance and enterprise among active participants.	Potential high costs.	Existing - could be extended

Table D2. Measures for Improving Performance – Financial Schemes

Measure	Logic behind intervention	Potential barriers	Feasibility in Scotland
Reduction in direct support	Most studies find a negative relationship between subsidies and productivity. May lead to significant restructuring in agriculture, particularly for smaller/more vulnerable farms.	Likely to have negative political impacts; may lead to further "middling out".	Can be implemented; may not be feasible due to Scottish agricultural context
Capital grants or loans	Studies find both positive and negative impacts on productivity: increased ability to innovate/develop business; low risk and potential crowding out. Loans may be more effective due to requirement to pay back.	May not be WTO eligible; may lead to overcapitalisation.	Can be implemented; limited by WTO rules
Support for new entrants	Younger entrants may have more innovative approaches to business, and may have stronger ICT and business planning skills.	Lack of retirement housing; lack of long leases for farmland.	Existing in the SRDP - could be extended
Support for exit	There are barriers to succession, meaning less productive management can continue longer than in other industries.	Lack of retirement housing; lack of business planning and succession.	Can be implemented
Changing tax incentives	Evidence from Ireland suggests that tax incentives for longer tenancies on agricultural land may increase productivity.	Potential high costs, both financial and administrative.	Can be implemented

Table D3. Measures for Improving Performance – Established Technologies

Measure	Logic behind intervention	Potential barriers	Feasibility in Scotland
Precision Agricultural Techniques	Evidence suggests some PATs can reduce fuel use and management time; there is a training requirement for farmers.	High initial costs; high training requirement; lack of take-up by farmers.	Needs wider adoption
Nutrient management and soil nutrient mapping	Promising in increasing yield and additional benefits in managing GHG emissions	Lack of take-up by farmers.	Needs wider adoption
Improved soil management	For example, nutrient management and mapping; reduced cultivations to increase soil quality.	Lack of take-up by farmers.	Needs wider adoption
Robotic Milkers	More effective for larger herds and potential for growth; there is a training requirement.	Lack of take-up by farmers.	Can be encouraged
EID	Appears to give significant savings in labour use.	High initial costs; lack of take-up by farmers.	Needs wider adoption
EBVs; pedigree recording	Studies suggest EBVs can increase profitability of livestock farms.	High initial costs; lack of take-up by farmers.	Needs wider adoption
Changing cereal yields and varietal uptake	Improved crop yields have not been consistent across Scottish farms; it is not clear why this is so.	Lack of take-up by farmers.	Further research required

Table D3. Measures for Improving Performance – Management Changes

Measure	Logic behind intervention	Potential barriers	Feasibility in Scotland
Precision livestock farming	Targeted precision livestock farming has potential to increase net margins per animal.	High initial costs; lack of take-up by farmers.	Needs wider adoption
Changing business size	Large farms tend to be more efficient and better adopters of new technology.	Politically unpopular "middling out"	Can be encouraged
Collaborative farming agreements	May be of particular benefit to new entrants, through increased availability of land.		Existing - could be extended
Disease control and eradication	Reduces loss and improves productivity.		Existing - could be extended
Risk management	Investment in productivity should be accompanied by steps to manage and reduce risk.	Could reduce incentive to innovate.	Can be implemented
Changing the input-output mix	Switching from specialised farms to more mixed operations may offer opportunities for recycling of inputs, and best use of land.	High training requirement for farmers.	Can be encouraged
Widen the range of planted crops	A wider range of crops could diffuse the intensity of work and machinery requirements over the course of the year.	High training requirement for farmers.	Further research required

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