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Reaching Net Zero in Scotland

Emissions reductions in agriculture

Report for WWF Scotland

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Executive summary

The Climate Change (Emissions Reduction Targets) (Scotland) Act 2019 committed Scotland to a climate change target of net zero by 2045. The recent Climate Change Plan Update (CCPu) contains a target of 5.3 Mt CO_2e y^{-1} agricultural greenhouse gas (GHG) emissions by 2032, based on an adjusted 2019 agriculture GHG emission baseline[1] of 7.7 Mt CO_2e y^{-1}.

The scope of the GHG emissions that the 2032 target relates to is emissions from agriculture as represented in the Agriculture category of the national inventory of GHGs. These emissions are mainly methane and nitrous oxide, with a smaller contribution from carbon dioxide. The following are the main sources:

- enteric fermentation,
- manure management,
- agricultural soils,
- liming,
- urea application.

In this study the potential for GHG emissions mitigation in agriculture, by 2032, has been assessed. We have also assessed the potential GHG mitigation that could arise from implementation of recommendations in other reports, namely:

- A transformation pathway interim report from the independent Farming for 1.5°C Inquiry (2020);
- Farmer-led group reports, comprising reports from the following groups:
    - Arable Climate Change Group
    - Dairy Sector Climate Change Group
    - Hill, Upland and Crofting Group
    - Scottish Pig Industry Leadership Group
    - Suckler Beef Climate Group
- The recent Scottish Government's Climate Change Plan Update (CCPu).

It should be noted that most agriculturally relevant emissions and removals (sequestration) of carbon dioxide are accounted for in the Land Use, Land-Use Change and Forestry (LULUCF) category of the national GHG inventory and were not included in our estimates.

The potential mitigation from 69 mitigation actions has been assessed, based on evidence from literature. Mid-range mitigation potential values are given in Table 1, alongside the agriculture emissions projected for 2032, assuming adoption of mitigation actions as recommended in each of the three reports.

The overall mitigation potential of each of the reports is lower than the overall mitigation potential for all actions analysed. This indicates some gaps in the mitigation actions represented in the reports, and these are identified in this study. The CCPu proposes policies and actions that are mainly to explore further policies to drive uptake of mitigation actions. We have made an interpretation of how these policies can lead to on-farm mitigation actions by 2032. Urgency is needed for actions to be adopted in time to show effects on emissions.

The mitigation potential for all three reports is not sufficient to reach the 2032 target of 5.3 Mt CO_2e y^{-1} (Table 1).

[1] This 2019 baseline value was provided by Scottish Government (SG) and agreed for inclusion in this report by WWF Scotland. Its inclusion facilitates comparisons between this work and studies being undertaken for SG.

Table 1. Summary of mitigation potential across all mitigation actions included in the analysis, and by inclusion in named reports.

Selection of actions	Mitigation potential (t CO_2e y^{-1})	Agriculture emissions at 2032 assuming a baseline of 7.7 Mt CO_2e y^{-1}
All mitigation actions analysed	1,126,396	6,573,604
Mitigation actions in Farmer-led group reports	1,047,013	6,652,987
Mitigation actions in the interim Farming for 1.5°C report	937,922	6,762,078
Mitigation actions that can follow from the CCPu	524,793 to 717,609	7,175,207 to 6,982,391

It is simpler to focus on and quantify individual mitigation actions rather than changes to the full farm system, and that is the focus of this report. System level change demands long-term commitment that is not implicit in many of the individual mitigation actions. Implementation and assessment of system level change is more difficult, at both farm and policy levels, but is still important and needs further work.

In efforts to reach the CCPu GHG target for 2032 of 5.3 Mt CO_2e y^{-1} it is important to recognise the large uncertainty in the estimates of mitigation potential presented in this report and elsewhere. In recognition of this uncertainty a supplement to this report gives ranges for mitigation potential values based on literature estimates. This uncertainty arises from differences in how and under what circumstances mitigation actions are applied. Further uncertainty, that is not quantified in this project, arises from the estimates of additional mitigation action uptake, which are largely based on expert judgement, either by this study, or in studies that are referenced. Changing these uptake values changes the estimates of overall mitigation potential across Scotland. Therefore, the progress towards GHG emissions mitigation will be dependent on both the quality of mitigation action implementation and the extent to which additional uptake values are achieved. These will, in turn, be dependent on industry engagement and policy development and implementation.

A further challenge in the pursuit of the CCPu target is the availability of data. Better and more activity data (e.g., from farm surveys) will be needed to monitor progress, at sufficient detail to allow uptake of mitigation actions to be estimated.

Finally, we note that the 2045 net zero target presents a greater challenge than the 2032 target and will require that the scope of the target includes agricultural activities that fall within the LULUCF category of the national GHG inventory. Further analysis is needed to estimate how further mitigation and sequestration actions that influence this emissions category can move Scotland towards this target.

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1 Introduction

1.1 Background and aims

The Climate Change (Emissions Reduction Targets) (Scotland) Act 2019 committed Scotland to a climate change target of net zero by 2045. This requires all sectors to substantially reduce their emissions by 2030. Scottish agriculture contributes around 20% of current total Scottish emissions. Between 1990 and 2018 these emissions reduced by 1.4 Mt CO_2e (Scottish Government; 2020b), nearly 16%. Unlike other sectors, the primary greenhouse gases emitted from agriculture are methane and nitrous oxide, not carbon dioxide. Scottish agriculture is the main source of both gases in Scotland.

Agricultural methane emissions have fallen by 0.9 Mt CO_2e, or 18%, between 1990 and 2018 due in a large part to a decrease in cattle and sheep numbers. Agricultural emissions of nitrous oxide are mainly produced by agricultural practices on soils, and to a lesser extent by animal manures. These have fallen by 0.4 Mt CO_2e or 14.8% between 1990 and 2018.

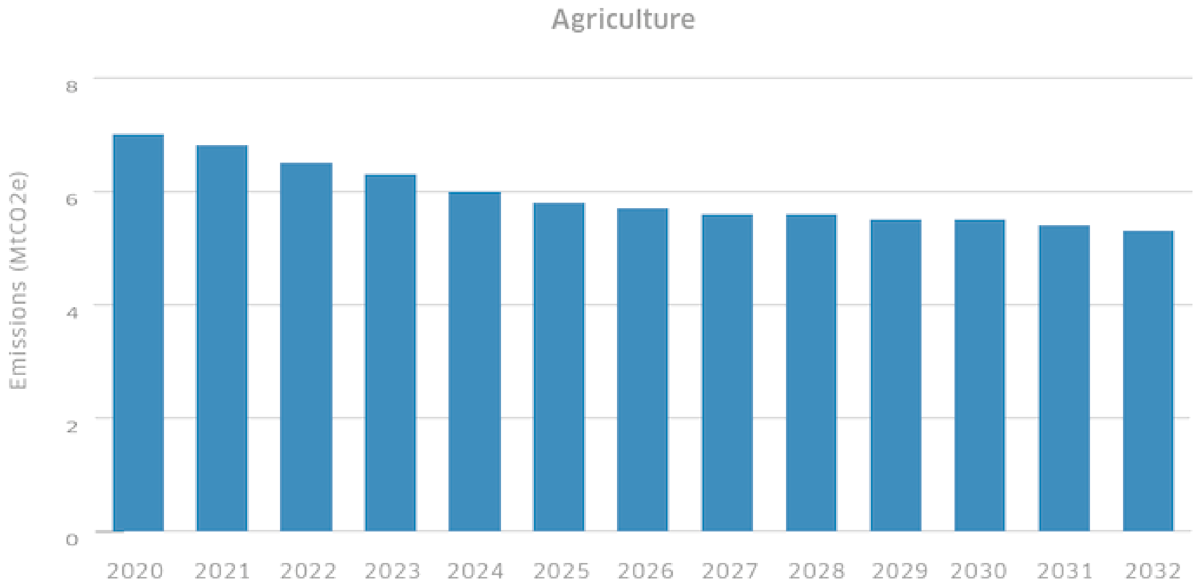

Figure 1: Emissions Reduction Pathway to 2032, from the Scottish Government Climate Plan Update (Scottish Government; 2020a)

There were a number of responses to the announcement of a net zero target of 2045 in terms of how Scottish agriculture could respond. Independent reports included:

- WWF Scotland's report 'Delivering on Net Zero Scottish Agriculture' (Lampkin et al; 2020)
- A transformation pathway interim report from the independent Farming for 1.5°C Inquiry (2020) (we used the interim report available at the commissioning of this study)
- The UK Climate Change Committee (UKCCC) published two reports: a progress report to Scottish Parliament on Scotland's general approach to climate change (2020) and a report setting out Land Use policies for a Net Zero UK (2020)

In November 2020 the Cabinet Secretary for Rural Economy and Tourism, Fergus Ewing MSP, invited farming leaders to form a series of 'farmer-led groups' with the purpose of recommending practical and evidence-based measures that farming sectors across Scotland can implement to reduce greenhouse gas (GHG) emissions and demonstrate how Scottish agriculture can help achieve the Scottish Government's statutory climate change targets. Each group produced a report. Groups include:

  - Arable Climate Change Group (ACCG)
  - Dairy Sector Climate Change Group (DSCCG)

- Hill, Upland and Crofting Group (HUCG)
- Scottish Pig Industry Leadership Group (SPILG)
- Suckler Beef Climate Group (SBCG)

The farmer-led groups are collectively referenced across this report as they represent different sectors of the same industry, while the other reports are individually referenced.

The Scottish Government's Climate Change Plan that covered the period 2018 - 2032 also needed to be updated to reflect the target changes and stipulate shorter-term targets. The resulting Climate Change Plan Update (CCPu) stipulated a mid-term target for agriculture of 5.3 Mt $CO_2e\ y^{-1}$ which is a reduction of 24% of emissions by 2032, based on a 2019 baseline of 7.7 Mt $CO_2e\ y^{-1}$. This equates to a reduction target of 2,400,000 t $CO_2e\ y^{-1}$ (2.4 Mt $CO_2e\ y^{-1}$). We use this target throughout this report unless otherwise stated.

The emissions decrease target given in the CCPu relates to emissions accounted for in the agriculture category of the national GHG inventory. These emissions are mainly methane from livestock and manures, and nitrous oxide from soils and manures. Most agriculturally relevant emissions and removals (sequestration) of carbon dioxide are accounted for in the Land Use, Land-Use Change and Forestry (LULUCF) category of the national GHG inventory. Other agriculturally relevant GHG emissions are accounted for on the energy and waste categories of the national GHG inventory. To achieve national (Scotland and UK) targets mitigation of emissions will be needed across all these categories of emissions, but in this report the focus is on the emissions categorised as agriculture, including the sub-categories of:

- enteric fermentation,
- manure management,
- agricultural soils,
- liming,
- urea application.

This report seeks to quantify the measures outlined in the reports listed above, to identify if they can achieve the 2.4 Mt $CO_2e\ y^{-1}$ reduction target. The report seeks to answer six key questions:

1. What is the mitigation potential of the measures proposed in the CCPu; across the farmer-led group reports; and in the Farming for 1.5°C report?

2. How well do the proposed measures in each of these match the recommended mitigation measures outlined in the WWF report, Reaching Net Zero: Scottish Agriculture, and the recommendations from the CCC Land Use report?

3. How well do the various proposals reflect the system level changes required to both reduce emissions and sequester carbon, for example agro-forestry, conversion to organic, conservation agriculture?

4. Would the proposed measures in the CCPu; farmer-led group reports; or the Farming for 1.5°C report deliver the CCPu target of 5.3 Mt $CO_2e\ y^{-1}$ direct agricultural GHG emissions by 2032?

5. Are there gaps remaining in the pathways presented by CCPu, farmer-led groups and Farming for 1.5 °C?

6. How should the package of policies and proposals in the CCPu be strengthened to secure uptake and delivery of the necessary mitigation measures to secure the 2032 direct agricultural emissions target of 5.3 Mt $CO_2e\ y^{-1}$?

1.2 Categorisation of emission sources

In this study, we look at emissions mitigation potential that occur on farms that fall into the agriculture category used for national inventory reporting. It is understood that the Scottish Government's CCPu mid-term target for agriculture encompasses emissions in only the Agriculture category.

It is important to note when considering mitigation measures that multiple levels of sub-categories are used for reporting emissions in national inventories of GHGs. Agriculture is a category that includes emissions from livestock, manures, soils, liming and urea application. Other emissions from farm production, such as from fuel combustion or electricity consumption, are reported in other categories. Therefore, care is needed in the assessment of mitigation potential from agriculture. Furthermore, some farm actions may mitigate GHG emissions in a way that will not be reflected in the national inventory (e.g. the effect of loosening compacted soils on nitrous oxide emission).

2 Methods

We structured the project into six tasks to assess the policy measures contained in the CCPu, the farmer-led groups' reports (to be considered as a package), and the interim pathway presented by Farming for 1.5°C, against the recommendations of the UK Climate Change Committee (CCC) and the previous report commissioned by WWF Scotland, Reaching Net Zero: Scottish Agriculture.

Details of our methods for each task are given in section 2 below. The work in tasks 1-6 is designed to answer the six questions given in section 1.1.

In terms of context, it is worth noting that leakage, or export of emissions (i.e. emissions increase in another country because of an emission decrease in Scotland or the UK) is an issue that adds to uncertainty. Since the analysis in the CCC 6th Carbon Budget report starts with the assumption that land is prioritised for food production before climate objectives, our analysis makes the same assumption, with the effect that leakage will not be a major issue because overall food production in the UK will be maintained.

2.1 An assessment of recent policy commitments for emissions reduction from agriculture in Scotland

2.1.1 Task 1: Collation and review of mitigation actions

To deliver this task, the CCPu for agriculture, the six farmer-led groups and the interim Farming for 1.5°C report were all reviewed to identify all the GHG mitigation measures recommended. These were then refined to remove those that count towards the following categories in the National Atmospheric Emissions Inventory (NAEI): Energy, Industrial Processes and Product Use, Land Use, Land-Use Change and Forestry (LULUCF), and Waste. For the purposes of this project, we concentrated on those counting towards the Agriculture category only. This requires some expert judgement as an action can have impacts in more than one sector of the inventory (as discussed in section 1.1).

2.1.2 Task 2: Mapping of measures

The measures identified and agreed under Task 1 were then mapped against the:

1) WWF Report Reaching Net Zero
2) UKCCC Land Use Report

This identified cross over and/or gaps and any areas of uncertainty due to the use of different language or approaches.

2.1.3 Task 3: Identify systems

This task identified the relevant systems that the mitigation measures collated in Task 1 apply to and provides a definition for each of them. The identified list of systems and their definitions were agreed with WWF Scotland and then mapped across the CCPu (agriculture), the six farmer-led groups, and Farming for 1.5°C interim report to identify where they are reflected.

2.1.4 Task 4: Mitigation potential assessment

In Task 4 we estimate the GHG mitigation potential for each of the measures identified in Task 1. This is informed by the paper by Lampkin et al. (2019) referred to in the ITT, the MACC work by SRUC (Eory et al., 2021), together with our own previous work (including reviewing agricultural GHG mitigation actions for the European Commission). This is backed up by a rapid evidence assessment (REA) to fill any knowledge gaps.

Using these various information sources, we estimated mitigation potential per ha or livestock head using relevant area/headage factors. We then scaled up the estimates to a national (Scotland) level, using the Scottish agricultural census data (Scottish Government; 2020a) to identify the maximum potential for individual measures. To ensure fair representation, an average of data from 2015 to 2020 was used. This is available under the 'Activity Data' in the accompanying spreadsheet.

2.1.5 Task 5: Assessing mitigation combination potential as per the reports

Using the outputs from Task 4, we then combined the measures as set out in each of the reports. The additional data required for this were:

- Uptake potential for each mitigation action by 2032
- An account of which measures cannot be, or are unlikely to be, applied together
- Estimates of how combinations of measures that can be applied together and affect the same source of emissions, influence mitigation potential

The combined effects of mitigation actions at a Scottish level are not the same as the sum of the mitigation potentials for each action. This is because not all mitigation actions are independent of each other: for example, adoption of one mitigation action can affect the uptake of another mitigation action. Therefore, we assessed all mitigation actions for interactions and those that are not independent were placed into groups. We then estimated the mitigation potential for the group, and sub-sets of the group.

This assessment is highly sensitive to mitigation action uptake. Each of the reports has a variation on levels of uptake required. Some reports are more detailed than others in outlining their expectation, usually due to the level and/or type of regulatory action. Data on current uptake of mitigation actions in the UK and in Scotland are incomplete. Some data are available from government surveys by Defra and the Scottish Government but estimates of uptake values above existing uptake required expert judgement. In doing this we have drawn upon our experience of providing estimates of mitigation action uptake for the European Commission and used literature evidence where available.

2.1.6 Task 6: Reflections

This task brought together the outputs from previous tasks to ascertain if the measures identified achieve the 5.3 Mt CO_2e y^{-1} emissions target for 2032 in the CCPu. We also identified gaps in the various pathways and highlight any missing mitigation options.

3 Mitigation actions

3.1 Selection of actions for analysis

A list of the mitigation actions considered in this study is given in Table 2. Mitigation actions that did not predominantly mitigate emissions represented in the agriculture category of the national inventory were identified and excluded from further analysis. The inclusion or exclusion of mitigation actions is shown in Table 2, together with brief reasons for exclusion. The reasons for exclusion included: that the emissions mitigated are not reported in the agriculture category of the national GHG inventory; that there is no clear evidence for mitigation of GHG emissions; and that the mitigation effect is covered by other mitigation actions.

Of the 101 mitigation actions in the full list, 69 were taken forward for further analysis.

Table 2. Full list of mitigation actions with reasons for exclusion from further analysis where relevant.

Mitigation action ID	Mitigation action	Included in analysis?	Reason for exclusion
Land use and land use change			
1	Arable to grassland	N	GHG emissions in the LULUCF category
2	Grassland management	N	GHG emissions/removals predominantly in the LULUCF category

Mitigation action ID	Mitigation action	Included in analysis?	Reason for exclusion
3	Sward diversity	N	GHG emissions/removals in the LULUCF category
4	New agroforestry	N	GHG emissions/removals in the LULUCF category
5	Afforestation	N	GHG emissions/removals in the LULUCF category
6	Forest management	N	GHG emissions/removals in the LULUCF category
7	Hedges and woody margins	N	GHG emissions/removals in the LULUCF category
8	Buffer strips/wildflower margins	N	GHG emissions/removals predominantly in the LULUCF category
9	Peatland conservation	N	GHG emissions/removals in the LULUCF category
10	Peatland restoration	N	GHG emissions/removals in the LULUCF category
11	Wetland Restoration	N	GHG emissions/removals in the LULUCF category
12	Lowland peat management	N	GHG emissions/removals predominantly in the LULUCF category
Build/retain soil organic matter			
13	Increasing soil organic matter	N	GHG emissions/removals in the LULUCF category
14	Zero tillage	N	GHG emissions/removals in the LULUCF category
15	Minimum tillage	N	GHG emissions/removals in the LULUCF category
16	Retain crop residues	Y	
17	Mulching	N	No clear evidence for GHG mitigation
18	Arable fallow	N	No clear evidence for GHG mitigation
Crop management			
19	Catch/cover crops	Y	
20	Legumes in rotation	Y	
21	Legumes in grassland	Y	
22	Intercropping	N	GHG mitigation is highly uncertain, with many possible scenarios; mitigation data are lacking

Mitigation action ID	Mitigation action	Included in analysis?	Reason for exclusion
23	Avoid soil compaction	Y	
24	Rotations with perennial forage	Y	
25	Integrated Pest Management	Y	
26	Polytunnels	N	GHG mitigation is highly uncertain because of indirect effects; lack of mitigation potential data
Crop nutrient management			
27	Optimal soil pH	Y	
28	Urease inhibitors	Y	
29	Nitrification inhibitors	Y	
30	No synthetic N	Y	
31	Slow release N	Y	
32	Avoid excess N	Y	
33	Crop breeding for N efficiency	Y	
34	Improving organic N planning	Y	
35	Change to spring manure applications	Y	
36	Change to spring cultivations	Y	
37	Improved drainage	Y	
38	Variable rate N fertiliser	Y	
39	Variable N and lime application	Y	
Slurry and manure management			
40	Cooling slurry	Y	
41	Slurry acidification	Y	
42	Cover slurry stores (general)	Y	
43	Cover slurry stores (dairy)	Y	
44	Cover slurry stores (beef)	Y	
45	Cover slurry stores (pigs)	Y	
46	Slurry aeration	Y	
47	Composting/covering FYM	Y	
48	Biogas from manures	Y	
49	Trailing shoe	Y	

Mitigation action ID	Mitigation action	Included in analysis?	Reason for exclusion
50	Trailing hose	Y	
51	Slurry injection	Y	
52	Rapid incorporation	Y	
53	Manure/slurry exchange	Y	
Livestock Management			
54	Livestock density limits	Y	
55	Pasture-fed livestock production	Y	
56	Precision livestock management	Y	
57	Age at calving	Y	
58	Livestock data capture	Y	
59	Cattle weighing	Y	
60	Stricter culling regime	Y	
61	Herd fertility	Y	
62	Bull fertility/fitness assessment	Y	
63	Increased milking frequency	Y	
64	Air scrubber and biofilters	Y	
Livestock health			
65	Reduction in endemic disease	Y	
66	Improved livestock health (Dairy)	Y	
67	Improved livestock health (Beef)	Y	
68	Improved health for sheep	Y	
69	Reduction in pig disease	Y	
70	Calf health	Y	
Livestock breeding/genetics			
71	Genetics for herd fertility	Y	
72	Whole herd breeding efficiency	Y	
73	Breeding for lower emissions (general)	Y	
74	Breeding for lower emissions (Dairy)	Y	
75	Breeding for lower emissions (beef)	Y	
76	Genomics	Y	

Mitigation action ID	Mitigation action	Included in analysis?	Reason for exclusion
77	Sexed semen	Y	
Livestock nutrition			
78	Feed additives (cattle)	Y	
79	Feed additives (dairy)	Y	
80	Feed additives (beef)	Y	
81	Optimised feed strategies	Y	
82	Sustainable feed sourcing	Y	
83	High starch diet (Dairy)	Y	
84	Precision feeding (Dairy)	Y	
85	Precision feeding (pigs)	Y	
86	Optimised forage utilisation	Y	
Energy Production			
87	Biogas from agriculture and forests	N	GHG mitigation predominantly in the energy category
88	Solar and wind energy	N	GHG mitigation in the energy category
89	Energy from biomass	N	GHG mitigation predominantly in the energy category
90	Biofuels	N	GHG mitigation predominantly in the energy category
91	Materials from biomass	N	GHG mitigation predominantly outside the agriculture category
Energy use			
92	Energy efficiency	N	GHG mitigation predominantly in the energy category
93	Capital support for machinery sharing	N	GHG mitigation predominantly outside the agriculture category
94	Trickle/drip irrigation	N	GHG mitigation predominantly outside the agriculture category
95	GHG audits, eco design, smart targets	N	Mitigation of GHGs is accounted for under other mitigation actions
96	Updating housing design	Y	
Other			
97	Biochar	N	Multiple effects on emissions, but conflicting evidence

Mitigation action ID	Mitigation action	Included in analysis?	Reason for exclusion
98	Better use of vet inputs and agrochemicals	N	Mitigation effect is covered under other mitigation actions (livestock health and crop management)
99	Responsible use of antibiotics	N	Mitigation effect is covered under other mitigation actions (livestock health and crop management)
100	Responsible use of anthelmintics	N	Mitigation effect is covered under other mitigation actions (livestock health and crop management)
101	SMART target for ruminant GHG intensity	N	Mitigation of GHGs is accounted for under other mitigation actions

3.2 Agricultural emissions reporting

For the purposes of reporting to the United Nations Framework Convention on Climate Change (UNFCCC), GHGs are divided between a small number of broad, high level sectors known as National Communication (NC) sectors, including: Energy supply, Business, Transport, Public, Residential, Agriculture, Industrial processes, Land use land use change and forestry (LULUCF), and Waste management.

These high-level sectors are defined by the International Panel on Climate Change (IPCC). Scottish emissions are included within the UK emissions submitted to the UNFCCC every year.

The Scottish Government have set a target in the CCPu (Scottish Government, 2020b) to reduce the Scottish agricultural sector's emissions to 5.3 Mt CO_2e y^{-1} by 2032. It is worth making clear that this target is for the agriculture sector's emissions as defined by the UNFCCC. It therefore does not include activities that would be included under LULUCF such as peatland restoration or tree planting, nor business emissions such as energy efficiency improvements in agricultural buildings, nor emissions from anaerobic digestion (AD) plants that are captured under Waste.

3.3 Relationships between actions and production systems

There are many approaches to tackling the climate emergency across society and in agriculture. There is the individual action approach or a 'systems approach'. One of the research questions for this project asked:

- 'How well do the various proposals reflect the **system level changes** required to both reduce emissions and sequester carbon, for example agroforestry, conversion to organic, conservation agriculture?'

To be able to sufficiently answer this question it is important to understand what is meant by 'system level changes' and to explore what these system level changes are. Here we differentiate these from 'systems' as 'systems' in an agricultural context is also used to refer to a type of farming i.e., sheep or beef system. We have understood system level changes to be confined to the farm and to be long-term changes that are not quickly reversible. Their success may depend on changes in supply chains, branding or societal dietary change but for the purposes of this report we are not looking beyond the farm gate.

A mitigation action can be applied alone, such as using feed additives to reduce methane emissions. On an enterprise there may be a number of mitigation actions at work, that may or may not interact with each other. Keeping with the feeding example, a female beef animal may be bred using genetics to reduce methane emissions, have high fertility, and be fed cereals that have been grown using precision technology to optimise inputs and yield. These are all individual actions that are used together to reduce overall emissions.

A different approach is to choose a system level change such as regenerative farming, organics or pasture for life, where the various mitigation actions are all dependent on and interact with each other to reduce overall emissions. Some system level changes include all elements of an enterprise, while others may interact in only some elements. This is further explained below.

Different options suit different business types, locations and the farmers managing the enterprise(s). These system level changes can be referred to using different terminology. For example, agroecology, and organic farming are often used interchangeably, but only organic farming has a legal definition. Regenerative and conservation agricultural systems also have a variety of interpretations. The Food and Agriculture Organization of the United Nations (2018) has created a list of 10 principles behind agroecology, while WWF Scotland has referred us to the Groundswell interpretation of regenerative farming, which is focused on soil health. Many of these systems overlap each other, while depending on the interpretation of the practitioner, may or may not interact. For further definitions please see Appendix A1.

For the purposes of this report, we have understood regenerative agriculture to allow the use of plant protection products such as herbicides, while agroecology does not. Please see Table 3 for further clarification between these two systems as understood in this report. Conservation agriculture, pasture for life and non-ploughing tillage may or may not allow their use depending on their interpretation, which is why many of the squares are yellow in Table 4.

Table 3. Comparison of the terms Agroecology and Regenerative farming.

Agroecology	**Regenerative Agriculture**
Local social focus	International focus
Flexible soil health measures without the use of herbicides	Minimal soil disturbance focus allowing the use of herbicides
Can be organic	Cannot be organic (because of herbicide use)
Ecology focus	Soil health carbon focus
Food systems focus	Climate focus

We have included on-farm AD within the list of system level changes as the installation of an AD plant using on-farm produced feedstock will require the interaction of a number of processes on the farm. This may include manure management, straw production, and use of the energy produced. The level of interaction across the farm can influence the farm's GHG emissions.

Similarly, outwintering of stock impacts decisions made about winter soil management, production or purchasing of straw, manure management and farm infrastructure. These decisions will interact with and impact other farm activities. Table 4 shows the potential for complementarity between the system level changes specified.

Table 4. System level changes and their potential for complementarity.

	Agroecology	Agroforestry	Conservation Agriculture	Non-ploughing tillage	On-farm anaerobic digestion	Organic agriculture	Outwintering	Pasture For Life (PFLA)	Regenerative agriculture
Agroecology		C	P	P	NL	C	C	P	P
Agroforestry	C		C	C	NL	C	C	C	C
Conservation Agriculture	P	C		C	NL	P	C	C	C
Non-ploughing tillage	P	C	C		NL	P	P	C	C
On-farm anaerobic digestion	NL	NL	NL	NL		NL	NL	NL	NL
Organic agriculture	C	C	P	P	NL		P	P	NC
Outwintering	C	C	C	P	NL	P		C	C
Pasture For Life (PFLA)	P	C	P	P	NL	P	C		P
Regenerative agriculture	P	C	C	C	NL	NC	C	P	

C	P	NC	NL
Complement each other well	Potential for complementarity if certain issues resolved	No complementarity	No link

4 Mitigation potential

4.1 Values by mitigation action

Mitigation potential values are tabulated in this report (Table 5, Table 6, Table 7), and more detailed data are provided in a separate Excel workbook provided to WWF Scotland. The data in the Excel workbook provide ranges based on the ranges of mitigation potential values found in published literature; in this report we present only the mid-range values.

The endpoint of the data analysis was the estimate of GHG emissions mitigation that takes account of farmer uptake and interactions between measures (Table 6).To reach this endpoint, for most mitigation actions we used values for mitigation potential (t CO_2e y^{-1}) per ha or per head of livestock and multiplied these by the relevant activity data (e.g., population of the relevant livestock type) to give a theoretical maximum mitigation potential value. An uptake factor (proportion of additional uptake between 2020 and 2032, Table 5) was then applied, giving a mitigation potential for each individual mitigation action (Table 5).

To determine the overall mitigation across Scotland, it was necessary to consider interactions between mitigation actions. This was done by sorting interacting mitigation actions into groups and estimating a maximum mitigation potential for the group. For example, mitigation actions 78, 79 and 80 (Table 2) are closely related in that mitigation actions 79 (dairy feed additives) and 80 (beef feed additives) are subdivisions of mitigation action 78 (cattle feed additives), so to include all three in a total would double count the mitigation potential. In this case, and for most other groups, to calculate the total emissions for all mitigation actions, we counted only the greatest value in the group. In table 5, related mitigation actions that are not independent of other mitigation actions are presented in groups, allowing a meaningful total to be calculated for all the mitigation actions considered, and for subsets of mitigation actions as represented in the three reports of interest: the farmer-led group reports (covered as a collection), the Farming for 1.5°C interim report, and the CCPu.

The mitigation potential data (Table 5, Table 6) show that important mitigation actions include use of cover crops, use of nitrification inhibitors, improvements in livestock health, and avoidance of excessive nitrogen applications to crops and grass.

- Catch/cover crops may increase or decrease nitrous oxide emissions, depending on the effect of the practice on the application rate of nitrogen fertiliser across the rotation (Jarecki et al., 2009). In a recent review of the impacts of cover crops on net GHG balance, Abdalla et al. (2019) reviewed studies at 372 sites and concluded that cover crops could mitigate the net GHG balance by 2.06 (± 2.10) t CO_2e ha^{-1} $year^{-1}$; typically, there is a mitigation effect, and this is reflected in the mid-range value presented in Table 5.
- Nitrification inhibitors can be applied with nitrogen fertiliser to slow nitrification and (indirectly) denitrification reactions in the soil, thereby decreasing the emission of nitrous oxide to air.
- Livestock health measures have a large potential to mitigate GHG emissions in Scotland. Livestock diseases that cause long-term health impairment may increase GHG emissions through reduced performance and decreased output, leading to greater GHG emissions per tonne of produce, but also a larger herd size to provide a given level of output. Skuce et al. (2016) reported three examples of diseases that are cost-effective and feasible to control. These were: neosporosis (beef cattle), infectious bovine rhinotracheitis (IBR; dairy cattle) and parasitic gastroenteritis (PGE; sheep).
- For avoidance of excessive nitrogen applications to crops and grass, emissions of nitrous oxide following application of nitrogen to land will be reduced in direct proportion to the reduction in nitrogen applied (IPCC, 2006).

For a variety of reasons, many mitigation actions in Table 5 (22 of the 69 mitigation actions in the table) have mitigation potential values of zero. In most cases the reason is either that there is no clear evidence (yet) for a mitigation effect, or that any mitigation effect is already accounted for in another measure that would also be adopted.

Table 5. Mitigation actions included in the assessment with additional uptake values used in calculations. Notes provide sources of uptake values and comment where uptake values were not used. Where the source is not indicated, uptake values were from a Ricardo analysis for the European Commission (unpublished at the time of this report).

Mitigation action ID	Mitigation action	Additional uptake (%)	Notes (uptake)	Mitigation potential (t CO_2e y^{-1}) assuming no interactions between mitigation actions
Build/retain soil organic matter				
16	Retain crop residues	0	Expert judgement: no increase likely since all removed residues are used and we assume they will still be required (e.g., animal bedding).	0
Crop management				
19	Catch/cover crops	12		291,870
20	Legumes in rotation	4		4,298
21	Legumes in grassland		Assumed zero mitigation because evidence for mitigation is lacking (Wiltshire et al., 2020), therefore uptake value not required.	0
23	Avoid soil compaction		Assumed zero mitigation because evidence for mitigation is lacking, therefore uptake value not required.	0
24	Rotations with perennial forage	4		2,479
25	Integrated Pest Management		No evidence found, assumed zero mitigation potential on the assumption that pest control will be similar to that for conventional control methods, therefore uptake value not required.	0

Mitigation action ID	Mitigation action	Additional uptake (%)	Notes (uptake)	Mitigation potential (t CO_2e y^{-1}) assuming no interactions between mitigation actions
Crop nutrient management				
27	Optimal soil pH		Assumed zero mitigation because evidence for mitigation is lacking, therefore uptake value not required.[2]	0
28	Urease inhibitors	100	Uptake value assumed to be 100% based on the assumption that this will be mandatory by 2032.	58,109
29	Nitrification inhibitors	20		99,707
30	No synthetic N		Assumed zero mitigation because evidence for mitigation is lacking, therefore uptake value not required. There is high uncertainty because of displacement effect, with potential for increased emissions per unit of production.	0
31	Slow release N	4		3,765
32	Avoid excess N	72	DG Clima study gives 90% over 6 years, i.e. all except poor performers; value is EU-wide. For Scotland, expert judgement suggests 20% current uptake. Value here is 90% of the remaining 80%.	135,156
33	Crop breeding for N efficiency	20	DG Clima study gives 20% over 6 years; expert judgement suggests this is high because breeding is slow; we use 20% over 12 years.	23,569
34	Improving organic N planning	72	Uptake as for MA32	44,448
35	Change to spring manure applications		Uptake is already factored into the estimate of mitigation potential, so uptake value not needed.	1,000
36	Change to spring cultivations	20	From WWF report (20% of rotational grass area)	14,000

[2] The use of lime leads to emission of carbon dioxide as calcium carbonate ($CaCO_3$) which dissolves following applications to land (Barton et al., 2014). Although evidence is very limited, we have concluded that emissions from dissolution of lime and abated emissions of nitrous oxide may have a similar order of magnitude with respect to global warming potential, and that the mitigation potential is therefore zero, albeit with high uncertainty.

Mitigation action ID	Mitigation action	Additional uptake (%)	Notes (uptake)	Mitigation potential (t CO_2e y^{-1}) assuming no interactions between mitigation actions
37	Improved drainage		Assumed zero mitigation because evidence for mitigation is lacking, therefore uptake value not required.	0
38	Variable rate N fertiliser	12		1,680
39	Variable N and lime application	12		1,680
Slurry and manure management				
40	Cooling slurry		Evidence for mitigation is lacking so uptake value not required. Savings in fertiliser through decreased N loss are highly uncertain and depend on an integrated approach to avoid losses of conserved N at later stages.	0
41	Slurry acidification		Uptake is already factored into the estimate of mitigation potential, so uptake value not needed.	67,000
42	Cover slurry stores (general)		Uptake is already factored into the estimate of mitigation potential, so uptake value not needed.	9,000
43	Cover slurry stores (dairy)		Uptake is already factored into the estimate of mitigation potential, so uptake value not needed.	4,238
44	Cover slurry stores (beef)		Uptake is already factored into the estimate of mitigation potential, so uptake value not needed.	3,643
45	Cover slurry stores (pigs)		Uptake is already factored into the estimate of mitigation potential, so uptake value not needed.	1,035
46	Slurry aeration		Uptake is already factored into the estimate of mitigation potential, so uptake value not needed.	42,000
47	Composting/covering FYM		Uptake is already factored into the estimate of mitigation potential, so uptake value not needed.	20,000

Mitigation action ID	Mitigation action	Additional uptake (%)	Notes (uptake)	Mitigation potential (t CO_2e y^{-1}) assuming no interactions between mitigation actions
48	Biogas from manures		Uptake is already factored into the estimate of mitigation potential, so uptake value not needed.	32,000
49	Trailing shoe	20		355
50	Trailing hose	80		1,745
51	Slurry injection	20		559
52	Rapid incorporation	20		28,448
53	Manure/slurry exchange		Mitigation potential value from Freeman et al. (2020), assuming 50% of manure exported from participating farms with housed dairy and beef cattle. Uptake value is factored into the estimate of mitigation potential, so uptake value not needed.	36,850
Livestock Management				
54	Livestock density limits		Assumed zero mitigation because evidence for mitigation is lacking, therefore uptake value not required.	0
55	Pasture-fed livestock production		Assumed zero mitigation because evidence for mitigation is lacking, therefore uptake value not required.	0
56	Precision livestock management		No mitigation beyond that included in other measures (e.g. MA65), therefore uptake value not required.	0
57	Age at calving	20	Expert judgement, 20% of farms, based on suitability (mainly more intensive suckler beef herds) and slow pace of change.	36,626
58	Livestock data capture		No mitigation beyond that included in other measures (e.g. MA56), therefore uptake value not required.	0
59	Cattle weighing		No mitigation beyond that included in other measures (e.g. MA56), therefore uptake value not required.	0

Mitigation action ID	Mitigation action	Additional uptake (%)	Notes (uptake)	Mitigation potential (t CO_2e y^{-1}) assuming no interactions between mitigation actions
60	Stricter culling regime		No mitigation beyond that included in other measures (e.g. MA65), therefore uptake value not required.	0
61	Herd fertility	40		25,939
62	Bull fertility/fitness assessment		No mitigation beyond that included in MA61, therefore uptake value not required.	0
63	Increased milking frequency		Assumed zero mitigation because evidence for mitigation is lacking, therefore uptake value not required.	0
64	Air scrubber and biofilters		No clear evidence of a mitigation effect. Filters capture N, avoiding indirect N2O emissions, but the N is likely applied to land so these emissions still occur. There may be some saving through decreased manufactured N fertiliser use, but no evidence has been found. Uptake value not required.	0
Livestock health				
65	Reduction in endemic disease[3]	40		112,160
66	Improved livestock health (dairy)	40		12,262
67	Improved livestock health (beef)	40		42,465
68	Improved health for sheep	40		49,935
69	Reduction in pig disease		Assumed zero mitigation because evidence for mitigation is lacking, therefore uptake value not required.	0

[3] This mitigation action has a mitigation potential that is the sum of the following actions, 66-70, which are estimated separately. See Table 6 for mitigation potential values that take account of interactions between actions.

Mitigation action ID	Mitigation action	Additional uptake (%)	Notes (uptake)	Mitigation potential (t CO_2e y^{-1}) assuming no interactions between mitigation actions
70	Calf health	40		7,498
Livestock breeding/genetics				
71	Genetics for herd fertility	40	Additional uptake from DG CLIMA study. This measure is similar to MA61 but with different a driver (breeding rather than management). We have assumed the same mitigation potential as MA61, and this is additional.	25,939
72	Whole herd breeding efficiency		No mitigation beyond that included in MA61, so uptake value not required.	0
73	Breeding for lower emissions (general)	2		211
74	Breeding for lower emissions (dairy)		Mitigation potential value from MA65 modified by population, so uptake value not required.	190
75	Breeding for lower emissions (beef)		Assumed zero mitigation because evidence for mitigation is lacking, therefore uptake value not required.	0
76	Genomics	2	This measure is similar to MA73 but with different breeding technology. We have assumed the same mitigation potential as MA73 (additional). Additional uptake from MA73.	211
77	Sexed semen	50	Uptake from Martineau et al., 2016.	8,622
Livestock nutrition				
78	Feed additives (cattle)	40		77,113
79	Feed additives (dairy)	4	Expert judgement based on WWF report, approx. 2/3 of 7% not currently adopting this measure.	2,109
80	Feed additives (beef)	40	From WWF report.	75,004

Mitigation action ID	Mitigation action	Additional uptake (%)	Notes (uptake)	Mitigation potential (t CO_2e y^{-1}) assuming no interactions between mitigation actions
81	Optimised feed strategies	20		68,861
82	Sustainable feed sourcing	10	Expert judgement.	21,955
83	High starch diet (dairy)	9.2	From Eory et al., 2020 (10% minus current uptake of 0.8%).	4,026
84	Precision feeding (dairy)		Mitigation potential value from MA81, modified by proportion of dairy cattle, so uptake value not required.	15,554
85	Precision feeding (pigs)		Mitigation potential value from WWF report. Uptake is already factored into this estimate, so not required here.	1,000
86	Optimised forage utilisation		Assumed zero mitigation because evidence for mitigation is lacking, therefore uptake value not required.	0
Energy use				
96	Updating housing design		Assumed zero mitigation because evidence for mitigation under agriculture GHG envelope is lacking, therefore uptake value not required.	0
			Total mitigation potential	**1,516,310**

Table 6. Mitigation potential for actions or groups of actions, for all mitigation actions included in the analysis, and showing representation of mitigation actions in the farmer-led group reports, the Farming for 1.5°C report, and the Update to the Climate Change Plan 2018 – 2032 (CCPu). The groups of actions allow consideration of interactions between individual mitigation actions. Values for CCPu in brackets indicate a wider interpretation of the effects of included policies (see text for more explanation). Blank cells indicate that the mitigation actions are not represented in the report at the head of the column.

Mitigation action ID	Mitigation action or group of actions	All mitigation actions: mitigation potential (t CO_2e y^{-1})	Farmer-led group reports: mitigation potential (t CO_2e y^{-1})	Farming for 1.5°C report: mitigation potential (t CO_2e y^{-1})	CCPu: mitigation potential (t CO_2e y^{-1})
Build/retain soil organic matter					
16	Retain crop residues	0	0	0	
Crop management					
19	Catch/cover crops	291,870	291,870	291,870	
20	Legumes in rotation	4,298	4,298	4,298	4,298
21	Legumes in grassland	0	0		
23	Avoid soil compaction	0	0	0	
24	Rotations with perennial forage	2,479	2,479		
25	Integrated Pest Management	0	0		
Crop nutrient management					
27	Optimal soil pH	0	0		0
28, 31	Urease inhibitors, slow-release N	58,109	58,109	3,765	(58,109)
29	Nitrification inhibitors	99,707	99,707	99,707	(99,707)
30	No synthetic N	0		0	
32, 34	Avoid excess N, planning N	135,156	135,156	135,156	135,156
33	Crop breeding for N efficiency	23,569	23,569	23,569	23,569
35	Change to spring manure applications	1,000	1,000		

Mitigation action ID	Mitigation action or group of actions	All mitigation actions: mitigation potential (t CO_2e y^{-1})	Farmer-led group reports: mitigation potential (t CO_2e y^{-1})	Farming for 1.5°C report: mitigation potential (t CO_2e y^{-1})	CCPu: mitigation potential (t CO_2e y^{-1})
36	Change to spring cultivations	14,000		14,000	
37	Improved drainage	0			
38, 39	Variable rate N, lime	1,680	1,680	1,680	1,680
Slurry and manure management					
40	Cooling slurry	0	0		(0)
41, 46-48	Slurry treatments	67,000	67,000	32,000	32,000 (67,000)
42-45	Cover slurry stores	9,000	8,915	9,000	9,000
49-51	Reduced emission slurry spreading	1,745	1,745	559	1,745
52	Rapid incorporation	28,448			28,448
53	Manure/slurry exchange	36,850		36,850	36,850
Livestock Management					
54	Livestock density Limits	0		0	0
55	Pasture-fed livestock production	0	0		0
56	Precision livestock management	0	0		0
57	Age at calving	36,626	36,626		36,626
58	Livestock data capture	0	0		0
59	Cattle weighing	0	0		0
60	Stricter culling regime	0	0		0
61, 71, 76	Livestock breeding and fertility	25,939	25,939	25,939	25,939

Mitigation action ID	Mitigation action or group of actions	All mitigation actions: mitigation potential (t CO_2e y^{-1})	Farmer-led group reports: mitigation potential (t CO_2e y^{-1})	Farming for 1.5°C report: mitigation potential (t CO_2e y^{-1})	CCPu: mitigation potential (t CO_2e y^{-1})
62	Bull fertility/fitness assessment	0	0		0
63	Increased milking frequency	0	0		0
64	Air scrubber and biofilters	0	0		
Livestock health					
65-68, 70	Improved livestock health	112,160	112,160	112,160	112,160
69	Reduction in pig disease	0	0		
Livestock breeding/genetics					
72	Whole herd breeding efficiency	0	0	0	0
73, 74	Breeding for lower emissions	211	211	211	211
75	Breeding for lower emissions (beef)	0	0	0	0
77	Sexed semen	8,622	8,622		
Livestock nutrition					
78-80	Feed additives	77,113	77,113	77,113	77,113
81, 83-85	Improving livestock feed	68,861	68,861	68,861	
82	Sustainable feed sourcing		21,995		
86	Optimised forage utilisation	0	0		
Energy use					
96	Updating housing design	0	0		
Totals		**1,126,396**	**986,427**	**1,047,013**	**937,922 (717,609)**

4.2 Uptake values

The full potential of each activity described in section 4 is dependent on a number of factors such as access to technology, climatic influences, access to capital, level of regulatory pressure and farmer attitudes. In the literature, levels of uptake are estimated by the scientific community, as actual uptake is difficult to assess. For example, a study on the use of Integrated Pest Management in Scotland (Stetkiewicz, et al; 2018) shows that the 'gaps between the actual and perceived recent practice were large' where 80% of farmers said they used crop rotations but 66% of the same farmers also reported sowing consecutive barley often/always.

There is often an assumption that where activities result in saving money, uptake rates will be high. However, a Defra (2018) study in England in 2016/17 found "only 1 in 3 farms regularly produce budgets, gross margins and cash flows or carry out in depth analysis of their profits and losses." Within the top 25% of farms, 56% did not produce these documents and grazing livestock farms were the least likely to look at their profit and loss accounts. Across the UK, nutrient management mitigation methods uptake in 2020 was only around 40% of the maximum potential reduction despite optimising productivity, reducing the incidence of diffuse water pollution and minimising GHG emissions (Defra; 2020b).

Research suggests that most practices to reduce GHG emissions could save farmers money. There are several key barriers to uptake which are non-financial, or not directly financial. These include a lack of willingness to undertake (e.g., limited trust in what is being asked and the outcomes that will result) and a lack of ability to undertake (e.g., a lack of understanding, skills, time or capital). Whilst most farm businesses should be able to implement key actions, not all measures are suitable for all farm businesses (Defra; 2020b). In Defra's Agricultural Statistics and Climate Change survey for 2020, 18% of farmers reported that it was "very important to consider GHGs when making decisions relating to their land, crops and livestock, with 66% taking actions to reduce emissions". 42% of respondents believed that no action was necessary.

The most common actions to reduce GHG emissions (cited by more than half of those undertaking actions in 2017) were recycling, improving nitrogen fertiliser application and improving energy efficiency; actions that are relevant to most farm enterprises. Those actions more suited to livestock enterprises had a lower level of uptake. Both recycling and energy efficiency are important contributors to climate change mitigation, but neither would be reflected within the agriculture GHG emissions record.

Undoubtedly regulation would create higher levels of uptake than purely voluntary approaches and there is some reference to Greening as an opportunity to improve climate mitigation. However, the European Court of Auditors (2017) found that Greening is unlikely to 'significantly enhance environmental performance' across the EU in its current format as they are either part of the beneficiary's normal activity or required by law through cross compliance. Any regulatory activity, such as including activities within Greening would need to be monitored and enforced to ensure higher uptake and results.

Taking these points into consideration, as well as the lack of detail in any of the reports as to the level of uptake expected, it is very difficult to suggest different figures for each report. Uptake will be a result of political decisions, retailer and trade pressures and their timeliness as to how much of an impact is made by 2032.

As such, we have assumed a consistent uptake value across the reports. There is potential to raise or lower the uptake values within the accompanying spreadsheet to identify where further savings can be made. This flexibility can be particularly helpful to adjust as new technologies are developed (such as uptake of a climate breeding index or feed additives) and are licensed for use in the UK.

5 Mitigation potential summary

The data presented in Table 7 provide a summary of the overall mitigation potential, at a Scotland level. Overall mitigation potential values are presented for each of the three reports:

- Farmer-led group reports (this is a group of five reports),
- Farming for 1.5°C interim report,
- Update to the Climate Change Plan 2018 – 2032 (CCPu).

Values are presented for the emissions in 2032 against a baseline of 7.7 Mt CO_2e y^{-1}.

For all the reports, and particularly for the CCPu a number of policies or measures that can indirectly lead to emissions savings are recommended, rather than detailing specific action. This makes it difficult to assign a mitigation potential figure.

Table 7. Summary of mitigation potential across all mitigation actions included in the analysis, and by inclusion in named reports.

Selection of actions	Mitigation potential (t CO_2e y^{-1})	Agriculture emissions at 2032 assuming a baseline of 7.7 Mt CO_2e y^{-1}
All mitigation actions analysed	1,126,396	6,573,604
Mitigation actions in Farmer-led group reports	1,047,013	6,652,987
Mitigation actions in the interim Farming for 1.5°C report	937,922	6,762,078
Mitigation actions that can follow from the CCPu	524,793 to 717,609	7,175,207 to 6,982,391

Each of the three reports include mitigation actions that give an overall mitigation potential that is lower than the overall mitigation potential for all mitigation actions analysed. This indicates some gaps in the mitigation actions represented in the reports, and the gaps can be seen in Table 6 by reference to blank cells in the columns for the reports.

Overall, the mitigation potential for all three reports is not sufficient to reach the 2032 target of 5.3 Mt CO_2e y^{-1}.

6 Discussion - reaching net zero

6.1 Reaching net zero

The analysis reported here focusses on mitigation of emissions reported in the agriculture category in the national GHG inventory. These emissions are dominated by methane from livestock and their manures, and nitrous oxide from soil, as a consequence of nitrogen fertiliser application. Mitigation of these emissions is possible to some extent, as is shown by the mitigation potential estimates in this report. As emissions are mitigated with changes in farming practices, the remaining emissions will become increasingly difficult to avoid without resorting to decreasing current levels of farm production. Considering only 'agriculture' emissions, as defined in inventory categories of emissions, there is at present no clear pathway to net zero GHG emissions. Consideration of mitigation and sequestration opportunities within a wider definition of agriculture, can open up a more promising pathway to net zero GHG emissions. The emissions sources within the LULUCF category of the national GHG inventory include stock change for large reserves of organic carbon stored in soil and biomass. Much of this carbon stock change is directly influenced by agricultural practices, such as grassland management practices, and land use change. It is our view that mitigation and sequestration actions, that influence carbon emissions and removals in the LULUCF category, will be needed to take agriculture closer to net zero GHG emissions.

The analysis reported here focusses on the CCPu GHG emissions target of 5.3 Mt CO_2e y^{-1} reduction in agricultural emissions by 2032, not the 2045 net zero target of the Climate Change (Emissions Reductions) Scotland Act 2019. Overall, our analysis estimates that the CCPu target of 5.3 Mt CO_2e y^{-1} GHG emissions by 2032 is not achievable with the set of mitigation actions included in this study, and at the levels of additional uptake given in Table 5. To reach the 2032 target it will be necessary to find additional mitigation actions, and/or increase the additional uptake of mitigation actions beyond our estimates in Table 5.

In efforts to reach the CCPu target of 5.3 Mt CO_2e y^{-1} GHG emissions by 2032, it is important to recognise the large uncertainty in the estimates of mitigation potential presented in this report and elsewhere. In the spreadsheet supplement ranges are given for mitigation potential values based on literature estimates. This uncertainty arises from differences in how and under what circumstances mitigation actions are applied. Further uncertainty, that is not quantified in this project, arises from the estimates of additional mitigation action uptake, which are largely based on expert judgement, either by this study, or in studies that are referenced. Changing these uptake values changes the estimates of overall mitigation potential across Scotland. It is, therefore, important to emphasise that our estimates of overall mitigation potential are dependent on both the quality of mitigation action implementation and the extent to which additional uptake values are achieved. These will, in turn, be dependent industry engagement and policy implementation.

A further challenge in the pursuit of the CCPu target is the availability of data. Activity data (e.g., from farm surveys) will be needed to monitor progress, at sufficient detail to allow uptake of mitigation actions to be estimated.

A note of caution in the pursuit of the CCPu 2032 GHG emissions target of 5.3 Mt CO_2e y^{-1} is that the target cannot be achieved by efforts to improve emissions intensity only. Emissions intensity is the quantity of emissions per unit of output and is often assessed using farm carbon audits. Production efficiency usually improves alongside emissions intensity improvements, and this can have benefits at a national scale; however, there can also be unintended consequences such as, when output per head of livestock is increased, some inputs may also increase, but livestock population may not decrease to keep production constant. Emissions per unit of production may decrease but emissions for the farm as a whole may decrease by less.

Like the 2032 GHG emissions target, the 2045 target is also a great challenge. If food production is to be maintained at current levels, neither of these targets will be achievable unless the scope of the mitigation includes agricultural activities that fall within the LULUCF category of the national GHG inventory. Further analysis is needed to estimate how further mitigation and sequestration actions that influence this emissions category can move Scotland towards this target.

6.2 Answers to questions posed by WWF

WWF Scotland asked six research questions, which we use as sub-headings here with our answers following each question.

6.2.1 What is the mitigation potential of the measures proposed in the CCPu; proposals across the farmer-led group reports; and in the Farming for 1.5°C report?

The mitigation potential of the measures proposed in the CCPu, proposals across the farmer-led group reports, and in the interim Farming for 1.5°C report, are shown in Table 7.

Overall, for the set of farmer-led reports, the mitigation potential estimated is 1,047,013 t CO_2e y^{-1}.

For the Farming for 1.5°C interim report, the mitigation potential estimated is 937,922 t CO_2e y^{-1}.

For the CCPu, the mitigation potential is estimated between 524,793 - 717,609 t CO_2e y^{-1} based on differing interpretations of how the policies in the CCPu will lead to uptake of mitigation actions.

It is worth adding that there may be measures not specifically mentioned in the CCPu report, but that does not mean they were explicitly excluded. Therefore, these figures do not necessarily represent the maximum emissions savings potential. Further measures can form part of the solution to fill the gap in mitigation potential (see 6.2.5.1).

6.2.2 How well do the proposed measures in each of these [reports in question 1] match the recommended mitigation measures outlined in the WWF report, Reaching Net Zero: Scottish Agriculture, and the recommendations from the CCC Land Use report?

The proposed measures in each of the three reports (the farmer-led group reports, the Farming for 1.5°C report, and the CCPu) are shown in Table 8 by green shaded cells, alongside the recommended mitigation measures outlined in the WWF report, Reaching Net Zero: Scottish Agriculture, and the recommendations from the CCC Land Use report (orange-shaded cells). The pale green cells in the CCPu column indicate a wider interpretation of the effects of policies included in that report.

Table 8. Recommended mitigation measures outlined in the WWF report, “Reaching Net Zero: Scottish Agriculture”, and the recommendations from the CCC Land Use report (R, orange cells); inclusion of mitigation actions in each of five reports is indicated by green cells (I); pale green cells in the CCPu column indicate a wider interpretation of the effects of included policies (P).

Mitigation action ID	Mitigation action name	WWF report	CCC report	Farmer-led group reports	CCPu	Farming for 1.5
Build/retain soil organic matter						
16	Retain crop residues			I		I
Crop management						
19	Catch/cover crops	R	R	I		I
20	Legumes in rotation	R	R	I	I	I
21	Legumes in grassland	R		I		
23	Avoid soil compaction	R	R	I		I
24	Rotations with perennial forage			I		
25	Integrated Pest Management			I		
Crop nutrient management						
27	Optimal soil pH			I	I	
28	Urease inhibitors	R		I	P	
29	Nitrification inhibitors	R		I	P	I
30	No synthetic N	R				I
31	Slow-release N	R	R	I	P	I
32	Avoid excess N	R		I	I	I
33	Crop breeding for N efficiency	R		I	I	I
34	Improving organic N planning	R	R	I		
35	Change to spring manure applications	R		I		
36	Change to spring cultivations	R				I
37	Improved drainage	R				
38	variable rate N fertiliser	R	R	I	I	I
39	Variable N and lime application		R	I	I	I
Slurry and manure management						
40	Cooling slurry			I	P	

Mitigation action ID	Mitigation action name	WWF report	CCC report	Farmer-led group reports	CCPu	Farming for 1.5
41	Slurry acidification	R	R	I	P	
42	Cover slurry stores (general)	R	R		I	I
43	Cover slurry stores (dairy)		R	I	P	
44	Cover slurry stores (beef)		R	I	P	
45	Cover slurry stores (pigs)		R	I	P	
46	Slurry aeration	R			P	
47	Composting/covering FYM	R			I	I
48	Biogas from manures	R	R	I	I	I
49	Trailing shoe	R	R	I	I	I
50	Trailing hose	R	R	I	I	I
51	Slurry injection	R	R	I	I	I
52	Rapid incorporation	R	R		I	
53	Manure/slurry exchange				I	I
Livestock Management						
54	Livestock density Limits				I	I
55	Pasture-fed livestock production	R		I	I	
56	Precision livestock management			I	I	
57	Age at calving			I	I	
58	Livestock data capture			I	I	
59	Cattle weighing			I	I	
60	Stricter culling regime			I	I	
61	Herd fertility			I	I	I
62	Bull fertility/fitness assessment			I	I	
63	Increased milking frequency			I	I	
64	Air scrubber and biofilters			I		
Livestock health						
65	Reduction in endemic disease		R	I	I	I
66	Improved livestock health (dairy)	R	R	I	P	I
67	Improved livestock health (beef)	R	R	I	P	I
68	Improved health for sheep	R	R	I	P	I
69	Reduction in pig disease		R	I		
70	Calf health		R	I	P	
Livestock breeding/genetics						
71	Genetics for herd fertility			I	I	I
72	Whole herd breeding efficiency		R	I	I	I
73	Breeding for lower emissions (general)	R	R	I	I	I
74	Breeding for lower emissions (dairy)	R	R	I	I	I
75	Breeding for lower emissions (beef)	R	R	I	I	I
76	Genomics			I	I	I
77	Sexed semen			I		
Livestock nutrition						
78	Feed additives (cattle)	R	R	I	I	I
79	Feed additives (dairy)		R	I	P	
80	Feed additives (beef)		R	I	P	

Mitigation action ID	Mitigation action name	WWF report	CCC report	Farmer-led group reports	CCPu	Farming for 1.5
81	Optimised feed strategies	R		I		I
82	Sustainable feed sourcing			I		
83	High starch diet (dairy)					I
84	Precision feeding (dairy)			I		I
85	Precision feeding (pigs)	R		I		I
86	Optimised forage utilisation			I		
Energy use						
96	Updating housing design			I		

Some highlights regarding mitigation actions with significant mitigation potential follow.

The farmer-led group reports have some gaps in mitigation actions recommended by WWF and the CCC, including:

- Change to spring cultivations
- Slurry aeration
- Composting/covering FYM
- Rapid incorporation

The farmer-led group reports include some mitigation measures that are not recommended by WWF and the CCC. These include:

- A wider range of livestock management actions (mitigation actions 54 to 64)
- Genetics for herd fertility
- Sexed semen
- Sustainable feed sourcing

The CCPu has some gaps in mitigation actions recommended by WWF and the CCC, including:

- Catch/cover crops
- Improving organic N planning
- Change to spring cultivations
- Optimised feed strategies
- Precision feeding (pigs)

Some mitigation measures that are not recommended by WWF and the CCC include:

- A wider range of livestock management actions (mitigation actions 54 to 64)
- Sexed semen
- Genetics for herd fertility
- Genomics

The Farming for 1.5 report has some gaps in mitigation actions recommended by WWF and the CCC, including

- Urease inhibitors
- Improving organic N planning
- Slurry acidification
- Slurry aeration
- Rapid incorporation

Some mitigation measures that are not recommended by WWF and the CCC include:

- Manure/slurry exchange
- Herd fertility
- Genetics for herd fertility
- Genomics
- High starch diet (Dairy)
- Precision feeding (Dairy)

6.2.3 How well do the various proposals reflect the system level changes required to both reduce emissions and sequester carbon, for example agroforestry, conversion to organic, conservation agriculture?

The reports were cross-referenced to find references to system level changes. A summary of the results can be seen in the table below with full references available in the associated spreadsheet.

Table 9: System level change as referenced in each of the farm-led group reports (arable, dairy, uplands, pig, beef), the CCPu and Farming for 1.5° interim report.

	ACCG	DSCCG	HUCG	SPILG	SBCS	CCPu	F1.5
Outwintering			DR		DR		
Agroecology	DR				R		DR
Regenerative farming	DR	R	DR		R	DR	R
Pasture for life			R				DR
Organic farming							DR
Conservation agriculture	R	R	R		R		R
Agroforestry	DR	DR	DR		DR	DR	DR
Non-ploughing tillage	DR	DR			R		DR
AD (with on-farm manure or crop waste)		DR		DR			DR

Direct reference (DR)	Reference to activity/ies that could be part of the system (R)

All of the reports referenced activities that would contribute to one or more of the system-level changes above. Nearly all reports, other than the SPLG, refer to agroforestry as part of future measures. Pasture for Life and organic farming were only explicitly referenced by the Farming for 1.5°C report; many of the reports referenced greater inclusion of legumes in rotations and reducing inorganic fertiliser use.

The ACCG refers to an Integrated Farm approach which, depending on its implementation and detail, could be a further vehicle for systems level change.

In general, the Farming for 1.5°C report is the only one that calls for system level change in any detail, while the other reports call for many mitigation measures to be used in combination.

6.2.4 Would the proposed measures in the CCPu; farmer-led group reports; or the Farming for 1.5°C report deliver the CCPu target of 5.3 Mt CO_2e y^{-1} direct agricultural GHG emissions by 2032?

6.2.4.1 The CCPu

The CCPu proposes policies and actions that are mainly to further explore policies to drive uptake of mitigation actions. We have made an interpretation of how these policies can lead to on-farm mitigation actions by 2032. Since the proposals in the CCPu are mainly for investigation of mitigation action feasibility, exploration of options, and consultation, there is concern about the timescale of mitigation action uptake. We are already into the period 2020 to 2032, and urgency is needed for actions to be adopted in time to show effects on emissions. Some actions can be taken up quickly and influence emissions immediately (e.g., use of nitrification inhibitors as nitrogen fertiliser additives), but many have a longer lead time, such as measures around livestock health and fertility. The CCPu needs to be followed up with more detailed proposals on specific mitigation actions and how uptake of these can be achieved: if the 2032 target is to be achieved, the uptake levels in Table 5 will need to be exceeded.

In the context of these caveats, we have estimated that the potential of mitigation actions that can follow from the CCPu is in the range of 524,793 to 717,609 Mt CO_2e y^{-1} (Table 7). It is therefore not feasible to reach the GHG mitigation target of 2.4 Mt CO_2e y^{-1} by 2032 (direct agricultural GHG emissions of 5.3 Mt CO_2e y^{-1} in 2032) with the set of mitigation actions that we expect to follow from the CCPu, and at the levels of additional uptake given in Table 5.

6.2.4.2 Farmer-led group reports

The mitigation potential of the mitigation actions in the farmer-led group reports have been assessed across the group of reports as a collection, thereby giving broader coverage of agricultural production sectors. We have estimated that the mitigation potential of mitigation actions in the farmer-led group reports is 1,047,013t CO_2e y^{-1} (Table 7) against the GHG mitigation target of 2.4 Mt CO_2e y^{-1} by 2032 (direct agricultural GHG emissions of 5.3 Mt CO_2e y^{-1} in 2032). This shows that the combination of mitigation actions in these reports will not deliver the required emissions reduction.

6.2.4.3 Farming for 1.5°C report

We have estimated that the mitigation potential of mitigation actions in the Farming for 1.5°C interim report is 937,922 t CO_2e y^{-1} (Table 7) against the GHG mitigation target of 2.4 Mt CO_2e y^{-1} by 2032 (direct agricultural GHG emissions of 5.3 Mt CO_2e y^{-1} in 2032). This shows that the activities listed in the interim report will not deliver the required emissions reduction.

6.2.5 Are there gaps remaining in the pathways presented by CCPu, farmer-led groups and Farming for 1.5°C?

References to individual measures are missing across the reports and are outlined below. It is worth stating that these are not necessarily explicit exclusions. Further, some measures may have been implied in the narrative but were missed in the analysis.

The greatest limitation to maximising emissions savings will be uptake. Many of the reports emphasised the importance of knowledge exchange and collaboration among farmers to engage them in climate change mitigation practices. This was particularly a strength of the Farming for 1.5 report, which didn't detail only mitigation measures, but also actions required to facilitate change. This included farmer to farmer collaboration and changes required for Scottish Government and advisory bodies too. None of these measures produce direct GHG savings but are integral to achieving high and efficient uptake levels but are not referred to in this analysis.

In the report 'Delivering on Net Zero: Scottish Agriculture' (Lampkin et al; 2020) for WWF Scotland, reference is made to the advantages of system level changes, as opposed to individual measures. Please refer to section 6.2.3 for detail on gaps referencing system level changes.

6.2.5.1 The CCPu

As mentioned in section 6.2.4.1 the CCPu proposes policies and actions that are mainly exploration of further policies to drive uptake of mitigation actions. The CCPu needs to be followed up with more detailed proposals on specific mitigation actions and how uptake of these can be achieved. This could be described as a gap since this is required to make progress towards GHG emissions mitigation.

Looking more specifically at the technical areas addressed, and specific mitigation actions, the gaps in the CCPu can be seen as blank cells in the relevant column of Table 6. Important gaps include policies leading to the following mitigation actions:

- Catch/cover crops
- Change to spring cultivations
- Sexed semen
- Improving livestock feed

Furthermore, it is not clear that the following are included in the policies to reduce Scotland's emissions from nitrogen fertiliser use.

- Urease inhibitors, slow-release N
- Nitrification inhibitors

6.2.5.2 Farmer-led group reports

Overall and in combination, the farmer-led group reports have good coverage of mitigation actions. The gaps can be seen as blank cells in the relevant column of Table 6. Important gaps include the following mitigation actions:

- Change to spring cultivations
- Manure/slurry exchange

There is little or no numerical uptake suggestion or recommendations. While the sector specific approach provided an opportunity to look at the detail of measures, more work will need to be done to see how the measures come together both practically (e.g. on mixed enterprises) and politically for Scottish agriculture as a whole. The SBCS sets out the proposed mitigation measures particularly well. Each measure was categorised, and the relevance, aim, emission abatement potential and applicability were detailed.

The SBCS has the most detail providing a structure and delivery of a scheme, with a discussion on how best to encourage take up of such a scheme. However, this is very specific to one area of Scottish agriculture and relies on voluntary uptake.

All of the reports focused on individual measures, with little attention other than in the ACCG, to a farm wide approach. The ACCG tabulated the mitigation measures at the end of the report, this would be useful in all of the reports to provide an overview of the measures at a glance. The table could include a description, examples of abatement potential and relevant sectors.

6.2.5.3 Farming for 1.5°C report

The gaps in the interim Farming for 1.5°C report can be seen as blank cells in the relevant column of Table 6. Important gaps include the following mitigation actions:

- Age at calving
- Sexed semen

6.2.6 How should the package of policies and proposals in the CCPu be strengthened to secure uptake and delivery of the necessary mitigation measures to secure the 2032 direct agricultural emissions target of 5.3 Mt CO_2e y^{-1}?

The CCPu proposes policies and proposes actions that are mainly exploration of further policies to drive uptake of mitigation actions.

Recommendation: the CCPu needs to be followed up with more detailed proposals on specific mitigation actions and how uptake of these can be achieved.

Since the proposals in the CCPu are mainly for investigation of mitigation action feasibility, exploration of options, and consultation, there is concern about the timescale of mitigation action uptake. We are already into the period 2020 to 2032, and urgency is needed for actions to be adopted in time to show effects on emissions. Some actions can be taken up quickly and influence emissions immediately (e.g., use of nitrification inhibitors as nitrogen fertiliser additives), but many have a longer lead time, such as measures around livestock health and fertility.

Recommendation: the development of more detailed proposals on specific mitigation actions and how uptake of these can be achieved needs to proceed quickly to maximise the GHG emissions mitigation by 2032. As well as ensuring the reduction of GHG intensity, it is key that a strategy is developed to reduce total emissions from the agricultural sector. This will need to be cross-sectoral and systematic in its approach.

Recommendation: the development of more detailed proposals on specific mitigation actions and how uptake of these can be achieved should include consideration of the gaps that can be seen as blank cells in the relevant column of Table 6; prominent examples are given in section 6.2.5.1.

Recommendation: the package of policies and proposals in the CCPu needs to be strengthened to include policies that will increase the uptake of mitigation actions beyond the levels of additional uptake given in Table 5.

Recommendation: targets to decrease emissions of GHGs from the agriculture emissions category of the national inventory of GHGs should be joined up with targets to decrease agriculture-related net emissions in other emissions categories such as LULUCF and energy.

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Appendix

A1 System level change definitions

A1.1 Agroecology

Agroecology is based on applying ecological concepts and principles to optimize interactions between plants, animals, humans and the environment while taking into consideration the social aspects that need to be addressed for a sustainable and fair food system (FAO, 2018).

A1.2 Agroforestry

Agroforestry is the growing of both trees and agricultural / horticultural crops or livestock on the same piece of land. The trees are grown to produce products or support the production of other products i.e. not just for aesthetics. Agroforestry differs from traditional forestry and agriculture by its focus on the interactions amongst components rather than just on the individual components themselves (Agroforestry Research Trust, n.d).

A1.3 Conservation agriculture

Conservation agriculture promotes minimum soil disturbance (i.e. no tillage), maintenance of permanent soil cover, and diversification of plant species. It enhances biodiversity and natural biological processes above and below the ground surface, which contribute to increased water and nutrient use efficiency and to improved and sustained crop production (FAO, 2017). Activities included within conservation agriculture include min-till, cover cropping, crop rotation and precision farming techniques (Cooper et al; 2020).

A1.4 Non-ploughing tillage system level practices

These systems include a scale of reduced to zero-tillage, using use a number of similar terms such as:

- min-till
- no-till
- zero-till
- direct drilling
- reduced tillage
- conservation tillage
- non-inversion tillage system

Generally, this system level change implies a method of establishing crops with the least amount of cultivations necessary (depth and intensity) while also retaining some of the previous crop's residues on the soil surface. It can encompass many systems that use a tine or disc cultivator to perform the cultivation. Depending on the activity, it ranges from direct drilling to only one cultivation between crop harvest and sowing (to a shallow depth of 50 to 100mm) or more. Stale seedbeds in combination with herbicides are often used for weed control. The type of cultivation equipment used and the depth and number of cultivations will depend on a number of factors, with user preference, soil type, previous cropping, current crop being sown and the time of considered.

Non or reduced ploughing tillage systems should reduce energy consumption, reduce labour, establishment time and machinery costs, help to conserve moisture and retain plant cover to minimise soil erosion, compared to conventional plough based systems, but these advantages are entirely related to the depth and intensity of cultivation (Teagasc, 2017; Defra, 2021).

A1.5 Organic agriculture

Organic agriculture relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs. Organic food and drink is governed by a rigorous regulatory framework (Scottish Government; 2016). Certification is legally required to grow, process or market organic products, and all organic farms and companies are inspected by a certification body, at least once a year (Soil Association; 2021). The certification prohibits the use of chemical fertilisers, plant protection products

A1.6 Outwintering

Outwintering systems include deferred grazing or in-situ grazing of alternative fodder and forage crops to reduce reliance on supplementary feeding (HUCG; 2020). This has the potential to conflict with non-ploughing tillage if the overwintering causes compaction or other soil damage.

A1.7 Pasture for Life (PFLA)

The Pasture for Life mark certifies that Pasture for Life meat and dairy comes from animals raised only on grass and pasture, thus restricting stocking density, and with specific animal welfare requirements. All the farms are visited to make sure the farmers follow a set of agreed production standards, based upon the animal's natural diet. The term "pasture" encompasses a range of different grasses, flowers, and herbs that are grown in diverse mixes. The standards cover land and animal management to ensure the delivery of environmental goods.

The Certification Standards encourage the use of legumes to enhance production and provide important sources of protein in livestock diets and in doing so significantly reduce the use of chemical fertilisers, provide food sources for insects and other animals. Grazing animals return nutrients and organic matter back to the ground as they pass by and deposit their dung. This natural process ensures the soil remains healthy and fertile. On a complete life-cycle analysis, the carbon footprint of pasture farms is characteristically lower than that of farms where cereal crops are grown to feed the animals. The Certification Standards specifically prohibit the use of Soya.

A1.8 Regenerative Agriculture

Regenerative agriculture has a variety of definitions with no international legal framework. Some are based on processes (e.g., use of cover crops, the integration of livestock, and reducing or eliminating tillage), outcomes (e.g., to improve soil health, to sequester carbon, and to increase biodiversity), or combinations of the two (Newton et al., 2020). For example, the IPCC's Special Report on Climate Change and Land listed regenerative agriculture as a "sustainable land management practice" focused on ecological functions that "can be effective in building resilience of agro-ecosystems."(IPCC; 2019)

However, other definitions reference both agroecology and sustainable intensification, which can be considered "a contrasting approach to agriculture futures" (Giller et al., 2021). There are many common threads to regenerative farming and agroecology, and in the US there is now a "Regenerative Organic Certification" (Giller et al; 2021) but there is no UK nor Scotland legal definition of either. Further the terms are used interchangeably in some languages and communities.

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