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Updated evidence to inform greenhouse gas emission modelling assumptions for Scotland's beef sector



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Updated evidence to inform greenhouse gas emission modelling assumptions for Scotland's beef sector

An output to SEFARI Gateway and the Scottish Government as part of the Specialist Advisory Group (SAG) on livestock nutrition within the Scottish Greenhouse Gas Inventory

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Key Points

- This Strategic Advisory Group was established by SEFARI Gateway, on behalf of the Scottish Government and the UK Beef Greenhouse Gas (GHG) National Inventory modelling team, to provide evidence and expertise to assess and update the underlying assumptions used to model GHG emissions from Scotland's beef sector.
- The June Agricultural Census 2023 (JAC) and SRUC's Agrecalc were identified as sources of quantitative data to inform the national inventory model. The data sources represented a significant proportion of the total beef herd but skewed towards larger enterprises.
- The main topics for review, identified by the national inventory scientists to improve the representativeness of Scottish Beef enterprises in the model (including spatial and historic variation) were: (i) frequency of housing/grazing; (ii) composition of housed diets; (iii) calorie and nitrogen content of diets; (iv) manure handling systems (liquid or solid); (v) manure storage types (lagoons or tanks *etc*), and; duration of manure storage
- Results suggest some parameters in the inventory model should be changed to better reflect Scottish Beef enterprises. In other cases, results confirm existing Inventory assumptions.
- Analysis of data sources can inform Inventory model assumptions, but differences in agricultural semantics often prevent one-to-one alignment between data and Inventory Model inputs.
- Limited historic data made it difficult to "back-cast" results to 1990 that are required for IPCC reporting. At best we were able to find quantitative evidence on some parameters going back to 2010.

Frequency of housing/grazing (Agrecalc):

- Compared to current model assumptions, bulls should be assumed to be housed longer, while heifers and suckler cows for less time. Allocating some animals to the "Grazing all year" regime could help address differences and reflect the presence of 100% grazing enterprises in Scotland.
- For other animal categories, there was general agreement with the model's assumptions, but subdividing housing by cattle age within the model would align better with quantitative evidence.
- Spatial variation was limited, although there was some indication that fewer animals were housed in warmer regions.
- There was no indication of historic variation between 2019 and 2025, but this does not preclude changes before this period.
- The Agrecalc evidence reviewed distinguishes between "pasture" and "hill ground" which can be used to inform feed properties (ratios) of the grazing diet (Rough grazing vs "Pasture") in the inventory model.

Composition of housed diets (Agrecalc):

- Diets were reported for enterprises in Agrecalc, making it difficult to determine diets for the individual animal roles/groups/ages used in the Inventory model.

- Finishing enterprises used more concentrates than suckler cow enterprises, and finishing dairy–beef had the lowest concentrate use amongst the finishing enterprises. Autumn-calving enterprises had very similar diets to their spring-calving counterparts (hill, upland, lowland).
- The majority of housed feed was home-grown rather than bought in.
- The analytical evidence yielded comparable total dry matter intakes to the assumptions that underpin the SAC Farm Management Handbook. However, the quantitative Agrecalc analysis suggests higher amounts of concentrates are fed to beef cattle. Differences in housing days (versus 'feeding days'), animal roles, and enterprise demographics were likely the reason for differences.
- Although the specific figures required for the Inventory model could not be produced from this analysis, the results, alongside the Farm Management handbook assumptions, can be used to inform the model's assumptions.

Manure handling systems (Agrecalc and JAC)

- The inventory model assumes that 70% of managed beef manure is in liquid (slurry) form, with the rest solid. Both the Agrecalc and JAC evidence suggest that slurry proportions should be much lower for the Scottish beef sector (25% and 34% respectively). It is recommended that the Agrecalc results be used to update these parameters in the model.
- In general, beef animals in regions associated with dairy farming were more likely to have their manure stored as slurry.

Manure storage types (Agrecalc and JAC)

- Semantic differences in manure storage classifications made it difficult to compare results. JAC evidence suggests that the inventory model's 'Farmyard Manure Direct Spread' category should be reduced from 60% to 6%. For liquid manure (slurry), the inventory model's assumptions are generally aligned with the JAC evidence.
- JAC results can be used to account for slurry coverings in the inventory model. No anaerobic digestion was used on beef enterprises in the Agrecalc evidence.
- There was some spatial variation in storage methods for liquid manures, but differences with solid manures may be attributed to agrisemantics, specifically regional terminology (e.g. manure heaps vs compost piles).
- The history of manure regulation in Scotland could possibly be used to backcast qualitatively.

Duration of manure storage (JAC)

- Manure stored as compost (interpreted as heaps) was stored the longest, while manure stored as deep litter was the shortest.
- Evidence on manure storage length could be aligned to the subset of manure storage types and used in the inventory model to improve estimates of emission factors.



Infographic created by ChatGPT using prompts and images.

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1 Introduction

1.1 Background Context

1. Scotland's ambitious climate change legislation sets a target date for net zero emissions of all greenhouse gases by 2045. The Scottish Greenhouse Gas Inventory is the key data source for understanding the origins and magnitudes of greenhouse gas emissions. The inventory is also used to report data against targets as required under the Climate Change (Scotland) Act 2009[1].

2. Working closely with the inventory team, the Scottish Government are making efforts to better understand and develop the greenhouse gas inventory for the agriculture sector. Mirroring an approach taken in Northern Ireland, the Scottish Government wanted to review and improve the dietary factors and intakes used in the greenhouse inventory from a Scottish perspective, to ensure that the estimates for Scotland reflect the best of local expert knowledge.

3. The Scottish Government commissioned SRUC, through SEFARI Gateway[2] to chair and provide secretariat for a Strategic Advisory Group (SAG) comprising academic and industry experts, supported by the national inventory sector specialists and Scottish Government officials, to focus on the existing assumptions used in the national inventory model for the Scottish beef sector.

4. The beef sector was selected for review following discussion with the Steering Group (Scottish Government, national inventory team, Sefari Gateway, SAG Chair and SAG Secretariat) and to maximise the impact of the work, and develop approaches that could be extended to other sectors in future. The work of this SAG was to assess key assumptions identified by the national inventory team that are currently used in modelling Scottish beef sector emissions within the national, update the evidence base upon which the current model assumptions are derived, whilst assessing the strengths and weaknesses of the current evidence from a Scottish context.

5. The national inventory team provided an overview of the Northern Ireland report at an initial Steering Group meeting and provided a specific set of questions they wanted the SAG to focus on. This mitigated the requirement for the SAG to review the Northern Ireland report.

6. The SAG was commissioned in March 2025 and completed in March 2026.

1.2 The Strategic Advisory Group Members

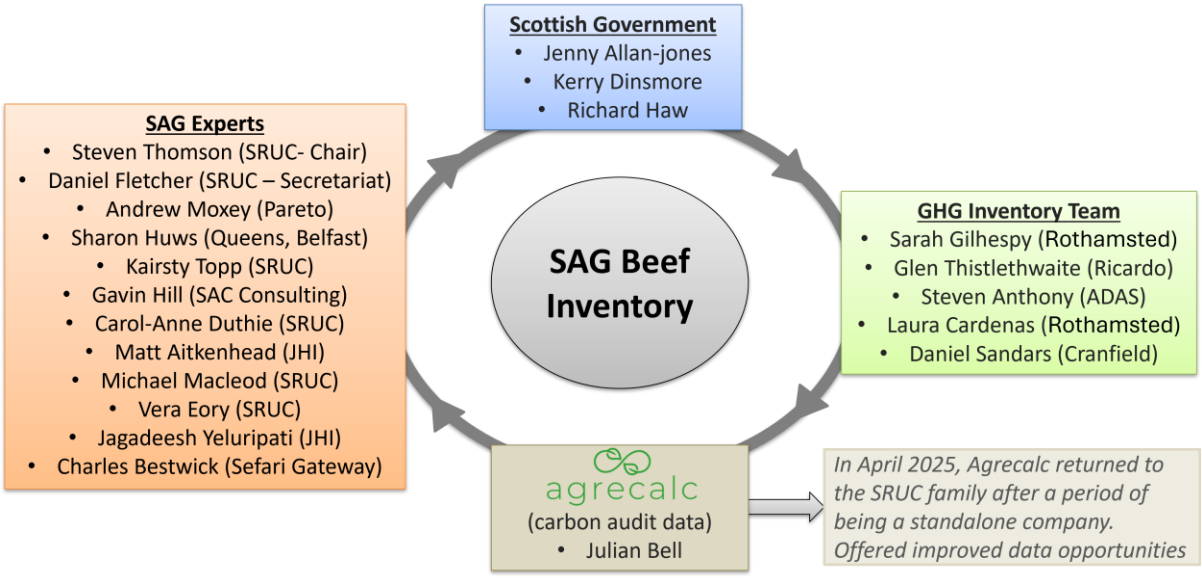
7. The purpose of the SAG was to "review and improve dietary, and other, factors for beef and intakes used in the greenhouse inventory from a Scottish

[1] Climate Change (Scotland) Act 2009
[2] Home | SEFARI

perspective, to ensure that the estimates for Scotland reflect the best of local expert knowledge".

8. As part of the commissioning process, SEFARI Gateway, the Scottish Government and the National Inventory team identified a range of topic experts that they wanted to engage as topic experts to the SAG (see Figure 1). SEFARI Gateway invited experts to join the SAG. During the early stages of the SAG, the Chair and Secretariat identified the opportunity and importance of access to Agrecalc data and expertise, and therefore also co-opted Agrecalc representation onto the SAG.

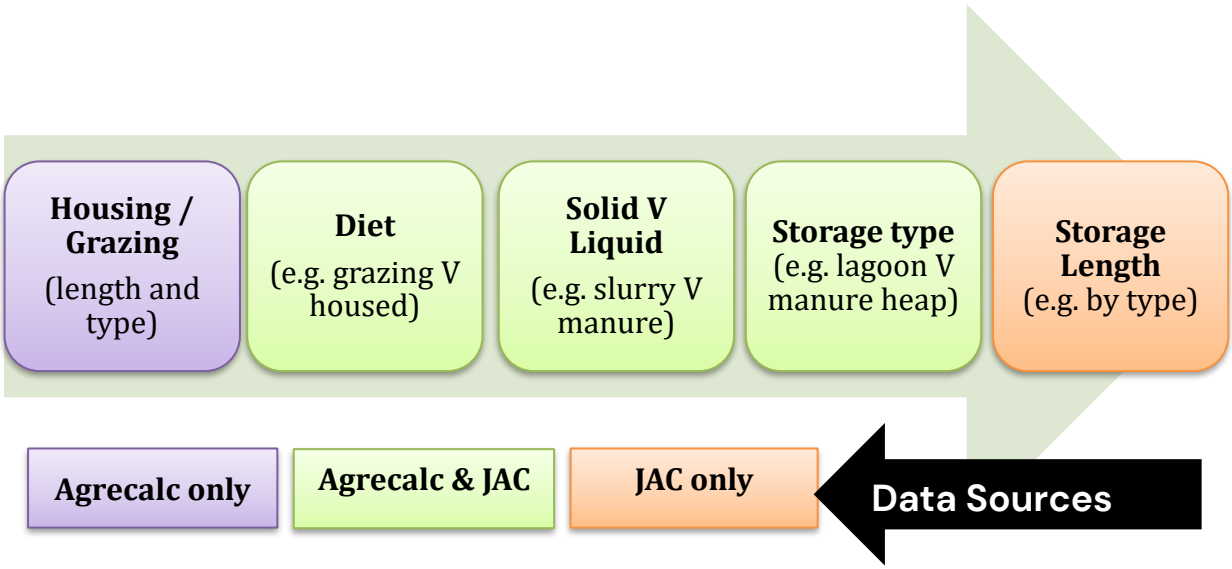
Figure 1 Structure of the SAG



9. The SAG operated to provide the SAG chair and secretariat with sources of evidence that could fill the data gaps identified by the national inventory team, and then to provide a critique of the written outputs drafted by the secretariat following presentation of results. SAG members were requested to provide thoughts on back-casting current data findings to the 1991 inventory baseline. SAG meetings were on individual topics (e.g. housing, diet, manure management) that were identified by the national inventory team, topics that the technical elements of this report are structured around (see Figure 2).

10. Feedback received from the SAG and the national inventory team was used to edit each draft chapter report, which forms the basis of this final report. The SAG provided useful insights on agrisemantics, specifically the various interpretations of definitions and data fields. Moreover, more substantive feedback was received on the initial presentation of the dietary composition section, which resulted in a more detailed analysis of the data, with further corroborating data also obtained.

Figure 2 Structure of the technical components of the report and main quantitative data sources used to provide evidence



11. The SAG experts, the national inventory team, the SEFARI Gateway and Scottish Government representatives are all thanked and acknowledged as having played an important role in forming and shaping this report. Particular thanks are offered to SRUC's Agrecalc team for working with the secretariat to extract relevant data and in interpretation of data fields.

12. The methods developed to support national inventory modelling for the beef sector could be replicated across other agricultural sectors, with most data extraction and analytical processes implemented in replicable code.



Photo: suckler cows and calves at pasture, Midlothian (S Thomson)

2 Data sources and representativeness of the Scottish Beef herd

2.1 Data Sources

13. To address the data requests from the National Inventory team, the SAG secretariat team assessed possible data sources that could be used to provide evidence on various components used in estimating greenhouse gas (GHG) emissions from the Scottish beef sector.

14. The researchers noted that the June Agriculture Census (JAC)[3] from 2023 contained modular questions that related to livestock housing, etc., at a holding (identified by County Parish Holding – CPH number) and business (identified by a Business Reference Number – BRN) level. Further, historic data on manure management was also available through the former EU Farm Structure Surveys[4]. SRUC researchers had access to the JAC data through the Data Sharing Agreement No 53 between the Scottish Government and SRUC.

15. In addition, the independent farm carbon calculator Agrecalc[5], was identified as a potential source of proprietary data at the beef enterprise level. Following a commercial spinout, Agrecalc was taken back into SRUC in 2025, which provided an opportunity to utilise this data source to respond to the specific data requests from the National Inventory team. Data access to Agrecalc beef enterprise data was secured for this project, and the data extraction was provided by the Agrecalc team in late summer 2025.

16. Additionally, the Scottish Government provided historical Farm Structure Survey data (2010, 2013, 2016) for the main agricultural holdings sampled. This data, particularly 2010 gives some historical context on some management practices, although the data variables are not directly comparable.

17. SAC Consulting data was utilised to assess silage quality. Using Agrecalc concentrate composition at the enterprise level, using assumptions on individual feed component's protein and energy properties, an estimate of the composition of concentrate diets for different beef enterprises.

2.2 Agrisemantics

18. There were differences in beef systems or cattle classification categories between the GHG Inventory model, the JAC and Agrecalc. These agrisemantic differences sometimes made alignment to the national inventory model

[3] Scottish Agricultural Census: results - gov.scot

[4] https://webarchive.nrscotland.gov.uk/20250701090631/http://www.gov.scot/collections/results-from-the-survey-of-farm-structure-and-methods/

[5] Farm carbon calculator | Home | Agrecalc

parameters more challenging. For example, Table 1 shows how the different beef cattle classifications may align (as discussed and agreed with SAG members).

Table 1 Agrisemantics of cattle classifications - aligning Agrecalc, June Agricultural Census and national inventory model classifications

Agrecalc	JAC	Inventory
Steer 0-12 mnth Heifer 0-12 mnth	Male cattle under 1 yr Female beef cattle under 1 yr	?
Bull	Male cattle aged 2 yrs and over	Bulls for Breeding
Entire 0-12 mnth Entire 12-24 mnth	Male cattle aged 1-2 yrs (%) Male cattle aged 2 yrs and over (%)	Cereal Fed Bull
Steer 24-36 mnth Steer 12-24 mnth	Male cattle aged 2 yrs and over (%) Male cattle aged 1-2 yrs (%)	Steers
Heifer 24-36 mnth (%) Heifer 12-24 mnth (%)	Female beef cattle aged 1-2 yrs (%) Female beef cattle without offspring aged 2 yrs and over (%)	Beef Females for Slaughter
Heifer 24-36 mnth (%) Heifer 12-24 mnth (%)	Female beef cattle without offspring aged 2 yrs and over (%)	Heifers for breeding
Suckler cow	Female beef cattle with offspring aged 2 yrs and over	Cows

2.3 Data Representativeness

2.3.1 JAC 2023 modular survey data

19. The JAC 2023 asked respondents a series of modular questions relating to 'Agricultural Production Methods', some of which were pertinent to this SAG (see Figure 30 in Appendix 1). CPHs without beef cattle[6] were filtered out using the various cattle variables within JAC. Table 2 shows that this left 10,249 holdings with beef cattle (8,127 with breeding suckler cows), 1.68m beef cattle, 394k breeding suckler cows (female beef cattle with offspring aged 2 yrs & over), with 5,266 full-time occupiers, c14.1k regular and casual workers, c.248k hectares of crops, c.1m hectares of crops and grass and c.1.2m hectares of rough grazing.

20. To assess the representativeness of the holdings that completed the manure management module in the 2023 JAC – the 'JAC module population' with beef cattle was compared to the wider population of holdings with beef cattle. Table 2 shows that the JAC data used in this analysis represented 56% of the holdings with beef cattle and 58% of the beef cattle herd reported in Scotland at the time of the JAC 2023. Those completing the manure management module also accounted for 64% of the breeding suckler cows in Scotland, 62% of full-time

[6] Beef cattle were calculated using total cattle (cts312) and then subtracting Female dairy cattle under 1 yr (cts302), Female dairy cattle aged 1-2 yrs (cts304), Female dairy cattle with offspring aged 2 yrs and over (cts306), and Female dairy cattle without offspring aged 2 yrs and over (cts308)

occupiers, 66% of the regular and casual workforce, and 66% of the agricultural area.

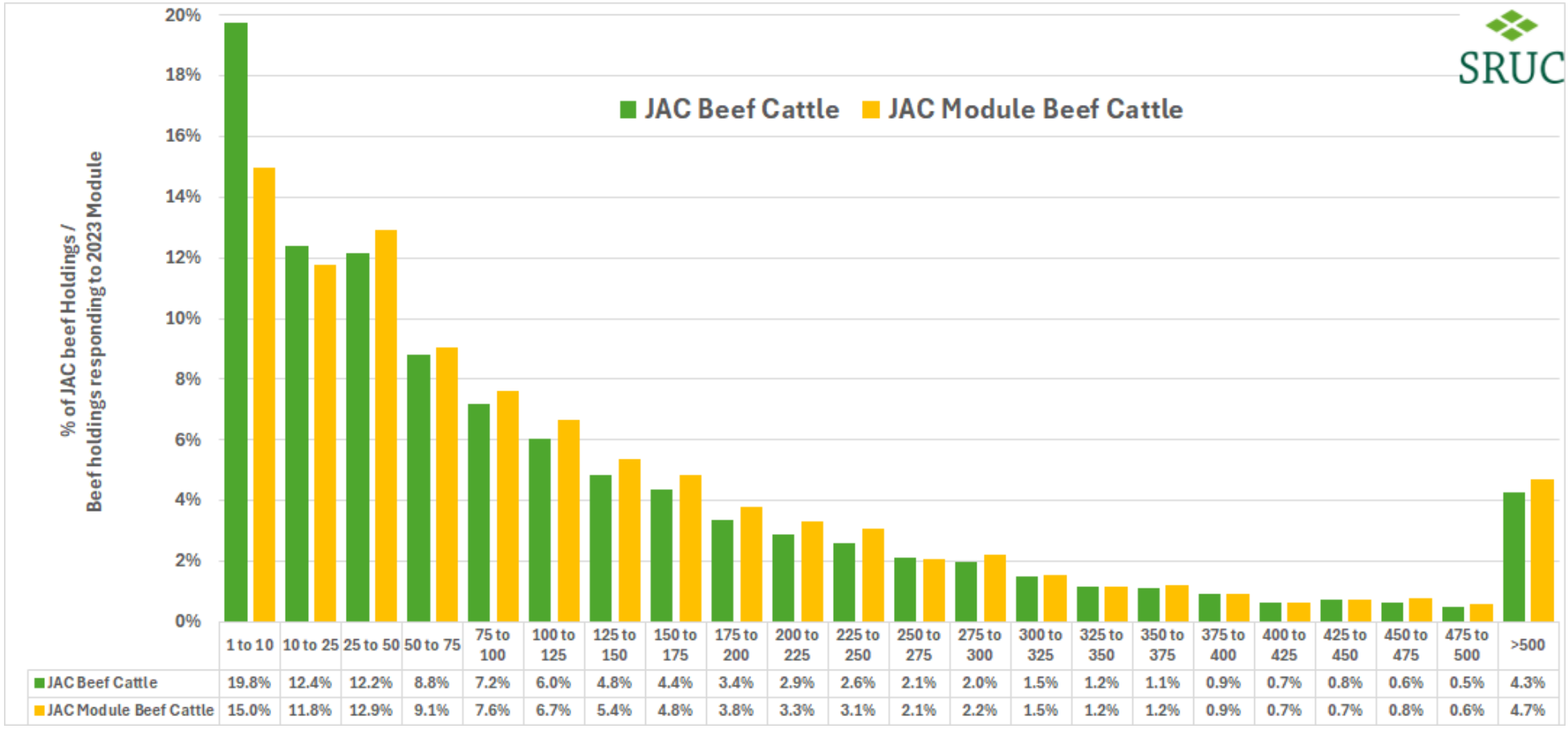
Table 2: Summary of animals, people and land areas on holdings with beef cattle within JAC 2023 agricultural holdings, compared to holdings completing the manure management module

Variable	Cattle / People / Ha			CPHs		
	JAC module	JAC Scotland	Module %	JAC Module	JAC Scotland	Module %
Female beef cattle with offspring aged 2 yrs & over	254,049	394,698	64%	4,754	8,127	58%
Total cattle	970,906	1,682,432	58%	5,783	10,249	56%
Beef Cattle	822,494	1,357,655	61%	5,783	10,249	56%
Full-time Occupiers	3,271	5,266	62%	3,271	5,266	62%
Part-time Occupiers (>50%)	818	1,317	62%	818	1,317	62%
Part-time Occupiers (<50%)	930	1,580	59%	930	1,580	59%
Regular & Casual Workers	9,332	14,149	66%	5,783	10,249	56%
Total Crops	156,164	248,299	63%	2,731	4,432	62%
Total Crops & Grass	664,918	1,049,097	63%	5,692	9,432	60%
Rough Grazing	814,775	1,212,449	67%	3,695	5,661	65%
Total Area	1,635,630	2,495,597	66%	5,746	9,525	60%

21. Table 34 to Table 37 in Appendix 1 also provides a breakdown of the distribution of holdings with beef cattle spatially (represented by 'Agricultural Regions') and by main enterprise type (represented by 'robust farm type'). Within these tables, the proportion of holdings that completed the manure management module in the JAC 2023 is also shown, providing full transparency on the relative representativeness of the evidence produced in this report from the JAC.

22. In addition to the spatial and farm type breakdown, Figure 3 shows the proportion of JAC 2023 holdings with beef cattle (JAC Beef Cattle), and those holdings that also completed the manure management module ('JAC Module Beef Cattle') by herd size (total beef cattle on the holding). The graph shows that there was an under-representation of the smallest herds (less than 10 head of beef cattle) in the sub-population that completed the manure-management module. For each size group over 25, there was a high proportion of holdings in the manure management sub-sample compared to the entire population. Whilst the smallest herds are therefore under-represented in the JAC analysis presented in this report, these holdings only accounted for 0.68% of 1.36m beef cattle across the entire JAC population and 0.53% of 822k of the JAC Module Beef Cattle in 2023.

Figure 3 Distribution of JAC 2023 holdings (CPHs) by beef cattle herd size compared to JAC 2023 holdings that completed JAC modular questions on management practices



	1 to 10	10 to 25	25 to 50	50 to 75	75 to 100	100 to 125	125 to 150	150 to 175	175 to 200	200 to 225	225 to 250	250 to 275	275 to 300	300 to 325	325 to 350	350 to 375	375 to 400	400 to 425	425 to 450	450 to 475	475 to 500	>500
JAC Beef Cattle	19.8%	12.4%	12.2%	8.8%	7.2%	6.0%	4.8%	4.4%	3.4%	2.9%	2.6%	2.1%	2.0%	1.5%	1.2%	1.1%	0.9%	0.7%	0.8%	0.6%	0.5%	4.3%
JAC Module Beef Cattle	15.0%	11.8%	12.9%	9.1%	7.6%	6.7%	5.4%	4.8%	3.8%	3.3%	3.1%	2.1%	2.2%	1.5%	1.2%	1.2%	0.9%	0.7%	0.7%	0.8%	0.6%	4.7%

2.3.2 Agrecalc data

23. Agrecalc data was extracted for all beef enterprises from 2019 to 2025. Normally, a CPH or BRN (or both) was available as a unique identifier in the data that could be used to match to the Single Application Form (SAF) and JAC data. It is worth noting that beef enterprises where carbon audits were undertaken as part of Scotland's Farm Business Survey (FBS)[7] were fully anonymised. Where a CPH was recorded, using Scottish Government lookup tables for 2024, each CPH was allocated to the Main Location Code (the main CPH of a business) and the associated BRN. These CPHs and BRNs were used as identifiers to link to official data to assess the relative representativeness of Agrecalc data to the Scottish beef sector population.

24. As part of the process of linking Agrecalc data to official data, any duplicate entries for an individual BRN were dropped from this comparative exercise, but not from the main data analysis reported in the report. Duplicates arose due to some businesses having either had more than one beef enterprise type audited at one time, or the business (BRN) having more than one audit in the 2019-2025 period. Table 3 shows that there were 4,364 beef enterprises over the 2019-2025 period, with 6% anonymised as part of the Farm Business Survey (FBS). It was possible to match a BRN to 4,113 enterprise extracts, with 3,677 unique BRNs identified. Using the 2024 SAF population, it was possible to match 3,500 Agrecalc BRNs to official data held in Scotland's Integrated Administration and Control System (IACS). Further, 3,350 Agrecalc BRNs were also matched to CPH data aggregated to business level data (BRN) in the JAC (some businesses are complex and have multiple holdings).

Table 3 From individual Agrecalc enterprise reports (2019-2025) to unique businesses (BRNs)

Summary	Agrecalc beef enterprise population	Proportion of Agrecalc beef enterprises
Agrecalc beef enterprise entries	4,364	100%
Anonymised FBS farms	283	6%
Number of enterprises with BRN identified	4,113	94%
Unique Agrecalc BRNs identified	**3,677**	**84%**
Unique Agrecalc BRNs matched to 2024 SAF	3,500	80%
Unique Agrecalc BRNs matched to JAC 2023 BRNs with beef cattle	3,350	77%

25. Table 4 shows that within the JAC there were 9,972 BRNs with beef cattle, of which 34% had at least one Agrecalc beef enterprise audit completed in the 2019-2025 period. These beef BRNS with an Agrecalc audit accounted for 53%

[7] Scottish Farm Business Survey | SRUC

of Scottish beef cattle and 58% of the suckler beef herd (Female beef cattle with offspring aged 2 yrs and over). The Agreclac sample accounted for 43% of beef BRNs with full-time occupiers (dropping to 25%-35% of part-time occupiers), and they accounted for over half of the land associated with BRNs carrying beef cattle (based on matching to 2023 JAC).

26. To show the representativeness of the Agrecalc spatially and by main enterprise types, the JAC 2023 beef-BRN population alongside the Agrecalc BRN data is provided for 'agricultural regions' (Table 36) and 'robust farm types' (Table 37) in Appendix 1.

Table 4 Summary of animals, people and land areas on JAC 2023 BRNs, compared to the Agrecalc beef sector BRNs (2019-2025)

Variable	Cattle / People / Ha			BRNs		
	Agrecalc	JAC Scotland	Matched Agrecalc %	Agrecalc	JAC Scotland	Matched Agrecalc %
Female beef cattle with offspring aged 2 yrs and over	226,897	394,065	58%	2,925	7,982	37%
Total cattle	767,296	1,680,877	46%	3,350	9,972	34%
Beef Cattle	720,707	1,355,810	53%	3,350	9,972	34%
Full-time Occupiers	2,213	5,331	42%	2,213	5,331	42%
Part-time Occupiers (>50%)	420	1,386	30%	420	1,386	30%
Part-time Occupiers (<50%)	438	1,732	25%	438	1,732	25%
Regular & Casual Workers	6,871	15,446	44%	2,169	5,020	43%
Total Crops	152,318	285,480	53%	2,004	4,483	45%
Total Crops & Grass	582,928	1,171,687	50%	3,336	9,307	36%
Rough Grazing	746,750	1,475,831	51%	2,336	5,774	40%
Total Area	1,476,109	2,932,564	50%	3,340	9,384	36%

27. Table 5 shows that within the SAF declarations, there were 7,145 BRNs with suckler cows in 2024, with 42% having had an Agrecalc beef enterprise audit between 2019 and 2024. These Agrecalc beef-BRNs accounted of 59% (c227k) of declared suckler cows (61% of Less Favoured Area suckler cows), and half of the total declared beef cattle on the 9,178 BRNs declaring any beef cattle (38% of these businesses had an Agrecalc audit completed). 9,048 beef-BRNs were supported through the Basic Payment Scheme (BPS) in 2024, covering 2.54m hectares (with c. 1.2m hectares in BPS Region 1). The Agrecalc sample accounted for 39% of the BPS-supported beef-BRNs and 51% of the BPS area claimed.

28. Figure 4 shows that the businesses with beef enterprises that have had an Agrecalc audit completed were skewed towards larger beef herds. For example, only 3.7% of the Agrecalc beef-BRNs had fewer than 10 beef animals, compared to 18.8% of beef BRNs in the 2023 JAC. In contrast, 8.6% of Agrecalc beef-BRNs had more than 500 beef animals compared to 4.5% in the JAC 2023 population. BRN herd sizes under 10 beef animals only contained c.8.8k beef cattle (0.65% of the 1.36m JAC population), and only 708 beef cattle in the Agrecalc sample (0.1% of the 721k beef cattle in Agrecalc beef-BRNs). Herds of over 500 beef animals

accounted for 27.5% of the JAC, and 33.7% of the Agrecalc beef cattle populations.

Table 5 Summary of animals, people and hectares claimed for Basic Payment Scheme support by beef-BRNs (2024), compared to the Agrecalc beef sector BRNs (2019-2025)

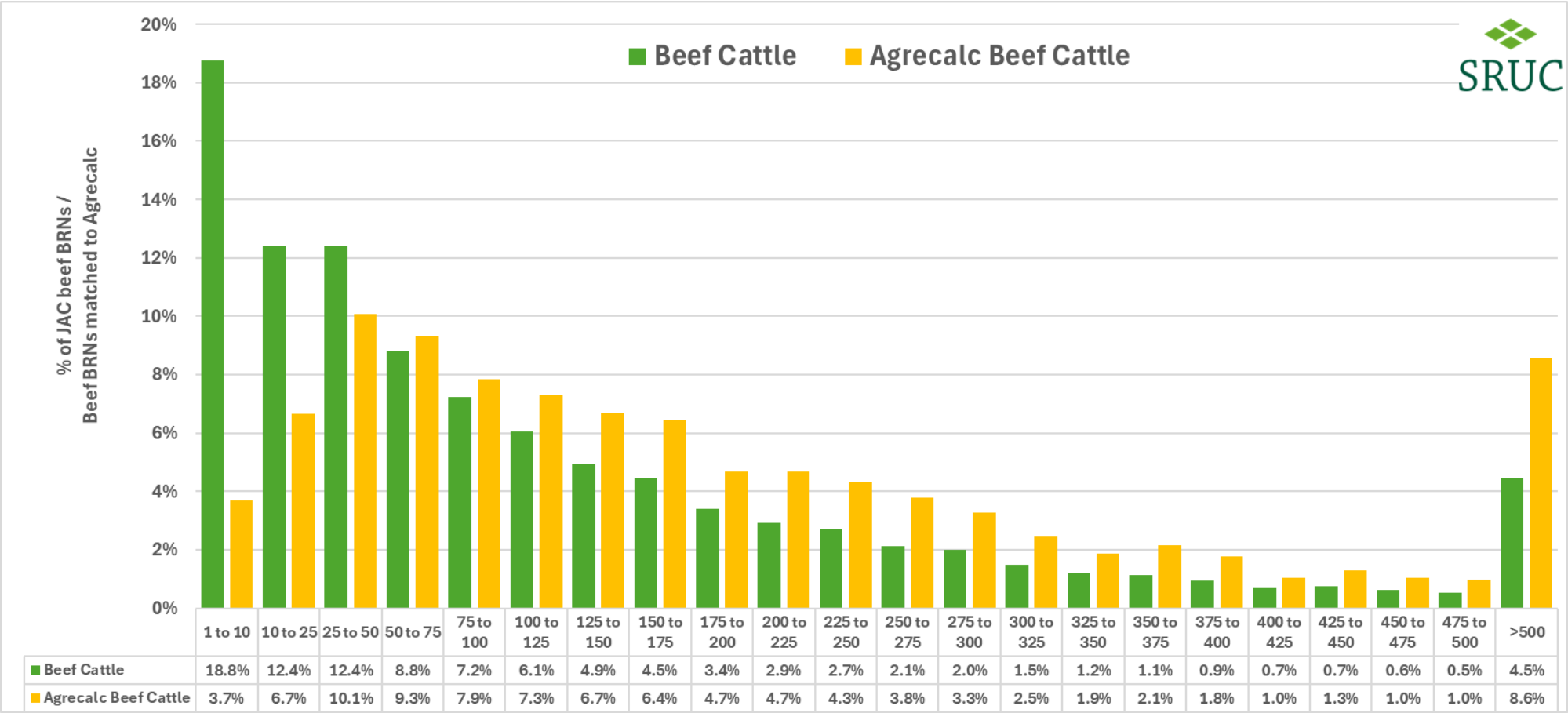
From SAF 2024	Head			BRNs		
	Agrecalc	SAF Scotland	Matched Agrecalc %	Agrecalc	SAF Scotland	Matched Agrecalc %
Suckler Cows	226,836	384,582	59%	2,966	7,145	42%
-LFA Suckler Cows	190,264	313,824	61%	2,495	5,764	43%
Other dairy & beef under 6mnth	61,927	163,383	38%	2,128	5,078	42%
-LFA Other dairy & beef under 6mnth	41,754	84,983	49%	1,654	3,578	46%
Other dairy & beef 6-24mnth	341,710	701,734	49%	3,360	8,299	40%
-LFA Other dairy & beef 6-24mnth	213,967	391,525	55%	2,452	5,729	43%
Other dairy & beef over 24mnth	37,972	86,919	44%	2,916	6,873	42%
-LFA Other dairy & beef over 24mnth	24,408	50,974	48%	2,232	4,977	45%
Total Beef Cattle	668,445	1,336,618	50%	3,500	9,178	38%
BPS Region 1 claimed	575,034	1,159,502	50%	3,488	8,972	39%
BPS Region 2 claimed	316,266	609,423	52%	2,397	5,516	43%
BPS Region 3 claimed	415,131	795,046	52%	635	1,941	33%
Total BPS Area	1,306,431	2,563,970	51%	3,494	9,048	39%

*LFA is a subset of the main categories



Photo: Hill farming – suckler cows grazing by Spey Dam, Laggan (Rory Richardson)

Figure 4 Distribution of JAC 2023 businesses (BRNs) by beef cattle herd size compared to Agrecalc unique businesses (BRNs) for 2019-2025



	1 to 10	10 to 25	25 to 50	50 to 75	75 to 100	100 to 125	125 to 150	150 to 175	175 to 200	200 to 225	225 to 250	250 to 275	275 to 300	300 to 325	325 to 350	350 to 375	375 to 400	400 to 425	425 to 450	450 to 475	475 to 500	>500
Beef Cattle	18.8%	12.4%	12.4%	8.8%	7.2%	6.1%	4.9%	4.5%	3.4%	2.9%	2.7%	2.1%	2.0%	1.5%	1.2%	1.1%	0.9%	0.7%	0.7%	0.6%	0.5%	4.5%
Agrecalc Beef Cattle	3.7%	6.7%	10.1%	9.3%	7.9%	7.3%	6.7%	6.4%	4.7%	4.7%	4.3%	3.8%	3.3%	2.5%	1.9%	2.1%	1.8%	1.0%	1.3%	1.0%	1.0%	8.6%

3 Housing, pasture and hill grazing in the Scottish beef sector

3.1 Introduction

29. Within the national inventory, alongside the management type and storage length of excreta, the amount of time cattle spend at grazing or housed impacts the modelled emissions released from beef cattle. The type and length of time that beef cattle are housed influences several key GHG emissions parameters, including:

- **Diet:** Housed cattle receive concentrates and silage rather than fresh grass. Typically, housing diets have a higher digestible energy percentage (DE, proportion of energy within a diet which is digestible by cattle), and a higher ration DE results in lower enteric methane emissions under equal energy consumption.
- **Energy requirements:** Grazing animals need to use more energy to move and keep warm, resulting in higher enteric methane emissions.
- **Manure**: Manure on 'Pasture Range and Paddock' typically has much lower GHG emissions than stored manure and slurry.
- **Feed additives**: Enteric methane-suppressing feed additives, like 3NOP[8], are currently only practically applicable to housed animals, where the additive can be mixed into the feed. Although feed additives are not currently included in the national inventory, improving beef cattle housing estimates for Scotland can improve the accuracy of modelling the impacts of methane suppressant feed additives in the future.

30. Currently, the national inventory uses 6 different management regimes for beef animals. These are:

- Housed all year
- Housed winter
- Grazing summer
- Grazing all year
- Housed all year + yarding[9]
- Housed winter, grazing summer + yarding

31. Table 6 shows how the national inventory model allocates animals to housing, grazing and yarding throughout the year in each management regime. Table 7 shows the proportion of cattle by 'animal type' that are allocated to each management system. Table 8 then shows the proportion of the year each animal is housed and is used to compare with the results from the Argecalc data analysis. In the national inventory, all beef 'animal types' are assumed to be housed for approximately half the year in Scotland, except 'Cereal Fed bulls', which are assumed to be housed for about 60% of the year.

[8] 3-Nitrooxypropanol (3-NOP), marketed as Bovaer (Methane Inhibitors - Bovaer®)
[9] "Yarding" was defined as the temporary location of cattle on open, uncovered gathering yards (for milking and health checks) and open over-winter feeding yards.

Table 6: Monthly housing/grazing/yarding proportions for management regimes in the national inventory for Scottish beef

Management Regime	Location	% month / year under each management regime												
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Housed All Year	Housing	100	100	100	100	100	100	100	100	100	100	100	100	**100**
	Grazing	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	Yarding	-	-	-	-	-	-	-	-	-	-	-	-	**-**
Housed Winter, Grazing Summer	Housing	100	100	98.6	83.7	29	0	0	17.6	33.3	67.7	92.8	100	**60.2**
	Grazing	-	-	1.4	16.3	72	100	100	82.4	66.7	32.3	7.2	-	**39.8**
	Yarding	-	-	-	-	-	-	-	-	-	-	-	-	**-**
Grazing All Year	Housing	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	Grazing	100	100	100	100	100	100	100	100	100	100	100	100	**100**
	Yarding	-	-	-	-	-	-	-	-	-	-	-	-	**-**
Housed All Year + Yarding	Housing	60	60	60	60	60	60	60	60	60	60	60	60	**60**
	Grazing	-	-	-	-	-	-	-	-	-	-	-	-	**-**
	Yarding	40	40	40	40	40	40	40	40	40	40	40	40	**40**
Housed Winter, Grazing Summer + Yarding	Housing	100	60	59.2	50.2	17	-	-	10.6	20	40.6	55.7	60	**39.4**
	Grazing	-	-	1.4	16.3	72	100	100	82.4	66.7	32.3	7.2	-	**39.8**
	Yarding	-	40	39.4	33.5	11	-	-	7	13.3	27.1	37.1	40	**20.7**

Table 7: Proportion of animals by 'beef cattle types' by management regime currently used in the national inventory for Scotland.

Animal Type	Housed All Year (%)	Housed Winter, Grazing Summer (%)	Grazing All Year (%)	Housed All Year + Yarding (%)	Housed Winter, Grazing Summer + Yarding (%)
Heifers for Breeding	-	55	-	-	45
Beef Females for Slaughter	-	55	-	-	45
Bulls for Breeding	-	55	-	-	45
Cereal Fed Bull	-	55	-	45	-
Steers	0.55	54.55	-	0.45	44.55
Cows	-	55	-	-	45

Table 8: Proportion of the year each animal type is kept as Housed, Grazing, or Yarding in the National Inventory. Derived from Table 6 and Table 7.

Animal Type	Housing (%)	Grazing (%)	Yarding (%)
Heifers for Breeding	50.9	39.8	9.3
Beef Females for Slaughter	50.9	39.8	9.3
Bulls for Breeding	50.9	39.8	9.3
Cereal Fed Bull	60.1	21.9	18.0
Steers	51.2	39.5	9.4
Cows	50.9	39.8	9.3

3.2 Housing data and analytic methods

3.2.1 Agrecalc data description

32. The primary data source used in this analysis is the input data from Agrecalc, which collects information on manure management and from which the percentage of time an animal is housed can be derived. Table 9 shows how Agrecalc manure deposit input data categories were allocated to summary 'Pasture', 'Hill ground', and 'Housed' grazing/housing systems in this analysis.

Table 9: Agrecalc manure deposits mapping to summary grazing/housing type.

Agrecalc "Manure percentages"	Summary grazing / housing type
Pasture	Pasture
Hill ground	Hill ground
Liquid Slurry	Housed
Solid storage (FYM)	Housed
Pit storage (Slats)	Housed
Deep bedding (retained > 1yr)	Housed
Anaerobic digestion	Housed

33. It was assumed that if *x*% of manure was deposited in a housed manure management system, then the animal spent *x*% of its time housed. Agrecalc does not collect information on the amount of time an animal is in a yard, but divides grazing into "Pasture" and "Hill ground" which can help improve assumptions about activity energy and grazing diet in the inventory.

34. Agrecalc has more classifications of beef animals than the national inventory for this parameter by accounting for age in housing parameters, namely

- Bull
- Entire 0-12 month
- Entire 12-24 month
- Heifer 0-12 month
- Heifer 12-24 month
- Heifer 24-36 month
- Steer 0-12 month
- Steer 12-24 month
- Steer 24-36 month
- 'Suckler cow'

35. There were 3,559 unique beef enterprises in the Agrecalc dataset. However, as each entry in the data represents an enterprise for a year, some businesses/enterprises can appear more than once across the 2019-2025 data extract. In total, the data contained 5,246 beef-enterprise years and 1.18 million cumulative beef cattle present on enterprises between 2019 to 2025. The analysis maintained the temporal component to investigate any changes over time that could help with back-casting.

3.2.2 Housing analytic methods

36. Two enterprise-years (a report from an enterprise in one year) were excluded because their manure percentages (Table 7) did not sum to 100, resulting in 5,244 enterprise-years and 1.18 million cattle-years in the analysis. The analysis aimed to calculate the proportion of time each Agrecalc beef type was housed, on pasture and on hill ground.

37. The analytical approach weighted the results by the proportion of the total beef-years each farm-year had within the total Agrecalc sample. The approach used was:

- Let h_i^j be the percentage of time farm i reports that a given Agrecalc beef type is on system j, where $j =$ 'housed', 'grazing' or 'hill ground'.
- Let n_i be the number beef animals on farm i and let N be the number of farms which have >0 of the given beef type.
- The weighted mean of system type j is calculated as:

$$\overline{h^j} = \sum_{i=1}^{N} \frac{h_i^j n_i}{\sum_{k=1}^{N} n_k}.$$

- The weighted variance is calculated as:

$$\sigma_j^2 = \sum_{i=1}^{N} \frac{n_i \left(h_i^j - \overline{h^j}\right)^2}{\sum_{k=1}^{N} n_k}.$$

3.3 Housing results

38. Table 10 shows that 'Bulls' had the lowest housing proportion at 38.1%, with 'Entire 12-24 month' the highest at 75%[10]. For entire males and heifers, the 12-24 month age range had the highest housing proportion, while for steers it was the 24-36 month age range (likely related to finishing periods). However, heifers had a narrow range of housing proportions (44.5% to 49.7%) across age groups, while entire males and steers had quite a wide range of housing proportions across age groups, 50.7% to 75% and 46.3% to 56.6%, respectively.



Photo: Suckler heifers, Blargie farm, Laggan, Highland (S Thomson)

[10] Can the 'Entire' ArgeCalc beef type translate to Cereal Fed Bull in the NI beef types?

Table 10: Proportion and standard deviation (std) of Agrecalc beef animal types in Housing or on Pasture and Hill ground (highest % in bold)

Agrecalc beef classification	Enterprise years (n)	Cattle years (n)	Housed % (std)	Pasture % (std)	Hill ground % (std)
Bull	4,202	18,387	38.10 (20.82)	**57.5** (21.43)	4.41 (13.37)
Entire 0-12 mnth	873	32,682	**50.73** (20.26)	47.70 (16.93)	1.57 (7.03)
Steer 0-12 mnth	4,415	170,094	46.34 (16.83)	**48.63** (16.26)	5.03 (14.07)
Heifer 0-12 mnth	4,696	193,458	45.67 (15.54)	**49.61** (15.50)	4.72 (13.40)
Entire 12-24 mnth	795	12,651	**75.00** (31.14)	24.41 (26.59)	0.59 (4.75)
Steer 12-24 mnth	3,373	136,144	**54.04** (21.48)	44.95 (18.33)	1.01 (6.83)
Heifer 12-24 mnth	4,515	164,099	**49.68** (21.47)	47.71 (19.03)	2.61 (10.79)
Heifer 24-36 mnth	3,080	42,189	44.53 (22.77)	**48.44** (19.50)	7.03 (17.59)
Steer 24-36 mnth	786	11,394	**56.58** (27.38)	41.90 (22.46)	1.52 (10.25)
Suckler cow	4,524	390,219	40.72 (17.21)	**50.35** (17.46)	8.93 (17.14)

39. There were non-normal distributions of the proportion of time housed, and many distributions were multi-modal, as shown in Figure 5. Every beef animal type had a mode housing proportion of 50%, except "Entire 12-24 month", which had a mode value of 100%. However, the lack of enterprises in the value intervals adjacent to the 50% (45-55%) range may indicate that there is a tendency by farmers and consultants to round to this value when inputting data.

40. In addition to the dominant mode (at 50% or 100%), the distributions were multimodal, with secondary peaks centred around 40% and 60%. In some beef types, further modes were also evident near 20% and 80%. The national inventory's approach of allocating animals to defined management regimes (Table 6) will help capture some of the multi-modal features in the GHG modelling.

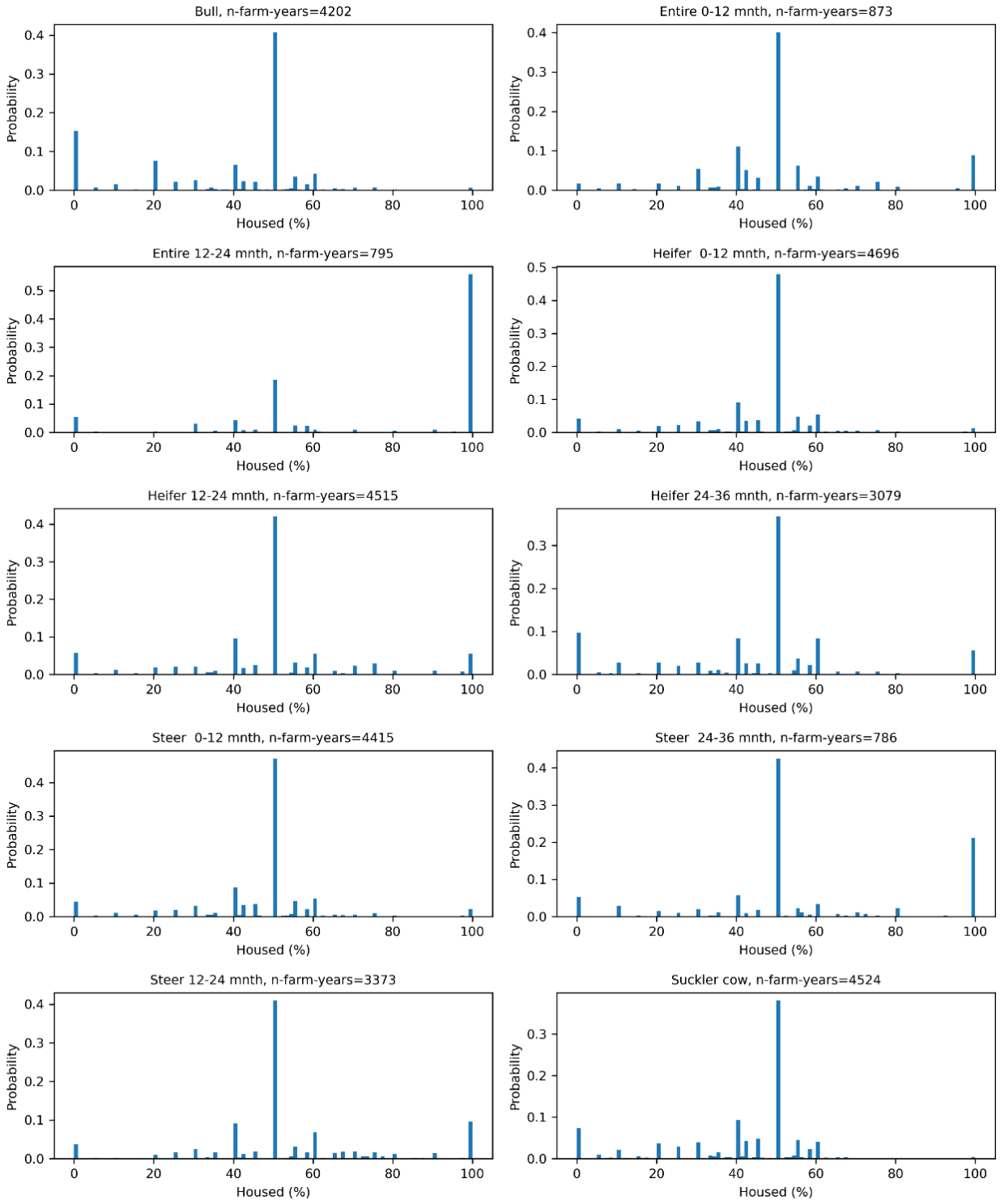


Figure 5: Probability density function of housed % weighted by the number of animals on each farm. Bin width is 1%. Each y-axis has a different scaling. Means and standard deviation are consistent with Table 10.

41. There were only minor changes in the housing system between 2019 and 2025, as shown in Figure 6. Some of the annual variation may be due to the differing population of farms/crofts submitting data to Agrecalc across years, but also

may reflect changes in the general operating environment on beef enterprises or policy changes.

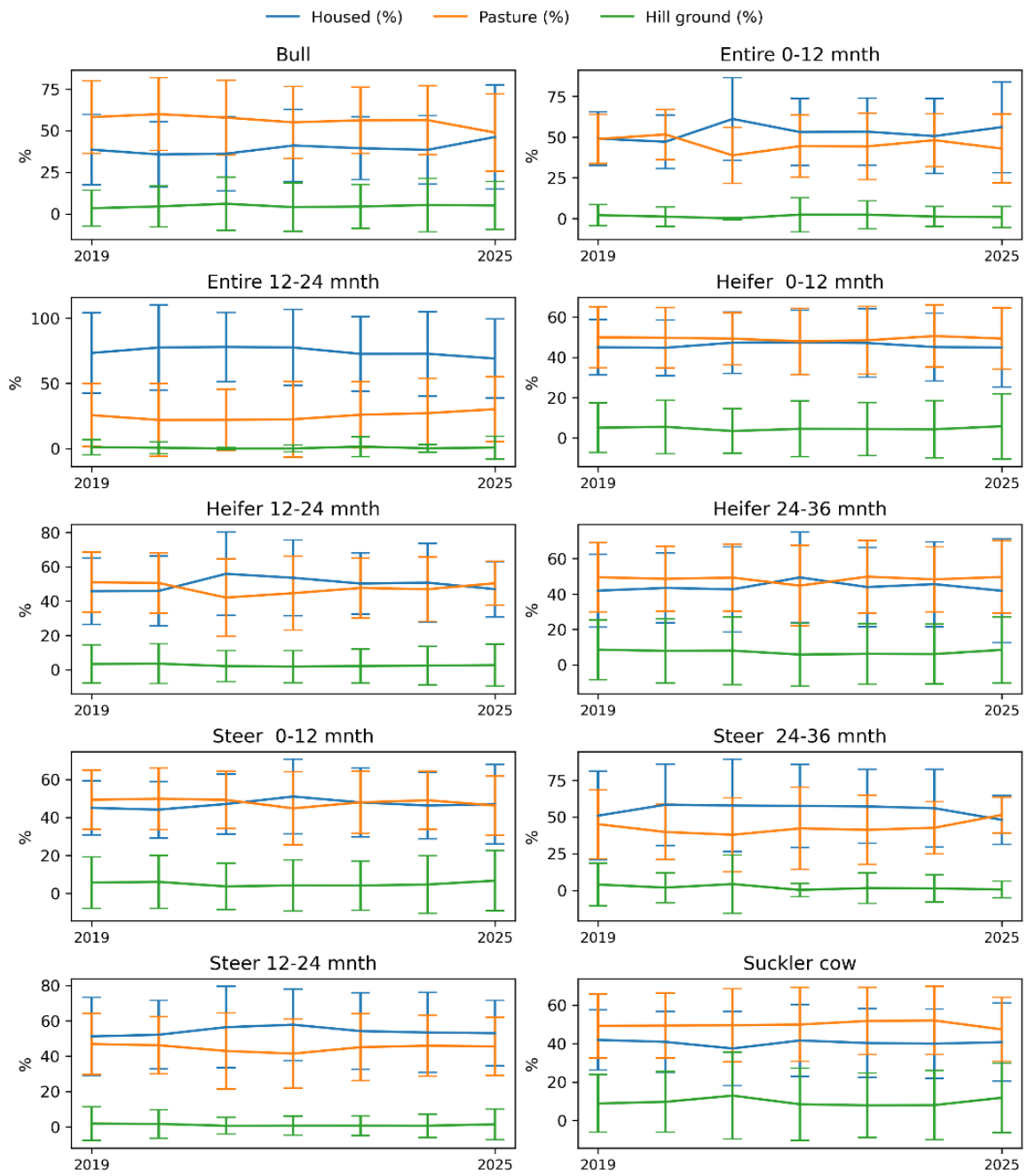


Figure 6: Trends in Housed, Pasture and Hill Ground percentage from 2019-2025. Error bars represent standard deviation.

42. The spatial trends in mean housed proportions can be seen in Figure 7. Orkney and Shetland had notably higher housing proportions than other regions, due to the harsher and longer winters. Argyle and Bute had lower housing proportions, presumably due to the milder winters (Kintyre peninsula), but also possibly related to the type of suckler cows kept. Steers 12-36 months were housed for more than 70% of the time in Angus due to the density of finishers in this region.

The Outer Hebrides had very little housing due to their extensive 'crofting' grazing, and potential shelter from Machair sand dunes (for example). The relative proportions of breed types across geographies could help with the interpretation of this data and can be extracted from ScotEID / Cattle Tracing System databases in the future.

43. Spatial trends using larger regions can be seen in Figure 7 which reduces the impact of low counts in smaller regions. Although some trends are obscured (e.g. low housing percentages in Argyle and Bute in Figure 7), the general trends persist. For example, a high amount of housing for non-breeding animals in the north east of Scotland.

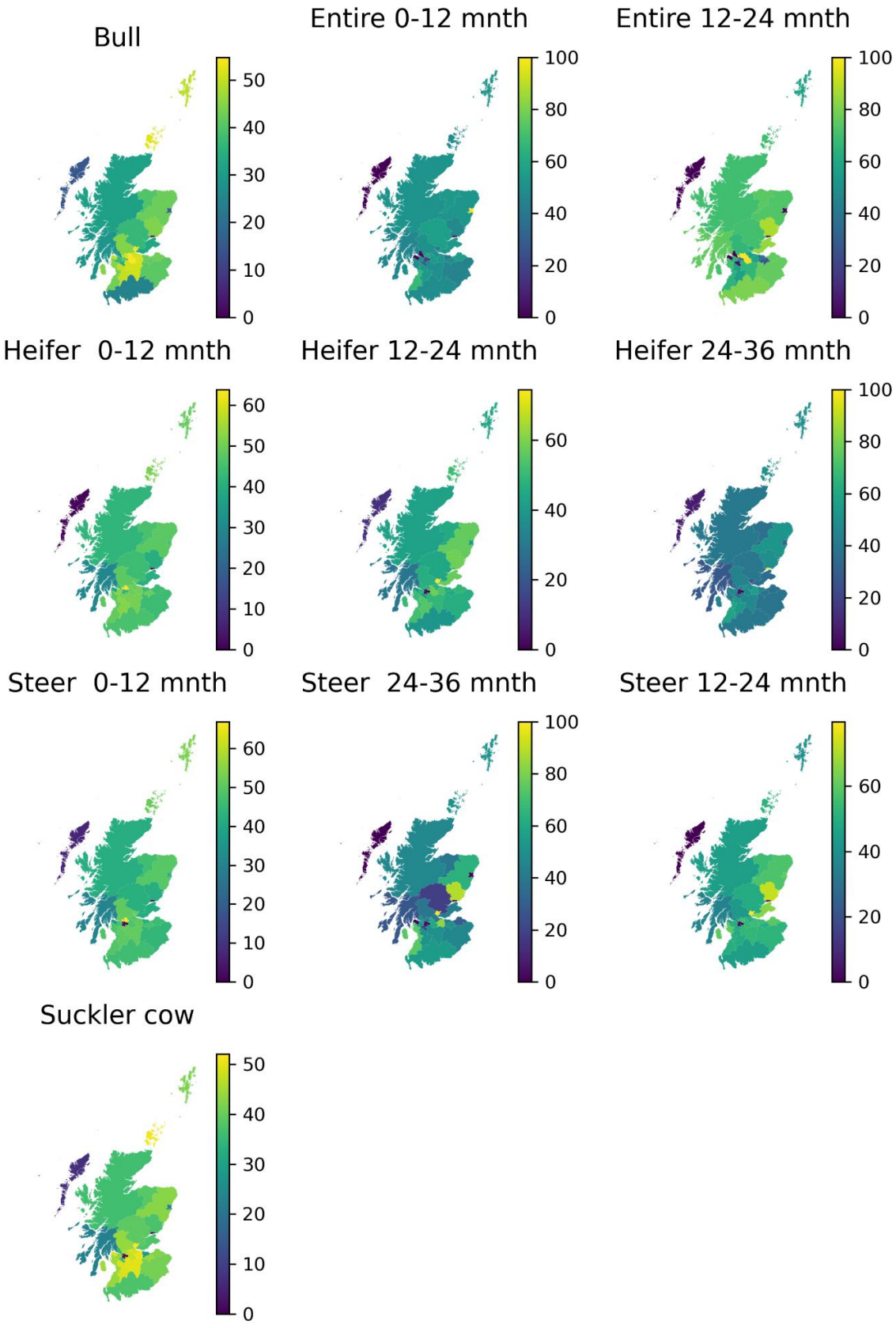


Figure 7: Spatial distribution of the proportion of a year (mean) that beef cattle are housed by Agrecalc beef classification. Local authority district (2022 boundaries)

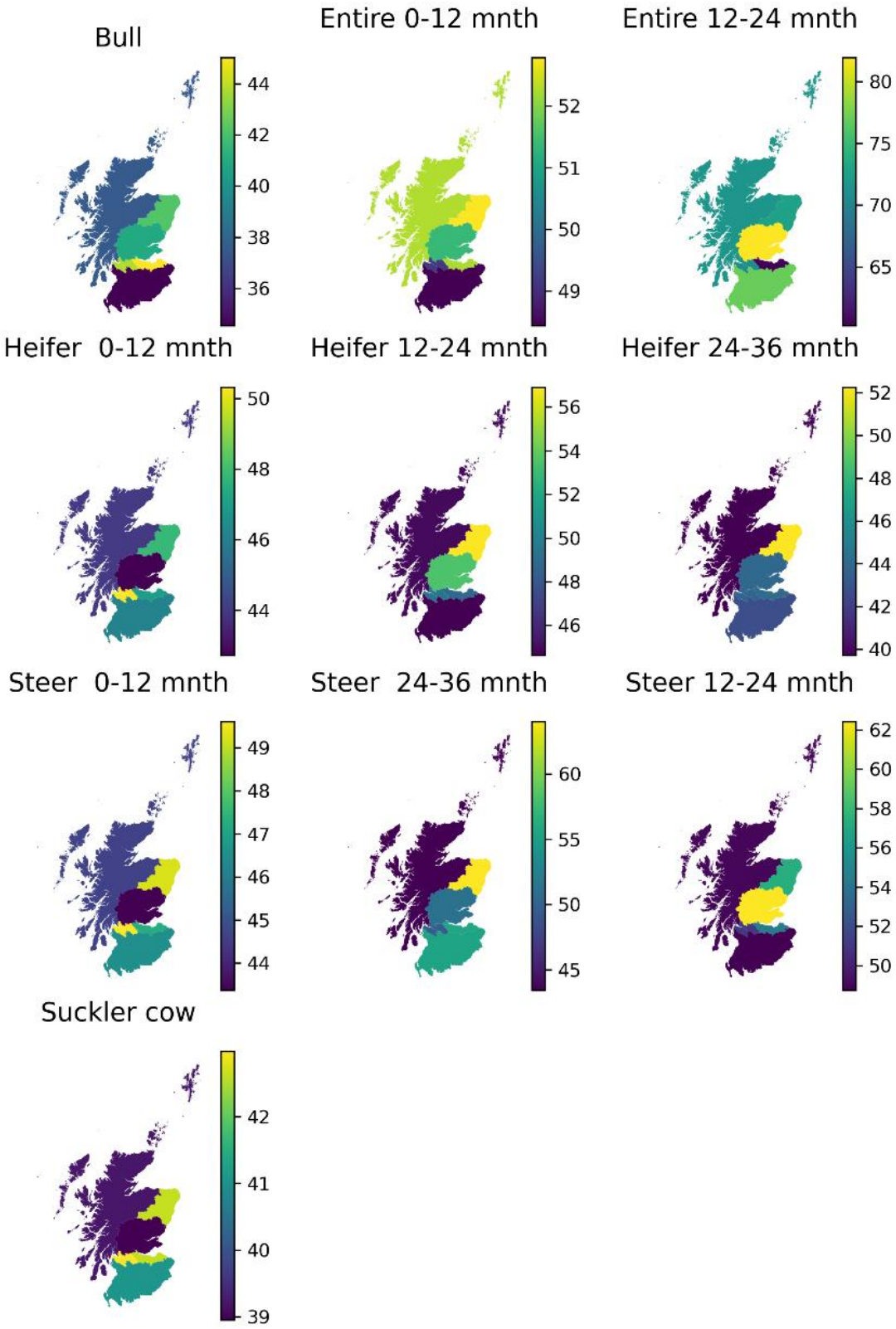


Figure 8: Spatial distribution of the proportion of a year (mean) that beef cattle are housed by Agrecalc beef classification. International Territorial Level 2 2025 boundaries: 'Eastern Scotland', 'East Central Scotland', 'Highlands and Islands', 'West Central Scotland', 'North Eastern Scotland', 'Southern Scotland.

3.3.1 Housing data comparisons

44. For comparison, the national inventory housing assumptions and results from Agrecalc are compiled in Table 11. Following feedback from the SAG experts Table 12 shows a similar table where the 'Yarding' category is distributed proportionally between housed and grazing, so values are more directly comparable**.** In general, the national inventory assumptions on the proportion of time beef cattle are housed in Scotland were greater than the data from Agrecalc suggests. There were notable differences of 12.8% for Beef Bulls and 9.9% for Beef Cows, as well as differences for certain age classes in the non-breeding part of the herd (see Table 12).

Table 11: Comparison of national inventory housing assumptions (blue text) to Agrecalc analysis (red text).

National Inventory Type	Agrecalc Type	Housed %	Grazing %	Yarding %
Bulls for Breeding		50.9	39.8	9.3
	Bull	38.1	61.9	
Cereal Fed Bull		60.1	21.9	18
	Entire 0-12 mnth	50.7	49.3	
	Entire 12-24 mnth	75	25	
Beef Females for Slaughter		50.9	39.8	9.3
Heifers for Breeding		50.9	39.8	9.3
	Heifer 0-12 mnth	45.7	54.3	
	Heifer 12-24 mnth	49.7	50.3	
	Heifer 24-36 mnth	44.5	55.5	
Steers		51.2	39.5	9.4
	Steer 0-12 mnth	46.3	53.7	
	Steer 24-36 mnth	56.6	43.4	
	Steer 12-24 mnth	54	46	
Cows		50.9	39.8	9.3
	Suckler cow	41	59	

Table 12: Comparison of national inventory housing assumptions (blue text) to Agrecalc analysis (red text) when "Yarding" for national inventory types are split proportionally between housing and grazing for ease of comparison.

National Inventory Type	Agrecalc Type	Housed %	Grazing %
Bulls for Breeding		56.1	43.9
	Bull	38.1	61.9
Cereal Fed Bull		73.3	26.7
	Entire 0-12 months	50.7	49.3
	Entire 12-24 months	75	25
Beef Females for Slaughter		56.1	43.9
Heifers for Breeding		56.1	43.9
	Heifer 0-12 months	45.7	54.3
	Heifer 12-24 months	49.7	50.3
	Heifer 24-36 months	44.5	55.5
Steers		56.4	43.6
	Steer 0-12 months	46.3	53.7
	Steer 24-36 months	56.6	43.4
	Steer 12-24 months	54	46
Cows		56.1	43.9
	Suckler cow	41.0	59.0

45. Currently, no animals are allocated to the 'Grazing all year' management regime in the national inventory model (Table 7), whereas the distribution of Agrecalc housing data suggests some animals should fall into this regime (see the 0% housed bin in Table 7), with up to 15% of the Bulls grazing all year. Allocating more animals to 'Grazing all year' in the national inventory would help align housing percentages to the Agrecalc results.

46. The Agrecalc data also offers the option of splitting the "Grazing" category into "Pasture" and "Hill Ground" which could be further utilised to adjust activity energies and grazing diet properties appropriately.

47. The SAG experts did not identify alternative data sources or dispute the Agrecalc proportions, and there was no indication from the group that these proportions would have differed materially over the back-casting period to 1991.

4 Housed diets in Scottish beef cattle systems

4.1 Introduction

48. The animal diet plays a crucial role in performance, affecting productivity and emissions intensity. In terms of direct greenhouse gas emissions, diet composition can affect the energy availability to an animal, and therefore the proportion of total consumed energy which is converted to methane. The nitrogen content and digestibility of the ration affect the amount of nitrogen and volatile solids excreted and thus manure ammonia, nitrous oxide and methane emissions. The embedded GHG emissions associated with the feed can play a role in the Scope 3 emissions[11] of the farm enterprise.

49. Recent preliminary evidence suggests that the methane-inhibiting feed additive 3NOP[12] can cause health problems when fed to cattle with a high sulphur diet (Meehan, 2026[13]). High sulphur concentrations are usually caused by rations with large proportions of brassicas, including rapeseed meal and rapeseed cake. Therefore, rape proportions in the ration will help inform the applicability of 3NOP to the Scottish Beef herd.

50. This section of the report is only concerned with the diet of the animals when they are housed. To account for the diet of housed beef animals, the national inventory utilises seven representative housed diets (called 'Feed composition types') and allocates beef cattle by *role* (beef cow, steer, etc.), *breed* (dairy or beef breed) and *age* (6-9, >12 months). The national inventory analysis only applies to animals over 6 months old.

51. The following lists the range of possible **housed diets** for use in Scottish beef animals within the national inventory model, with the bracket showing the animal role, breed and age groups which have this diet:

    a) **Lowland cows:** (Suckler Cows)
    b) **LFA cows:** (Suckler Cows)
    c) **Store cattle from suckler calves or stores:** (Beef Breed Female for Slaughter 6 to 9 months; Beef Breed Male for Slaughter 6 to 9 months; Beef Breed Cereal Fed Bull from 6 to 9 months.
    d) **Fat cattle from suckler calves or stores:** (Female for Slaughter >9 months; Beef Breed Male for Slaughter >9 months)
    e) **Store cattle from dairy bred calves:** (Dairy Breed Male for Slaughter 6 to 12 months; Dairy Breed Cereal Fed Bull 6 to 9 months)

[11] See Scope 3 Emissions in the UK Reporting Landscape: summary of responses
[12] 3-Nitrooxypropanol (3-NOP), marketed as Bovaer (Methane Inhibitors - Bovaer®)
[13] Meehan, S. (2026, January 26). Trials to start on link between sulphur content in feed, metabolic issues and Bovaer. Agriland. https://www.agriland.ie/farming-news/trials-to-start-on-link-between-sulphur-content-in-feed-metabolic-issues-and-bovaer/

f) **Fat cattle from dairy bred calves:** (Dairy Breed Male for Slaughter >12 month; Beef Breed Cereal Fed Bull >9 months; Dairy Breed Cereal Fed Bull 9 to 12 months).
g) **Other cattle:** (replacement heifers, bulls)

52. Table 13 provides details of the assumed feed composition for the Scottish housed diet of the 7 national inventory feed composition types.

Table 13: The seven housed beef cattle feed composition types used by the national inventory (national inventory) for Scotland by % of total dry matter intake[14]

National Inventory Housed Diets	Feed Composition: (%) of total dry matter intake							
	Conce-ntrate	Grass Silage Bunker	Grass Silage Bale	Maize Silage	Hay	Straw	Whole Crop	Forage roots
Lowland cows	9	28	49	0	13	1	0	0
LFA cows	12	15	40	1	27	3	1	1
Store cattle from suckler calves or stores	27	12	41	1	16	2	0	1
Fat cattle from suckler calves or stores	35	22	26	2	12	3	0	0
Store cattle from dairy-bred calves	30	17	24	2	24	3	0	0
Fat cattle from dairy-bred calves	56	18	14	2	8	1	0	1
Other cattle (replacement heifers, bulls)	29	17	27	1	20	2	2	2

53. The national inventory also makes assumptions regarding the properties of each feed group, Table 14. The individual components of the concentrate (e.g. proportions of barley, molasses) and the quality of grass silage will affect these properties.



Photo: Bull at summer grazing, Gaskbeg farm, Laggan, Highlands (S Thomson)

[14] The concentrate type used varies with animal type.

Table 14: Current feed property assumptions used in the national inventory. Metabolizable Energy (ME), Gorss Energy (GE) and Crude Protein (CP).

Feed group	Subgroup	GE (MJ/kgDM)	ME (MJ/kgDM)	CP (g/kgDM)
Concentrates	Cow Concentrate	18.5	13	163
	Over-Wintering Concentrate	18	12.5	163
	Finishing Concentrate	18	13	140
Conserved Feeds	Grass Silage	18.9	10.6	130
	Maize Silage	18.5	11.2	98
	Hay	18.4	8.8	107
	Straw	18.5	6.5	43
	Whole Crop Silage	19.0	10.5	95
Fresh Grass	Improved Grass	18.8	12	173
	Improved Grass with White Clover	18.9	12.60	203
	Rough Grazing	18.5	9.50	120

4.2 Housed dietary compositions data and analytic methods

4.2.1 Agrecalc data description

54. The primary data source used for this diet analysis was input data from Agrecalc, which collects information on:

- **Home-grown feed:** with an estimated allocation provided to different livestock enterprises made by the user of the tool (i.e. the farmer/consultant). This section draws on allocations to beef cattle. The variables are classed as 'Home-grown feed' in this section has suffix **'_hg'** in figures/tables.
- **Feed bought-in:** with the estimated allocation fed to beef cattle enterprises. Such feed is called 'Bought feed' in this section and has no suffix.

55. It is important to note that within Agrecalc there is no distinction between the diets of beef animal types (e.g. a suckler cow or a steer) within an enterprise, and therefore only the housed diet of each beef enterprise can be determined. Note, these enterprises can include a mix of Argecalc beef types (A) and ages which are:

- Bull
- Entire 0-12 month
- Entire 12-24 month
- Heifer 0-12 month
- Heifer 12-24 month
- Heifer 24-36 month
- Steer 0-12 month
- Steer 12-24 month
- Steer 24-36 month
- Suckler cow.

56. The Agrecalc categorisation of 'beef enterprise types' (self-selected by the farmer / consultant inputting data) is shown in Table 15. The majority of Agrecalc enterprises were either 'Spring calving upland suckler cows' (45%) or 'Spring calving lowland suckler cows' (33%), with a further 10% as 'Spring calving hill suckler cows'.

57. There were 3,559 unique beef enterprises in the dataset. As each entry in the data represents an enterprise for a year, some businesses / enterprises can appear more than once across the years that the data extract covers (2019-2025). In total, the data contained 5,246 beef-enterprise years and 1.18 million cattle years from 2019 to 2025. The analysis maintains the temporal component to investigate any changes through time to help with back-casting.

Table 15: The proportion of Agrecalc enterprises by 'enterprise type' (excludes p of animal counts).

Agrecalc Enterprise Types	Proportion of enterprises (%)
Spring calving upland suckler cows	45.12
Spring calving lowland suckler cows	32.64
Spring calving hill suckler cows	9.58
Finishing of beef bred or continental cross calves	4.68
Autumn calving upland suckler cows	3.64
Finishing of dairy - beef cross calves	2.30
Autumn calving lowland suckler cows	1.92
Intensive finishing of Holstein dairy bred bulls	0.11

58. The full list of the Agrecalc feed types (with author allocated dry matter yield, gross energy, metabolizable energy and crude protein values based on generic lookups[15]) are detailed in Table 38 in Appendix 2. Each feed type was allocated to one of the following feed categories by the authors to provide coherent summarised feed data.

- Concentrate
- Silage
- Maize Silage
- Hay
- Straw
- Whole Crop
- Forage roots
- Additives
- Other (mostly Brassica)

4.2.2 Dietary composition analytic methods

59. For each Agrecalc enterprise type, the average diet of the average animal when it is housed was estimated to determine the dietary composition of Agrecalc enterprises. Since the diet of individual cattle types cannot be determined, the

[15] https://www.feedipedia.org/

distribution of cattle types within each enterprise is presented to help inform diet decisions for individual animal types by the National Inventory team.

- The variable n_i^t denotes the number of beef animal type $t \in A$ (Agrecalc beef types) in report i. The total number of beef animals on farm i is denoted n_i.

60. To account for feed demand differences of Agrecalc animal types, livestock units as defined by the Farm Management Handbook[16] were used to normalise the data. The variable u^t represents the livestock units of Agrecalc animal type t as detailed in Table 16.

- $E = \{e_1, e_2, \dots, e_8\}$ represents the set of enterprise types, and the notation $i \in e_k$ was used to indicate that report i is an enterprise of type k.
- The mean proportion of beef animals of type t on enterprise type e_k was calculated as the mean p_t:

$$p_t = \frac{\sum_{i \in e_k} \frac{n_i^t}{n_i}}{\sum_{i \in e_k} n_i}$$

Table 16: Livestock units used in calculations.

Agrecalc animal type (t)	Livestock unit (u)
Bull	0.65
Entire 0-12 month	0.34
Entire 12-24 month	0.65
Heifer 0-12 month	0.34
Heifer 12-24 month	0.65
Heifer 24-36 month	0.8
Steer 0-12 month	0.34
Steer 24-36 month	0.8
Steer 12-24 month	0.5
Suckler cow	0.75

4.2.2.1 Home grown feed for housed consumption

61. Each Agrecalc report details the amount of home-grown crop that is 'Fed or used for bedding' in fresh mass and the proportion which is allocated to the beef enterprise ('beef crop use'). From this, the total dry mass (using dry matter yield information in Table 38 in Appendix 2) of each home-grown crop allocated to beef animals is derived.

[16] Beatie, A (Ed) The Farm Management Handbook 2024/2025. SAC Consulting. Farm Management Handbook 2024/25 | Information helping farmers in Scotland | Farm Advisory Service

- The variable m_i^h denotes the dry mass (t) of home-grown crop h in Agrecalc report i allocated to beef animals and H represents the set of home-grown feeds. This value includes any crops used for bedding. It is assumed 80% of homegrown straw is used for bedding and the remaining 20% is used for feed.

62. Key assumptions used include:

- Some Agrecalc home-grown crops were deemed to be forage crops (not eaten while housed) and were excluded from the analysis. As such 'Forage rye - Forage_hg', 'Kale /stubble turnips/ swedes - Forage_hg', 'Legume forages (clovers, lucerne) (all) - Forage_hg', 'Fodder beet - Forage_hg', 'Grass - grazing' do not appear in Table 38.
- It was assumed that all silage is fed indoors rather than outdoors as supplementary feed to grazing animals.
- Home-grown feed was detailed for an entire Agrecalc report, even though one report can be made up of several beef enterprise types. Although multi-beef enterprise reports make up only 1% of reports, homegrown feed was allocated to each enterprise on a livestock unit basis.

4.2.2.2 Bought feed for housed consumption

63. Similarly to home-grown feed, Agrecalc reports detail the amount of feed bought in for the enterprise in fresh mass and the dry matter yields detailed in Table 38 (Appendix 2) were used to convert to dry mass.

- The variable m_i^b denotes the dry mass (t) of bought feed b in report i and B denotes the set of all bought feeds.

64. Unlike home-grown feed, bought straw for bedding is accounted for in another Agrecalc input table, so all bought straw listed is used for feed. Additionally, bought-feed is listed for each enterprise, so no allocation for multi-enterprise reports is required. All bought feeds are assumed to be eaten indoors, even those that are listed as 'fodder crops'.

4.2.2.3 Average diet calculations

65. When it is not important whether cattle feed consumed during housing periods is home-grown or bought, index j is used representing all feed types.

- The total dry mass of feed (t) used for feeding housed beef animals in enterprise i was calculated as:

$$m_i = \sum_{j \in F} m_i^j,$$

- where F is the set of *all* feeds i.e. $F = H \cup B$.
- The total number of livestock units in report i was calculated as:

$$u_i = \sum_{t \in A} u^t \, n_i^t,$$

- where A is the set of Agrecalc cattle types.
- To calculate the mean dry mass intake per livestock unit of housed feed type j over reports in enterprise e_k the livestock unit weighted mean was calculated as:

$$\overline{m_{e_k}^J} = \frac{\sum_{i \in e_k} m_i^j}{\sum_{i \in e_k} u_i}$$

- which provides tonnes (t) of dry mass per livestock unit per year.
- The mean *proportion* of feed type j (indexing all feeds) used on enterprise e_k was calculated as the livestock unit weighted mean:

$$\overline{p_{e_k}^J} = \frac{\sum_{i \in e_k} \frac{m_i^j}{m_i} u_i}{\sum_{i \in e_k} u_i}.$$

4.2.3 Concentrate feed properties

66. By using assumptions about the properties of concentrate feed types (see Table 38) it was possible to determine the average properties of the typical "concentrate" used in beef enterprises in Scotland.

67. The same approach is not applied to the silage or hay feed groups because results would depend on author-defined assumptions on silage quality, which would not capture the variation in silage properties across Scotland. For future improvement to the national inventory model, it is recommended that silage analysis be used to define the properties 'Grass silage – average', 'good' and 'poor', and the Agrecalc dataset used here can determine the amount of each class and average silage quality.

68. The variables GE^j, ME^j (MJ kgDM^{-1}) and CP^j (kgCP kgDM^{-1}) denote the gross energy, metabolizable energy and crude protein of the feed type $j \in F$ which can be seen in Table 38. The gross energy of concentrate feed used in report i is calculated as the dry mass weighted average of concentrate feeds

$$GE_i = \frac{\sum_{j \in C} GE^j \, m_i^j}{\sum_{j \in C} m_i^j},$$

- where $C \subset F$ is the set of feeds which are categorised as concentrate shown in Table 38.
- ME^j and CP^j are calculated similarly.

69. The average gross energy of concentrate used in enterprise type e_k is then calculated as the livestock-unit weighted mean of all reports belonging to that enterprise group

$$\overline{GE}_{e_k} = \frac{\sum_{i \in e_k} GE_i u_i}{\sum_{i \in e_k} u_i},$$

- where u_i is the number of livestock units in report i.
- $\overline{ME}_{e_k}$ and $\overline{CP}_{e_k}$ are calculated similarly.

4.2.4 Conserved feed properties

70. Conserved feed (hay and silage) properties were determined from laboratory analysis of samples processed by SAC Consulting. The samples included all samples of conserved feed used in Scotland, and were not specific to conserved feed properties used for beef cattle systems. Samples collected for 2024 and 2025 were used to determine average properties, reducing the influence of year-to-year variation on the results. Data came from 1,022 grass silage samples of varying cuts and around 50 wholecrop silage samples (cereal not determined).

4.3 Housed dietary composition results

4.3.1 Beef enterprise cattle mixes

71. The proportion of animal types on each enterprise can help infer the diet classifications from Agrecalc enterprises. Figure 9 shows that the majority of suckler herds (i.e. 'Spring calving upland suckler cows', 'Spring calving lowland suckler cows', 'Spring calving hill suckler cows', 'Autumn calving upland suckler cows', 'Autumn calving lowland suckler cows') are largely made up of suckler cows and calves aged 0-12 months old. However, on average, enterprises contain a mix of animals across 'beef types'. Autumn calving enterprises tended to have more 12-24 month steers and heifers than their spring counterparts. Unsurprisingly, the finishing enterprise types had very different animal type profiles with very few breeding animals.

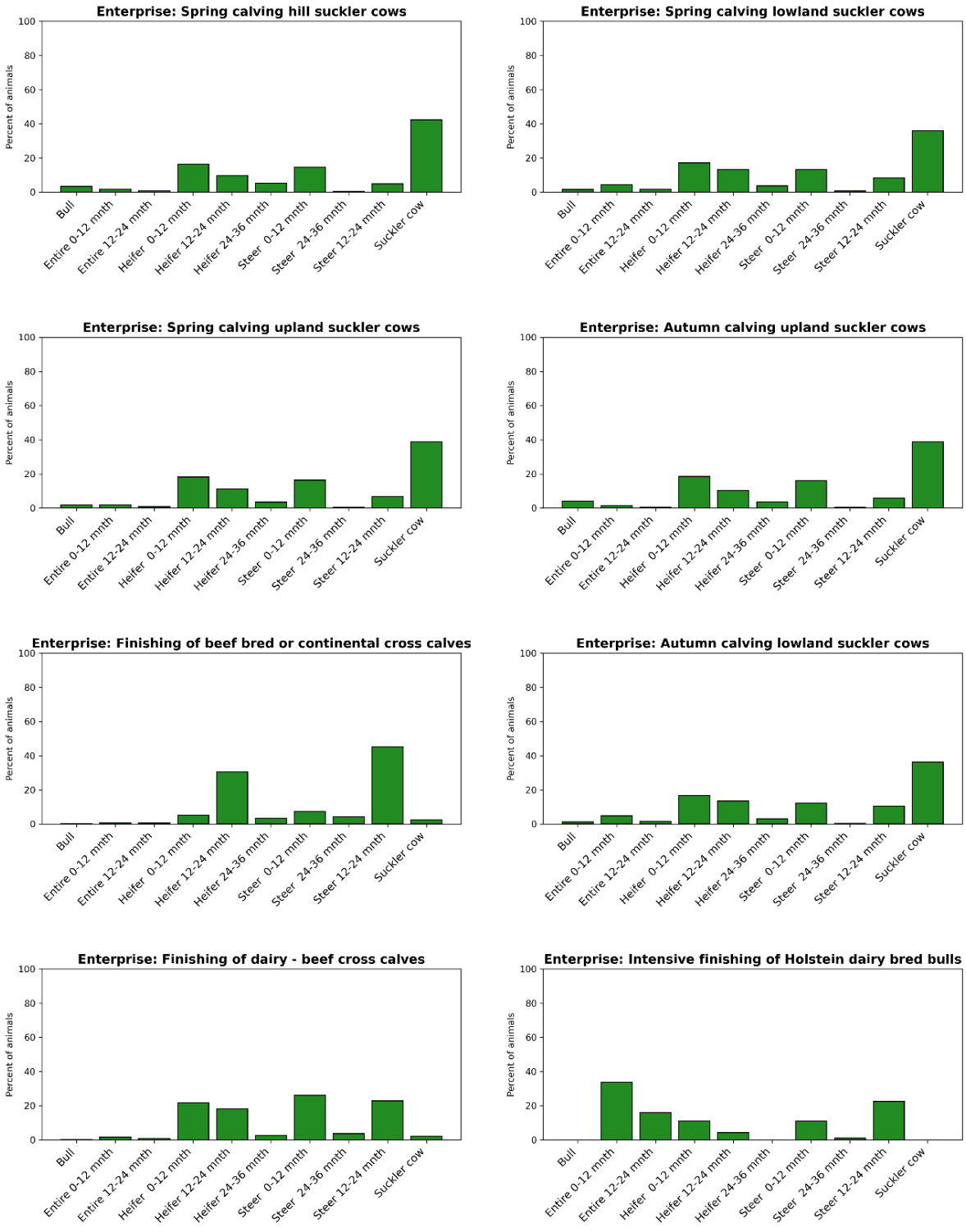


Figure 9: Agrecalc 'beef types' composition within 'enterprise types' (proportion of total head count)

4.3.2 Beef Enterprise Diets

72. Figure 10 (with granular detail shown in Appendix 3) shows the housed dietary mix for each Agrecalc enterprise type by grouped feed type. These figures

represent the proportion of dry matter intake for housed animals and do not account for their dietary intake when they are not housed.

73. The granular dietary data (Appendix 3) shows that the majority of feed was home-grown silage across all enterprise types. However, due to the large number of feed types, it is difficult to see differences between enterprise types.

74. Finishing enterprises had greater use of concentrates than suckler enterprises (see Figure 10). Amongst the finishing enterprises, finishing of dairy-beef used the lowest amount of concentrates at 45% (closer to lowland sucklers), while other finishing enterprise diets were around 60%, on average. Autumn calving lowland/upland suckler cow enterprises had very similar diets to their Spring counterparts, and it would appear unnecessary to distinguish these animals for housed diet assumptions. Spring calving hill suckler enterprises used the most hay in their housed diet (see Figure 10). In reality, some of this hay will be fed outdoors, but the analysis cannot distinguish between hay or silage that is fed indoors or outdoors.

75. Spring lowland, upland and hill suckler cow enterprises were the best-represented enterprises in the Agrecalc data, with other enterprise types making up less than 5% of the dataset or less than 262 enterprise-years or 177 enterprises (i.e. 177 unique enterprises, but some have had multiple carbon audits completed).



Photo: Winter feeding of suckler cattle (and sheep), Drumgask farm, Laggan, Highlands (Rory Richardson)

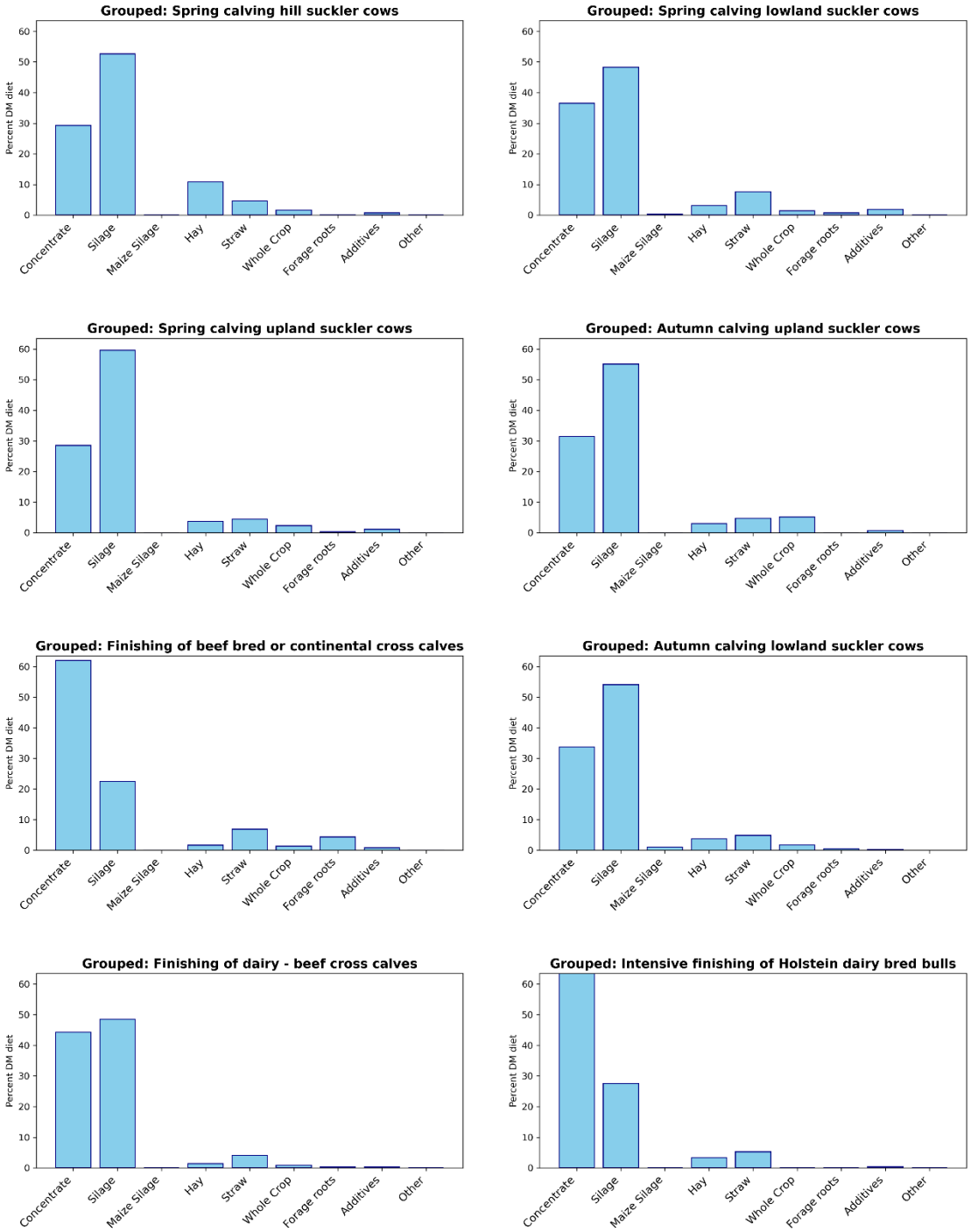


Figure 10 Average housed dietary mix of beef animals within Agrecalc enterprise types, by broad feed groups

4.3.3 Dietary composition data comparisons

76. The results of the Agrecalc analysis were compared with housed dietary recommendations extracted from the Farm Management Handbook (FMH)[17] to provide a practical benchmark and reality check for the calculated feed rations. Table 17 shows that the Agrecalc housed total dry matter intake per livestock unit overestimated the FMH recommendations for Spring calving suckler herds by approximately 30% (see column '% Difference (t DM/LU)'). It overestimated Autumn calving lowland suckler herds by 53%, while agreeing with Autumn calving upland suckler herds (-2%). Differences in suckler herds may be due to the addition of the calf livestock unit (0.34 for <12 months animals) when converting from head of cattle to livestock unit from the FMH recommendations that did not fully capture the feed demand of the calf assumed in the FMH scenarios.

77. Within finishing enterprises, total dry matter intake had relatively small differences except for Finishing of dairy - beef cross calves, where the Agrecalc data was underestimated by -33%.

78. In general, the Agrecalc data overestimated the proportion of the feed that was concentrate, except for Finishing of dairy - beef cross calves and Autumn calving lowland suckler cows, Table 17. Here, 'head' was converted to LU in FMH data using fixed values from Table 16. For example, for suckler enterprises, the FMH reports diets for a cow and calf (0.75+0.34). The FMH recommendations report "Winter days" for suckler herds and "Feeding period" for finishing herds, where it is unclear if these can/should be interpreted as "Housed days" in comparison to Agrecalc data analysis.

79. Differences between Agrecalc and FMH data may arise due to:

- The FMH dietary recommendations for enterprises may not fully account for the wide range of animal types that are present in the Agrecalc enterprise types (shown in Figure 9) such as steers > 1 year old present within suckler cow systems. Further, the FMH has high-performance assumptions that do not account for inefficiencies that are observable through analysis of livestock registration and movement data[18].
- The FMH does not account for the number of days that animals are housed for their assumed diet. Instead, it makes recommendations for all 'feeding days' (e.g. 210 days for hill suckler cows with calf). However, in the Agrecalc analysis, the dietary mix is estimated for LU-Weighted Mean Mass per housed day (t DM/LU/day) column in Table 17, where a 'housed day' was calculated from the Agrecalc housing data (see Section 3). In the

[17] Farm Management Handbook 2025/26 | Information helping farmers in Scotland | Farm Advisory Service

[18] e.g. see SRUC_Report_Structure_and_Efficiency_of_the_Scottish_Beef_Herd_CTS_FINAL.pdf

Agrecalc analysis, the daily housed dry matter intake varied between 15kg and 20 kg per livestock unit. Suckler cow enterprises generally had higher dry matter intakes due, in part, to the relatively high proportion of calves on suckler herds which have a livestock unit of 0.34.

- The FMH are recommendations, whilst the Agrecalc data was based on reported use from industry. Agrecalc uses self-reported data, and estimated allocations to different enterprises can have embedded inaccuracies: for example, many feed amount estimates appear rounded.
- Dry matter yield estimates used for this analysis (Table 38 in Appendix 2) do not capture the variance in feed quality across Scotland, particularly for silages where dry matter yields can vary by 100%.
- Assuming 20% of home-grown straw being utilised as feed in the Agrecalc data may be an underestimate.

80. Table 18 shows the current proportion of concentrate in the national inventory housed diets and comparative enterprises in the current analysis. **Due to differences in analysis and inventory categories, and limitations discussed above, it is not recommended that this be used as a one-for-one replacement in the national inventory.** However, this analysis and the FMH recommendations may be used to inform changes to current assumptions.



Photo: Suckler cow grazing in the Pentland Hills, Midlothian (S Thomson)

Table 17: Comparison of the Agrecalc data analysis to all winter feeding diets recommended in the Farm Management Handbook (FMH). 'Forage' refers to all feed items which are not concentrates.

Enterprise Type	Feed group	Agrecalc Housed Diet				FMH Feeding recommendations				Comparison
		LU-Weighted Mean Proportion of diet	LU-Weighted Mean Mass (t DM/LU/year)	Percent of year housed	LU-Weighted Mean Mass per housed day (kg DM/LU/day)	FMH (t DM/ head)	% FMH diet	FMHB (t DM/LU /year)	% "Winter days" or "Feeding period"	% Difference (t DM/LU/year)
Spring calving hill suckler cows	**Total**		**1.67**	**23%**	**20.36 kg**	**1.44**		**1.32**	**61%**	**27%**
	Concentrate	*29.2%*	0.50	*(82 days)*	6.11 kg	*0.09*	6%	**0.08**	*(220 days)*	492%
	Forage	*70.8%*	1.17		14.25 kg	*1.35*	94%	**1.24**		-5%
Spring calving lowland suckler cows	**Total**		**2.63**	**44%**	**16.28 kg**	**2.18**		**2.00**	**49%**	**32%**
	Concentrate	*36.5%*	1.01	*(162 days)*	6.24 kg	*0.53*	24%	0.49	*(180 days)*	98%
	Forage	*63.5%*	1.62		10.03 kg	*1.65*	76%	1.51		10%
Spring calving upland suckler cows	**Total**	100.0%	**2.42**	**45%**	**14.87 kg**	**2.03**		**1.86**	**49%**	**30%**
	Concentrate	*28.5%*	0.72	*(163 days)*	4.41 kg	*0.17*	8%	0.16	*(180 days)*	342%
	Forage	*71.5%*	1.70		10.47 kg	*1.86*	92%	1.71		1%
Autumn calving upland suckler cows	**Total**		**2.38**	**42%**	**15.60 kg**	**2.64**		**2.42**	**55%**	**-2%**
	Concentrate	*31.5%*	0.77	*(153 days)*	5.02 kg	*0.47*	18%	0.43	(200 days)	74%
	Forage	*68.5%*	1.62		10.58 kg	*2.17*	82%	1.99		-18%
Autumn calving lowland suckler cows	**Total**		**3.34**	**46%**	**20.02 kg**	**2.38**		**2.18**	**55%**	**53%**
	Concentrate	*33.7%*	1.13	*(167 days)*	6.81 kg	*1.28*	35%	1.17	*(200 days)*	-4%
	Forage	*66.3%*	2.20		13.21 kg	*1.11*	66%	1.02		117%
Finishing of beef bred or continental cross calves	**Total**		**4.16**	**69%**	**18.71 kg**	**1.72**		**5.06**	**49%**	**-18%**
	Concentrate	*62.0%*	2.62	*(222 days)*	11.78 kg	*0.6*	54%	1.76	*(180 days)*	46%
	Forage	*38.0%*	1.54		6.93 kg	*1.13*	47%	3.32		-52%
Finishing of dairy - beef cross calves	**Total**		**3.41**	**58%**	**16.14 kg**	**1.72**		**5.06**	**93%**	**-33%**
	Concentrate	*44.4%*	1.52	*(211 days)*	7.21 kg	*0.6*	35%	1.76	*(340 days)*	-14%
	Forage	*55.6%*	1.88		8.92 kg	*1.13*	66%	3.32		-43%
Intensive finishing of Holstein dairy bred bulls	**Total**		**3.90**	**65%**	**16.39 kg**	**2.17**		**3.34**	**68%**	**17%**
	Concentrate	*63.5%*	2.49	*(238 days)*	10.48 kg	*1.83*	84%	2.82	*(247 days)*	-12%
	Forage	*36.5%*	1.41		5.91 kg	*0.34*	16%	0.52		172%

Table 18: Current national inventory (NI) assumptions regarding percent housed concentrate percentage and an indicative comparison to the current analysis by matching enterprise results to NI housed diets.

NI Housed diets	Animal Roles Assigned diet	Current NI Concentrate	Comparison concentrate
Lowland cows	Cow	9%	36.5% (*Spring calving lowland suckler cows*)
LFA cows	Cow	12%	29.2% (*Spring calving hill suckler cows*)
Store cattle from suckler calves or stores	Beef Breed Female for Slaughter (from 6 to 9 months); Beef Breed Male for Slaughter (from 6 to 9 months); Beef Breed Cereal Fed Bull (from 6 to 9 months)	27%	36.5% (*Spring calving lowland suckler cows*)
Fat cattle from suckler calves or stores	Female for Slaughter (from 9 months); Beef Breed Male for Slaughter (from 9 Months)	35%	62.0% (*Finishing of beef bred or continental cross calves*)
Store cattle from dairy-bred calves	Dairy Breed Male for Slaughter (from 6 to 12 months); Dairy Breed Cereal Fed Bull (from 6 to 9 months)	30%	36.5% (*Spring calving lowland suckler cows*)
Fat cattle from dairy-bred calves	Dairy Breed Male for Slaughter (from 12 months); Beef Breed Cereal Fed Bull (from 9 months); Dairy Breed Cereal Fed Bull (from 9 to 12 months)	56%	44.4% (*Finishing of dairy - beef cross calves*)
Other cattle (replacement heifers, bulls)	Heifers for Breeding; Bulls for Breeding	29%	36.5% (*Spring calving lowland suckler cows*)

4.3.4 Concentrate feed properties results

81. Table 19 shows summary statistics of concentrate feed properties and Figure 11, Figure 12amd Figure 13 show the distribution of gross energy, metabolizable energy and crude protein in concentrates respectively. Results are dependent on the author-defined feed properties for each item shown in Table 38 (in Appendix 2) which could be further refined to be more relevant to the Scottish context.

82. Mean GE is consistently approximately 18.6 MJ $kgDM^{-1}$ across all enterprise types, Table 19 and distributions are unimodal with low spread. This was slightly higher than current national inventory assumptions, which assumes either 18 or 18.5 MJ $kgDM^{-1}$, depending on animal type Table 14. **Based on the results we recommend that GE is 18.5 for all animals.**

83. Concentrate ME is less consistent across enterprise types with finishing enterprises having higher values, Table 19. Distributions are also more spread with some enterprises showing bimodality, Figure 12. The current national inventory assumes ME is between 12.5 and 13 MJ $kgDM^{-1}$ depending on animal, Table 14 which is consistent with current analysis. Further categories could be introduced to capture deviation within beef system.

84. Concentrate CP shows large variations across and within enterprise types, with some enterprises showing several modes, Table 19 and Figure 13. Current NI assumptions of CP are between 0.14 and 0.163 kg $kgDM^{-1}$, depending on the type of animal (see Table 14). **Current analysis suggests that the top value could be reduced to approximately 0.156 $kgDM^{-1}$ (see Table 19).**

Table 19: Summary statistic of concentrate gross energy (GE, MJ $kgDM^{-1}$) metabolizable energy (ME, MJ $kgDM^{-1}$) and crude protein (CP kg $kgDM^{-1}$).

Enterprise type	Enterprises	Livestock units	ME mean	ME std	GE mean	GE std	CP mean	CP std
Autumn calving lowland suckler cows	100	11,487	12.73	0.51	18.58	0.27	0.143	0.026
Autumn calving upland suckler cows	166	20,813	12.63	0.47	18.63	0.26	0.146	0.025
Finishing of beef bred or continental cross calves	604	75,520	12.98	0.39	18.58	0.29	0.135	0.035
Finishing of dairy - beef cross calves	183	19,178	12.79	0.55	18.61	0.29	0.152	0.029
Intensive finishing of Holstein dairy bred bulls	10	1,037	13.17	0.09	18.75	0.43	0.150	0.052
Spring calving hill suckler cows	553	34,004	12.30	0.49	18.57	0.26	0.156	0.027
Spring calving lowland suckler cows	1,534	243,068	12.81	0.48	18.60	0.33	0.142	0.027
Spring calving upland suckler cows	2,211	297,384	12.68	0.49	18.60	0.29	0.145	0.028

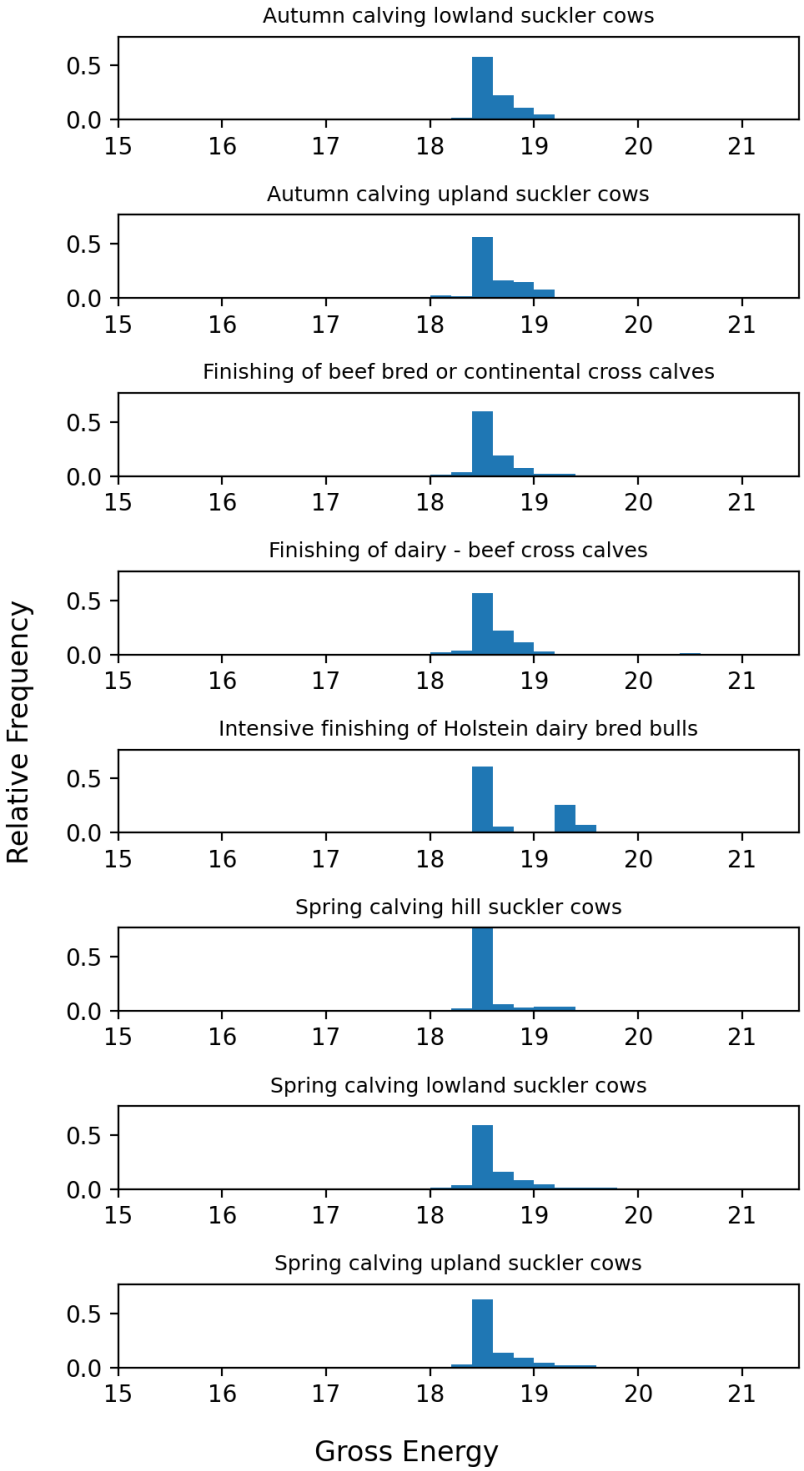


Figure 11: Distributions of Concentrate Gross energy (MJ kgDM^{-1}) of each Agrecalc enterprise type

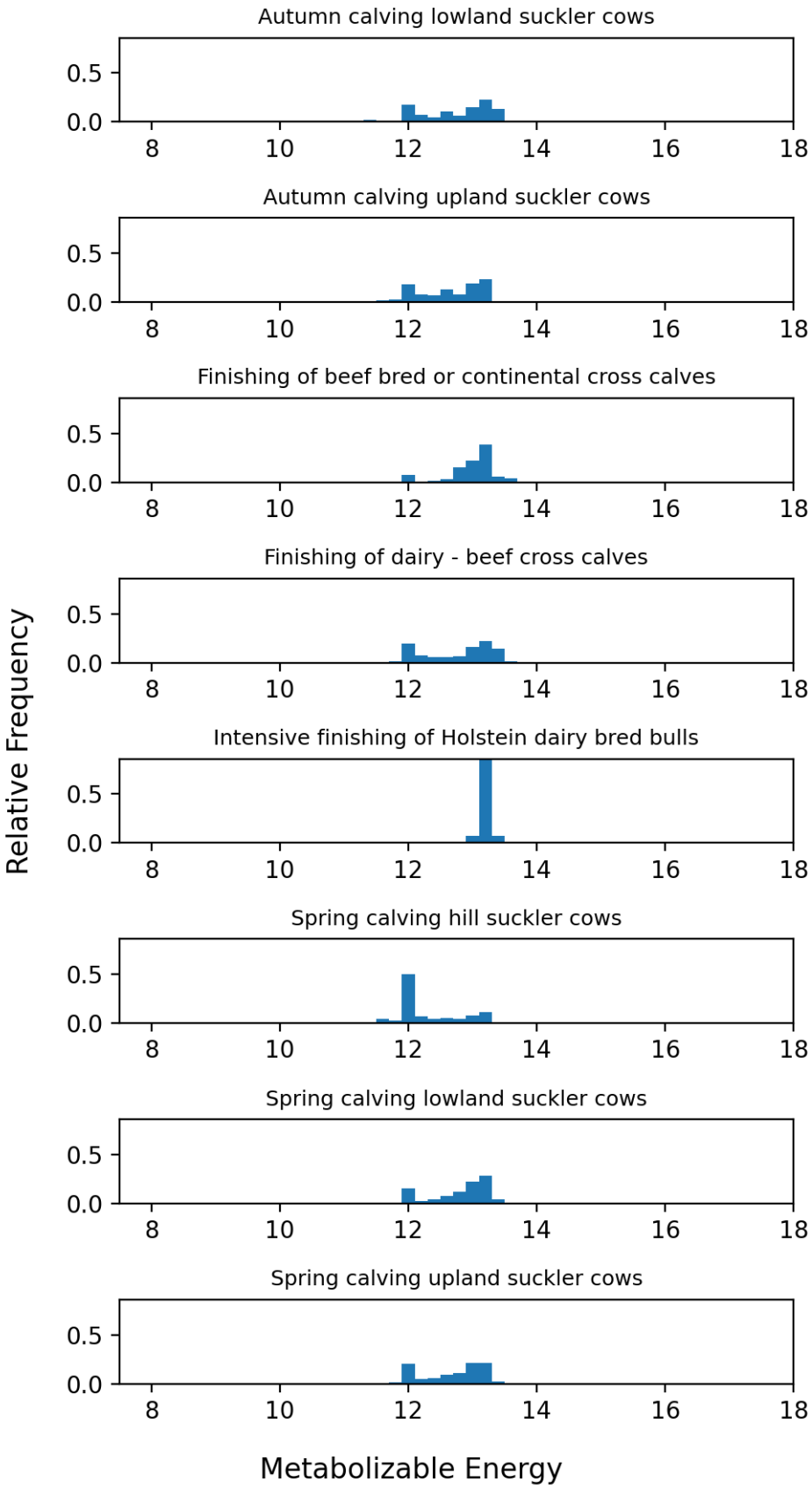


Figure 12: Distributions of Metabolizable energy (MJ kgDM^{-1}) of each Agrecalc enterprise type

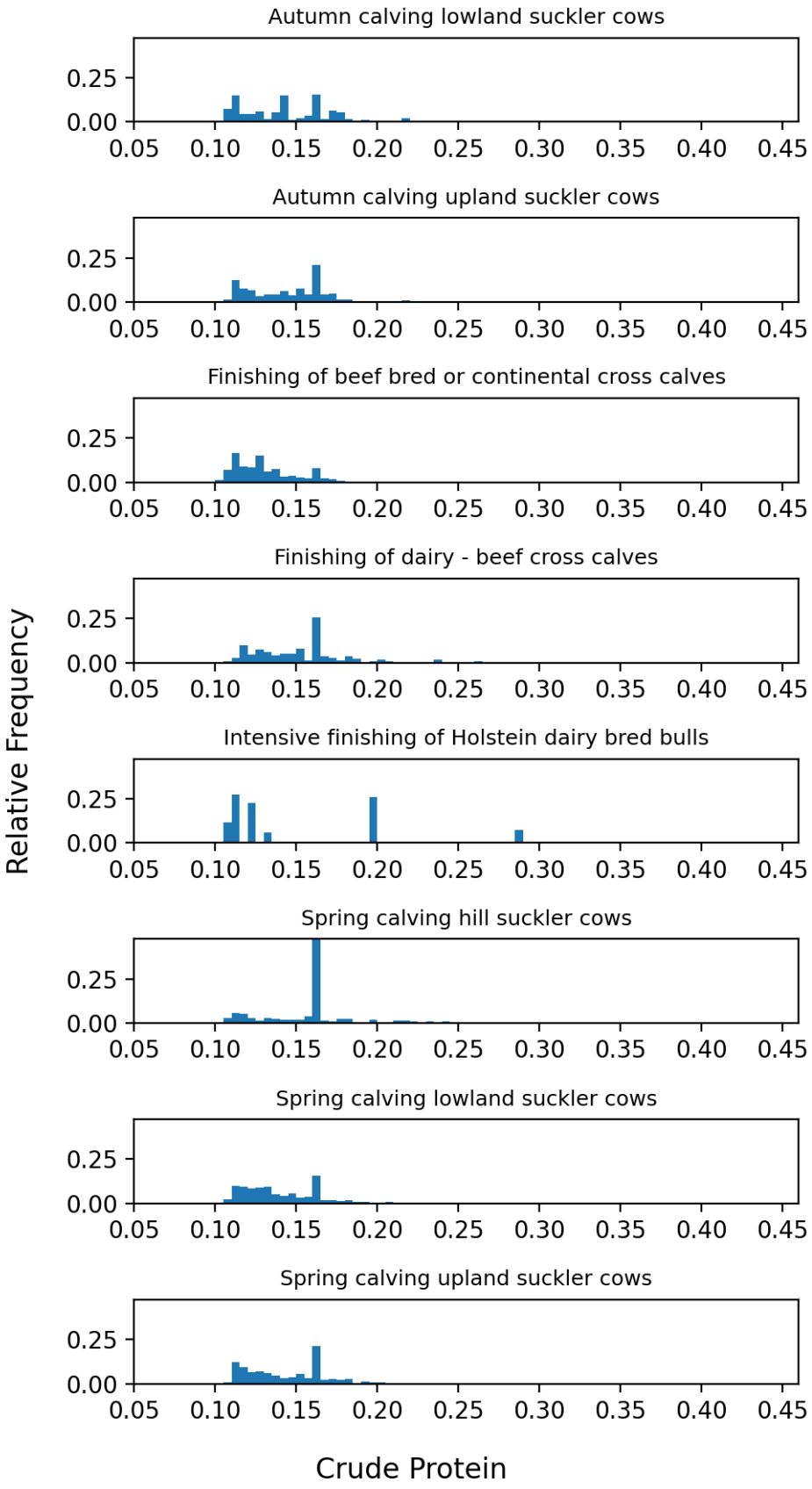


Figure 13: Distributions of Crude Protein (g protien kgDM^{-1}) of each Agrecalc enterprise type

4.3.5 Conserved feed properties results

85. Lab analysis averages of conserved feed (silage and hay) properties and how they compare to current NI assumptions can be seen in Table 20. GE was lower for all conserved feed types in the current analysis. ME was higher in the current analysis for maize silage and hay, but lower for grass silage and whole crop silage. CP was lower for all crops but Whole Crop Silage in the current analysis.

86. These results (Table 20) can be used to update NI assumptions for Scotland.

Table 20: Results of conserved feed properties ('Results') compared to assumptions used in national inventory (NI). Metabolizable Energy (ME), Gross Energy (GE) and Crude Protein (CP).

Conserved feed type	GE (MJ/kgDM)		ME (MJ/kgDM)		CP (g/kgDM)	
	NI	Results	NI	Results	NI	Results
Grass Silage	18.9	17.0	10.6	10.4	130	122
Maize Silage	18.5	18.5	11.2	11.4	98	90
Hay	18.4	16.0	8.8	9	107	90
Straw	18.5	15.7	6.5	6.5	43	43
Whole Crop Silage	19.0	16.9	10.5	9.9	95	105



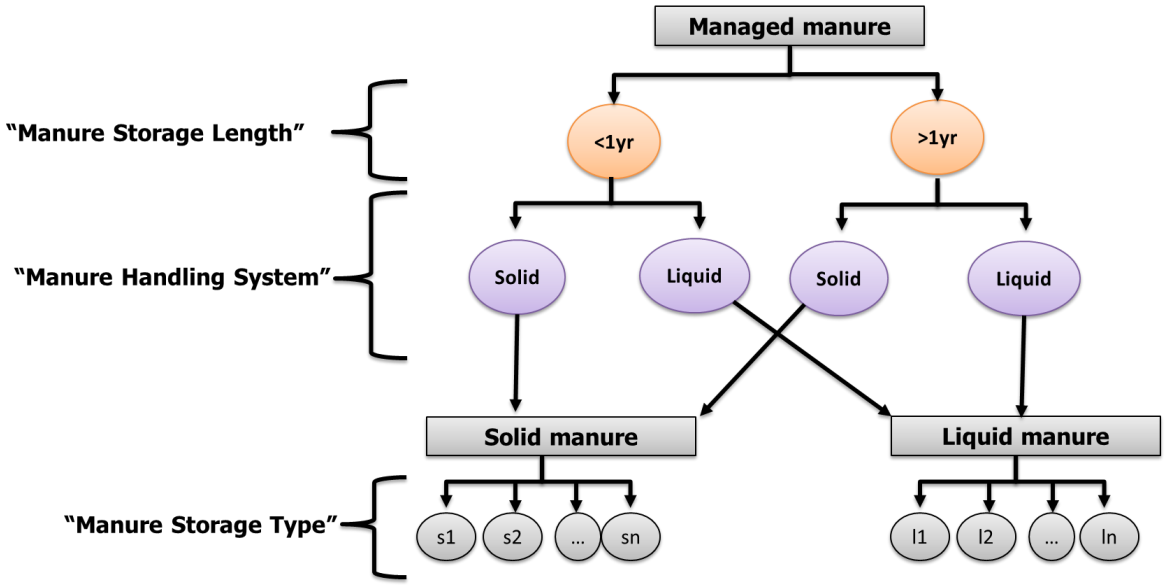
Photo: Suckler cows in summer sun above Edinburgh (S Thomson)

5 Manure handling systems in Scottish beef cattle systems

5.1 Introduction

87. Within the national inventory model, manure emissions from housed livestock require assumptions on "length of time stored", whether it is in "liquid" (i.e. slurry) or "solid" (i.e. farmyard manure), state, and the "type of storage" utilised (see Figure 14).

Figure 14 Illustration of factors that affect manure emissions from housed cattle within the national inventory model



88. Manure handling systems are classified as either liquid (slurry) or solid (farmyard manure). This is an important factor for methane, ammonia and nitrous oxide emissions in national inventories. For example, the anaerobic conditions of liquid systems favour the decomposition of organic matter into methane rather than carbon dioxide, resulting in methane emissions from liquid systems being 8.5 times (or more) than those from solid systems in typical inventory models[19].

89. The national inventory currently assumes that beef animals less than a year old have 100% of their **managed manure**[20] stored as farmyard manure, while animals older than a year have 30% of their managed manure stored as solid, with the rest liquid. This ratio has been used since 1996. SAG members expressed a view that some proportion of calf manure was likely to be in the form of liquid, if calves have access to, for example, cubicle sheds, where slurry is scraped into

[19] Gavrilova et al., (2019). Chapter 10: Emissions from Livestock and Manure Management 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol. 4, IPCC (2019), pp. 1-2009

[20] Note that in field deposits by grazing animals are not accounted for here

tanks (also noting that in housed periods, a proportion of calves and cows may also have access to paddocks during the day for feeding).

5.2 Manure handling data and analytic methods

5.2.1 Scottish Government data description

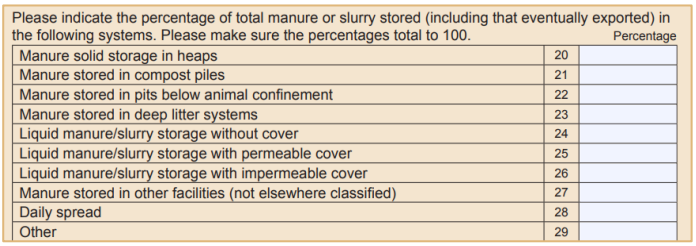
90. The primary data source used was the 2023 June Agricultural Census (JAC), which had a special module on manure management[21], as shown in Table 26. These entries refer to the proportion of managed manure stored by each storage type on each holding/main location code (rather than sub-holding enterprise types). This makes it hard to directly disaggregate the manure management systems to beef animals from other cattle manure stored on the same farm (i.e. if dairy cows are present), or between different beef enterprise types, if present.

Table 21: June Agricultural Census variables used in analysis

Storage Type	Unit	Liquid/Solid
Manure solid storage in heaps	%	Solid
Manure stored in compost piles	%	Solid
Manure stored in pits below animal confinement	%	Liquid
Manure stored in deep litter systems	%	Solid
Manure stored in other facilities (not classed elsewhere)	%	Solid
Daily spread	%	Liquid
Liquid manure/slurry storage without cover	%	Liquid
Liquid manure/slurry storage with permeable cover	%	Liquid
Liquid manure/slurry storage with impermeable cover	%	Liquid
Other	%	N/A

91. The 2023 JAC contained data for 57,325 agricultural holdings. The JAC collects data on 'Female beef cattle under 1 yr' and 'Male cattle under 1 yr', which are defined in this analysis as beef cattle under 1 year. All other JAC classifications of beef cattle over 1-year-old aligned with national inventory classifications. Since the 'Male cattle under 1 yr' JAC classification was ambiguous on whether they were beef or dairy cattle, the analysis only included enterprises which have more than 10 beef animals in the analysis (noting that whilst most dairy-born male calves are destined for beef production, they are managed differently from suckler-born beef calves). Using this filter left 8,223 holdings/main location codes, of which 3,305 were removed

Figure 15 JAC 2023 manure handling question



Please indicate the percentage of total manure or slurry stored (including that eventually exported) in the following systems. Please make sure the percentages total to 100.

		Percentage
Manure solid storage in heaps	20	
Manure stored in compost piles	21	
Manure stored in pits below animal confinement	22	
Manure stored in deep litter systems	23	
Liquid manure/slurry storage without cover	24	
Liquid manure/slurry storage with permeable cover	25	
Liquid manure/slurry storage with impermeable cover	26	
Manure stored in other facilities (not elsewhere classified)	27	
Daily spread	28	
Other	29	

[21] The form is available here: June Agricultural Census Form 2024 - Interactive - Scottish Agricultural Census - News, guidance and sample forms - gov.scot

since they did not complete the manure module of the JAC. A further 49 enterprises were removed since they reported >100% total manure storage, and a further 1,279 were removed since they reported no liquid or solid storage ('Other' in Table 21), leaving 3,590 holdings/main location codes to analyse.

5.2.2 Agrecalc data description

92. Agrecalc data contained information on beef enterprises' manure handling systems between 2019 and 2025. Unlike the JAC data, the animals were classified by groups (either beef or dairy), so no filtering based on the number of animals was required. The data had five different classifications of manure storage, grouped as either solid or liquid, as shown in Table 27. Additionally, unlike the JAC data, the Agrecalc data had manure storage information per cattle type, rather than per enterprise. However, the extent to which farmers differentiate between cattle types should be investigated (i.e. intra-enterprise variability). Agrecalc data animals classified as 'Entire 0-12 month', 'Heifer 0-12 month', 'Steer 0-12 month' were classed younger than 1 year, and all other animal classifications were considered older than 1 year.

Table 22: Agrecalc manure storage type

Storage Type	Unit	Liquid/Solid
Liquid Slurry	%	Liquid
Solid Storage (FYM)	%	Solid
Pit Storage (Slats)	%	Liquid
Deep bedding (retained > 1yr)	%	Solid
Anaerobic digestion	%	Solid

93. The Agrecalc data extract started with 5,246 enterprise years. Two enterprise-years were dropped since the managed manure percentage did not sum to 100%. A further 414 enterprise-years were dropped as they had no recorded managed manure (perhaps suggesting no-housed systems, for example, for Galloways, or Highlanders kept on hills all year round), leaving 4,830 enterprise-years for analysis.

5.2.3 Manure handling systems analytic methods

94. The analysis followed the following processes:

- Let $n_i^{>}$ and $n_i^{<}$ be the number of beef animals greater than and less than one year old on holding/enterprise i that stores at least some manure, respectively.
- Let l_i be the percentage of manure stored as liquid on holding/enterprise i as defined by Table 26 in the JAC data and Table 27 in the Agrecalc data extracts, respectively.
- The average quantity of manure stored as liquid for beef animals greater than 1 year was calculated as:

$$l^{>} = \sum_{i=0}^{N} \frac{n_i^{>} l_i}{\sum_{k=0}^{N} n_k^{>}(l)},$$

- The corresponding weighted standard deviation was calculated as

$$\sigma_{l,>}^2 = \sum_{i=1}^{N} \frac{n_i^{>}(l_i - l^{>})}{\sum_{k=0}^{N} n_k^{>}}$$

- where $N = 3{,}590$ is the number of enterprises in the JAC and $N = 4{,}830$ enterprise-years in the Agrecalc data.
- Since the Agrecalc data had manure entries per animal type $l_i = l_i^{>}$ in the sums above for calculations using Agrecalc data. $l^{<}, s^{<}$ and $s^{>}$ were calculated similarly. These calculations ensure that $l^{>} + s^{>} = 100$ and $\sigma_{l,>} = \sigma_{s,>}$ in each data source.

95. For the JAC data analysis, the approach provides the average manure handling system of each holding, weighted by the proportion of the selected beef groups on that holding. Importantly, this misses any manure management differences between distinct beef enterprise groups within a holding. For example, using this approach, the analysis may not reveal if calves have their manure managed as farmyard manure (e.g. they have access to straw bedding areas) compared to older animals within an enterprise. This gap is not present in the analysis of the Agrecalc data, where intra-enterprise variation was measured.

5.3 Manure handling results

96. The results of the analysis of the Agrecalc and JAC data compared to the national inventory modelled assumptions can be seen in Table 23. The JAC results suggest that a higher proportion of younger animals (on all holdings) were more likely to have liquid slurry handling systems (38.5%) compared to older animals (33.9%). These weighted JAC means differed from the assumed national inventory values and Agrecalc analysis, which had more older animals with excreta stored as liquid slurry compared to younger animals (70% versus 0% in the national inventory, and 25.9% versus 20.7% for Agrecalc. Standard deviations should be interpreted with care since the distributions are not normal (see Figure 27).

97. In both age groups, the Agrecalc and JAC data suggest that the assumptions used in the national inventory would benefit from updating, with the national inventory model underestimating slurry storage from younger animals, whilst overestimating slurry storage for older animals. The differences in reported use of slurry storage in younger cattle may reflect estimates of time a calf spends on straw versus in cubicle sheds whilst with mothers, and also reflect younger animals bought in as stores at 8-10 months and being wintered on slats. The

Agrecalc data appears more reliable than JAC in this case, since manure management information is completed for each beef "animal type" rather than for the whole holding, as reported through the JAC. **It is recommended that the national inventory use the Agrecalc results to update assumptions on liquid and solid manure handling proportions.**

Table 23: Weighted averages of manure handling system proportions of beef animals less than 1 year old and 1 year and over, national inventory, Agrecalc and JAC comparisons (values in brackets are weighted standard deviations)

Beef animal age	Manure Handling System	1990 National Inventory (%)	1996-2023 National Inventory (%)	2019-2025 Agrecalc (%)	2023 JAC (%)
<1 yr	Slurry ($l^{<}$)	0	0	**20.74** (36.39)	**38.48** (39.23)
	Farmyard manure ($s^{<}$)	100	100	**79.26** (36.39)	**61.52** (39.23)
≥1 yr	Slurry ($l^{>}$)	47	70	**25.91** (40.41)	**33.92** (38.12)
	Farmyard manure ($s^{>}$)	53	30	**74.09** (40.41)	**66.08** (38.12)

98. According to the JAC analysis, about 45% of Scottish beef holdings (weighted by number of animals) only had solid manure systems, and only about 5% had purely liquid slurry systems, as shown in Figure 16.

99. Figure 17 shows that the Agrecalc analysis had more single manure management system enterprises, with about 70% of Scottish beef enterprises with only solid manure systems, whilst 15% only reported liquid slurry systems. This difference could be due to slight differences in data filtering: The filtered JAC data potentially included beef animals present on dairy enterprises, while the filtered Agrecalc data only included beef enterprises. The observed small peak at 50% solid/liquid for both Agrecalc age groupings (<1 year and >1 year) is potentially indicative of farms reporting any mixed system as 50:50, regardless of actual quantities of manure allocated to each system.

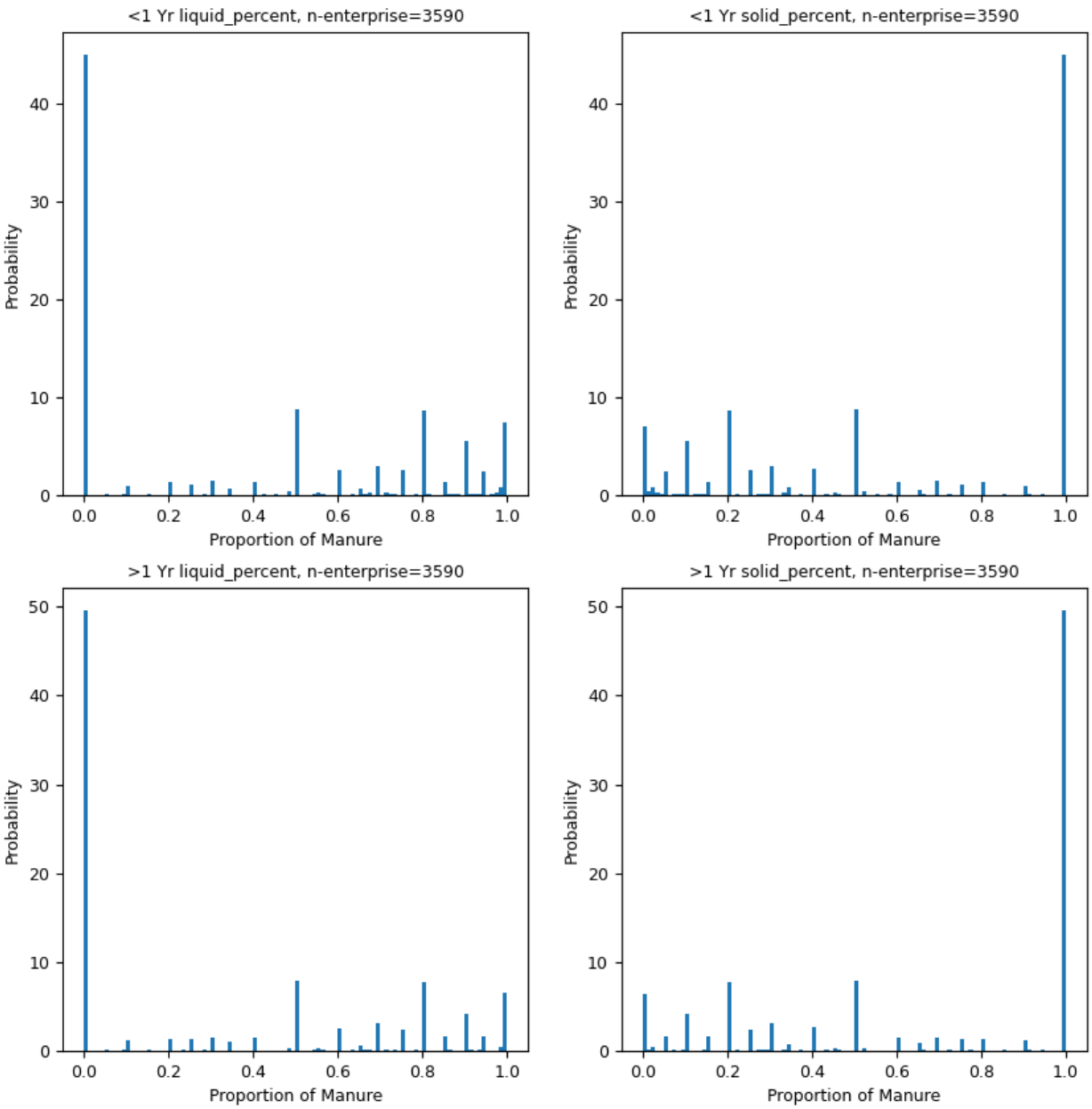


Figure 16: JAC 2023. Probability density functions of holding manure handling system weighted by the number of animals of each beef age classification on agricultural holdings. Bin size is 1 %.

Note: The expected values of these distributions agree with Table 23

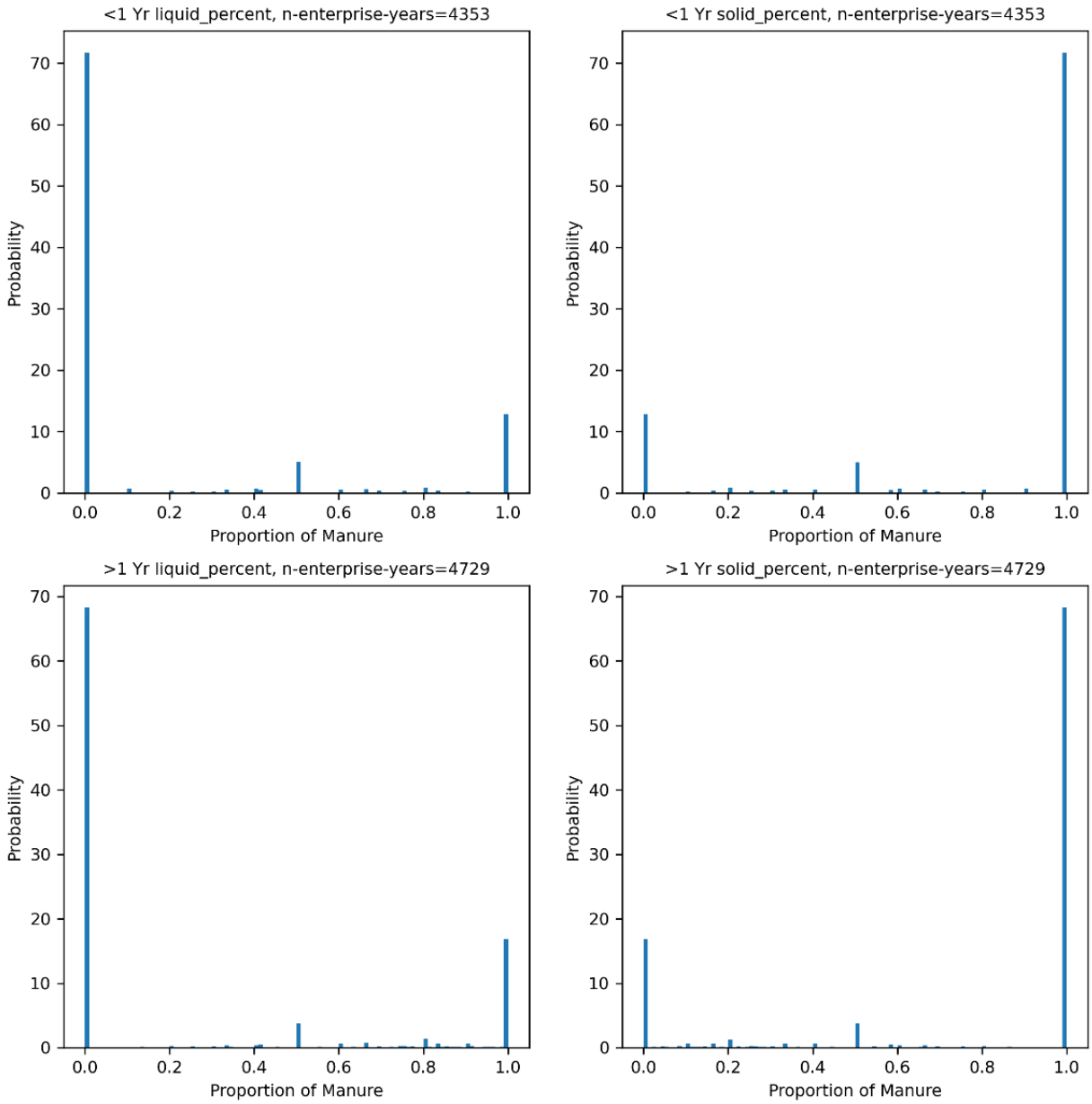


Figure 17: Agrecalc. Probability density functions of farm manure handling system weighted by the number of animals of each classification on the enterprise according to Agrecalc data. Bin size is 1 %.

Note: The expected values of these distributions agree with Table 23

100. Figure 18 and Figure 19 show the spatial differences in the proportion of beef cattle manure managed as liquid using the JAC and Agrecalc data, respectively. Both data sources show that beef animals in regions associated with dairy production (Dumfries and Galloway, and Ayrshire) were more likely to have their manure stored as slurry, while mostly suckler beef rearing and finishing regions had greater use of solid manure systems (the inverse of Figure 18 and Figure 19), with notably higher reliance on solid manure in the East of Scotland, potentially linked to straw availability from arable cropping. The South of Scotland had the highest use of liquid slurry management for the beef sector for both age

groupings in the JAC data (spatially at International Territorial Level 2 - ITL2[22]) which aligns with dairy production in the UK (Figure 28). However, in the Agrecalc data <1 year grouping (ITL2), the North West of Scotland has the highest proportion of liquid management, which comes from the contribution from Shetland and is likely dominated by a few farms (LAD, Figure 28).

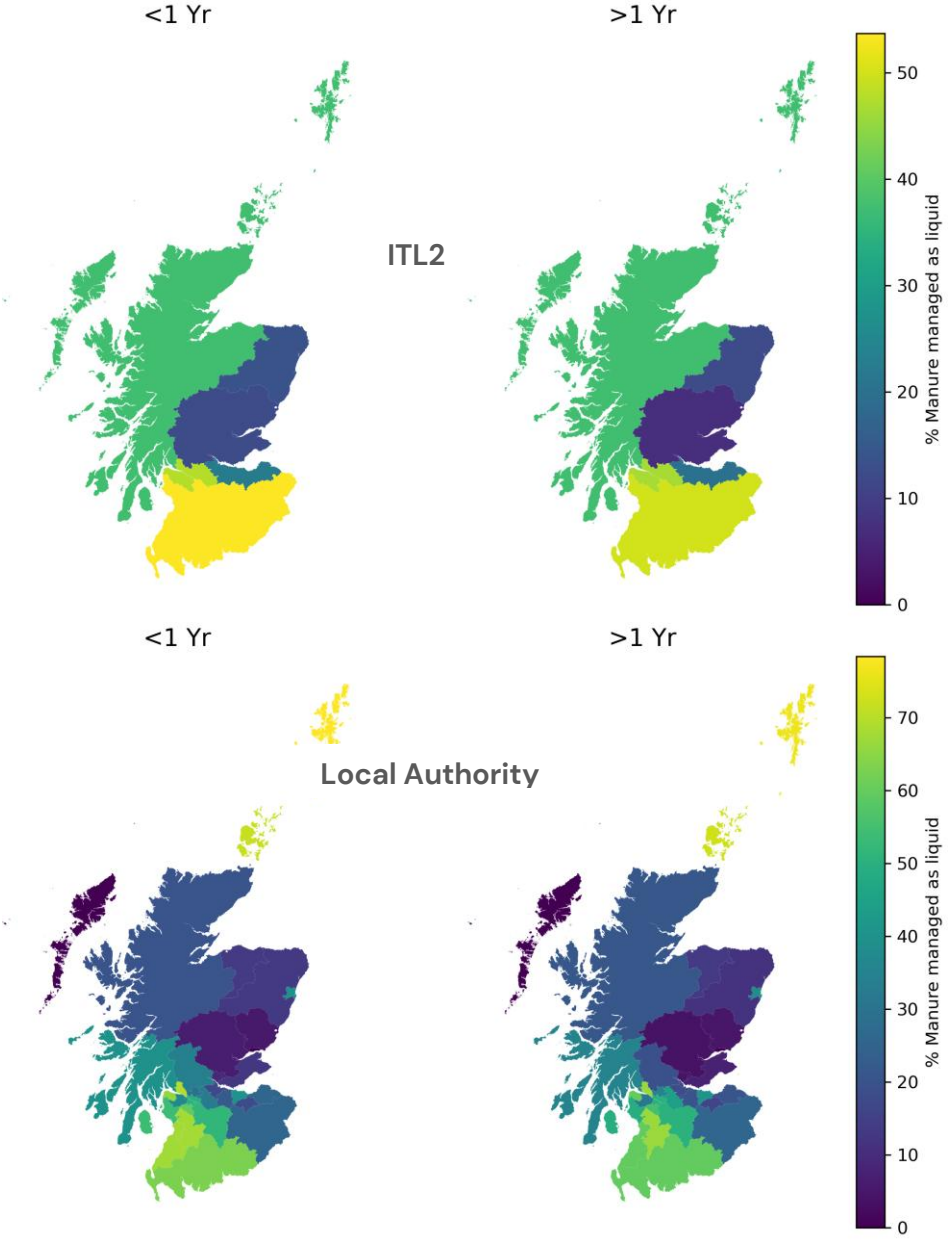


Figure 18: June Agricultural Census. Percentage of excreta stored as liquid slurry on holdings weighted by the number of beef animals less than one year old (left column) and greater than one year old (right column) i.e. $l^{<}$ and $l^{>}$for each spatial scale, International Territorial Level 2 region (top row) and Local authority district 2022 (bottom row). Note the differing colour-ramp scales for different spatial scales.

[22] International geographies - Office for National Statistics

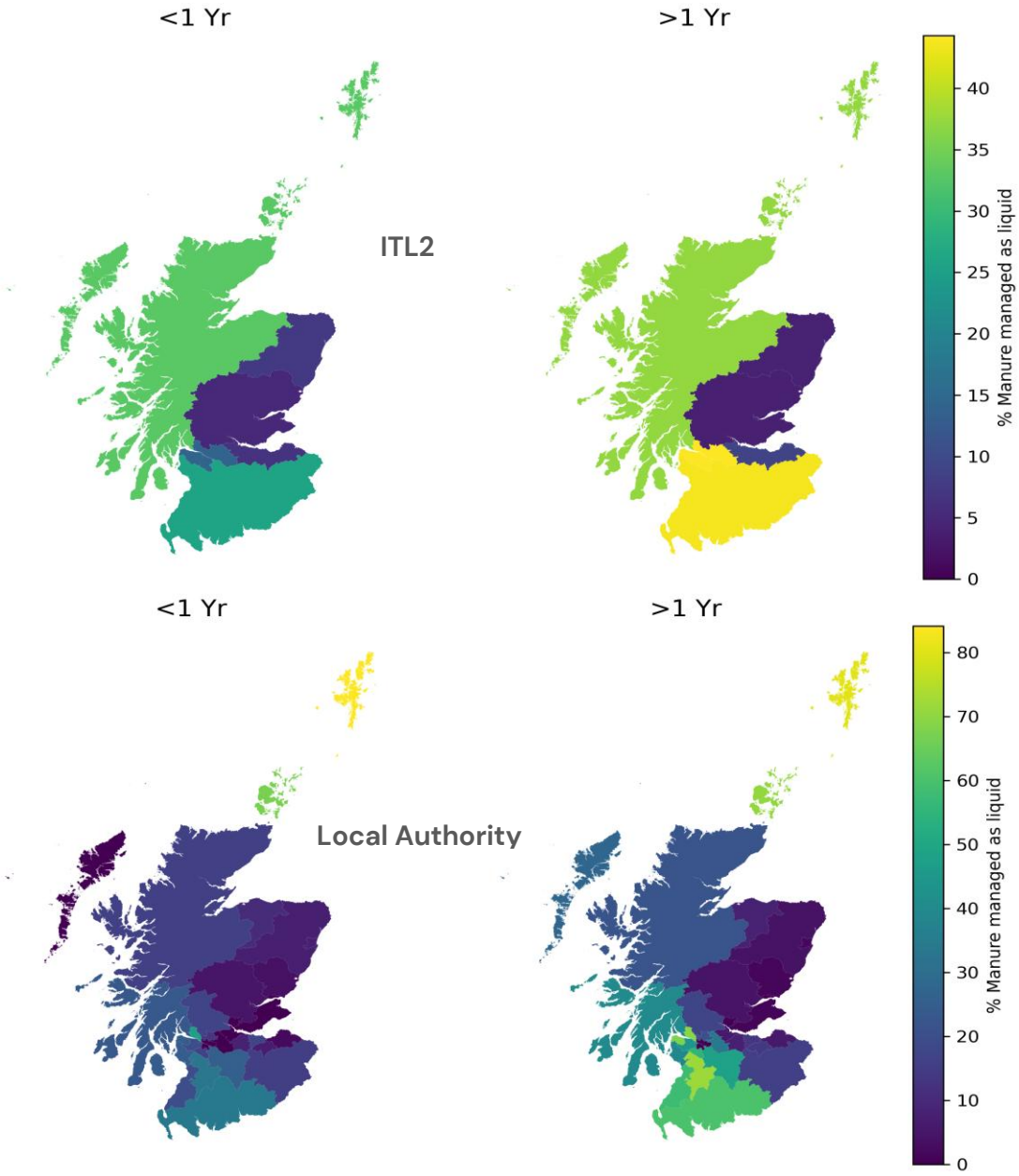


Figure 19: Agrecalc. proportion of excreta stored as liquid slurry on enterprises weighted by the number of beef animals less than one year old (left column) and greater than one year old (right column) i.e. $l^{<}$ and $l^{>}$ for each spatial scale: International Territorial Level 2 region (top row) and Local authority district 2022 (bottom row). Note the differing colour-ramp scales.

101. Only the Agrecalc data had temporal data, which can be seen in Figure 20. However, the data is not longitudinal. Rather, it includes different enterprises in each year, and individual enterprises may have entries in more than one year. Error bars were not included in Figure 20 to make it easier to observe changes, but standard deviations are similar to those reported for Agrecalc in Table 23. There was a notable drop in the proportion of manure managed as liquid in 2021 for both age groupings, falling from 33% to 17% (about 50% drop) for the older than 1 year group (Figure 20). This may have been related to audit completions in

that year due to the Covid pandemic. If changes in the manure handling system were consistent between age groups, it would be expected that the manure handling systems would vary similarly (gradients of the same sign) if enterprises kept both animal age groups. However, in 2020, 2024 and 2025 this was not the case, which indicates that differing manure handling systems between the age groups were likely related to the changing populations annually completing an Agrecalc carbon audit.

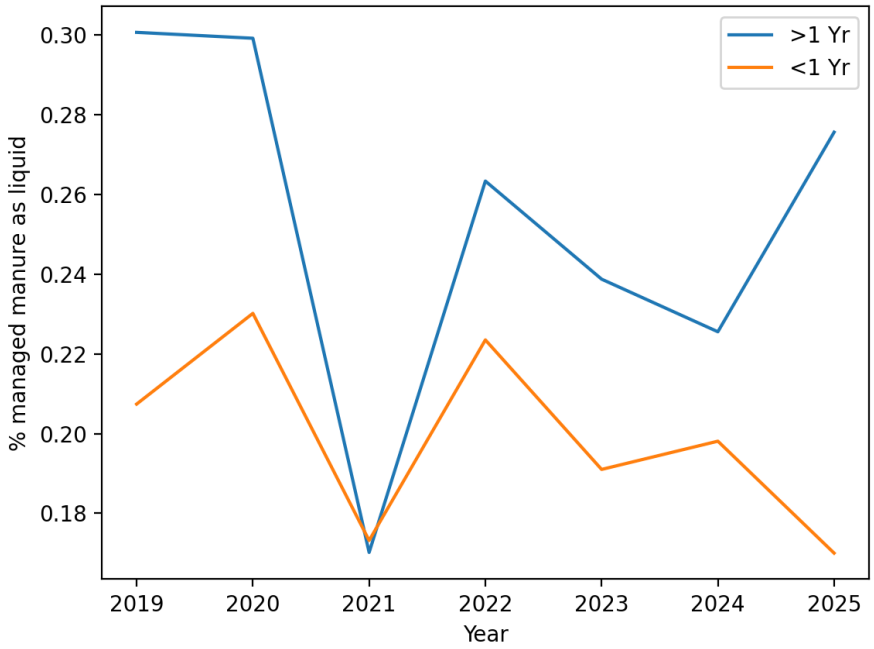


Figure 20: Agrecalc. proportion of manure managed as liquid for beef animals greater than or younger than 1 year (i.e. $l^{<}$ and $l^{>}$) from 2019-2025

5.4 Manure handling back casting

102. The 2010 Survey of agricultural production methods provided an extra data point for back casting these parameters. Details of data source can be found in Appendix 4: Backcasting data sources.

103. Yet another set of agri-semantics to describe manure storage made it hard to directly compare historic and current data, but comparing liquid vs solid was possible. Results suggest that in 2010, 54% of beef animals' manure was stored as solid and 46% liquid, Table 41. This is less solid storage than shown in both the 2019-2025 Agrecalc and 2023 JAC (Table 23, >1 yr) suggesting that solid storage has increased since 2010. However, non-mutually exclusive survey questions may also reduce data quality.

6 Manure storage type in Scottish beef cattle systems

6.1 Introduction

104. Manure storage type refers to how manure is stored once it has been allocated to either liquid (slurry) or solid in the 'Manure handling system' part of the national inventory beef model. This affects inventory GHG and ammonia emissions estimations. For example, in liquid systems, manure that is stored in an 'uncovered anaerobic lagoon' can have twice as much methane emissions as manure stored in slurry tanks. The existing national inventory assumptions for the storage of liquid and solid manures in Scottish beef systems can be seen in Table 24 and Table 25 respectively. Notice that the data needed for the national inventory does not distinguish between beef types and refers to the proportion of liquid/solid manure stored using each method.

Table 24: Existing national inventory assumptions on manure storage for liquid manures (slurry) as a percentage of total liquid manure

Manure Storing System	Existing proportions (%)			
	1990	2000	2010	2020
Slurry above ground tank	35.0	35.0	35.0	34.2
Slurry below ground tank	50.0	50.0	50.0	48.9
Slurry earth bank lagoon	10.0	10.0	10.0	9.8
Slurry bag	0.0	0.0	0.0	0.0
Slurry weeping wall	0.0	0.0	0.0	0.0
Slurry anaerobic digestion	0.0	0.0	0.0	2.1
Slurry direct spread (*no storage)	5.0	5.0	5.0	4.9

Table 25: Current national inventory assumptions on manure storage for solid manure as a percentage of total solid manures

Manure Storing System	Existing Proportions (%)			
	1990	2000	2010	2020
Farmyard Manure Steading Heap	38	38	38	37.2
Farmyard Manure Field Heap	2	2	2	2
Farmyard Manure Direct Spread (*No Storage)	60	60	60	58.7
Farmyard Manure Anaerobic Digestion	0	0	0	2.1

6.2 Manure storage data and analytic methods

6.2.1 Scottish Government data description

105. The 2023 June Agricultural Census (JAC) had a special module on manure management, and Table 26 shows the categories of manure storage types that data was gathered. These JAC data refer to the proportion of managed manure stored in a given storage type on a given holding in 2023. The JAC manure

categories (Table 26) do not perfectly align with the national inventory manure categories (shown in Table 24 and Table 25).

106. The JAC 2023 data contained entries for 57,325 agricultural holdings. To be consistent with manure handling system analysis, only enterprises which had >10 beef animals were included in the analysis, leaving 8,223 agricultural holdings for the analysis. Of these 8,223 holdings, 3,305 were removed since they did not complete the manure storage module of the JAC. A further 49 holdings were removed since they reported >100% total manure storage, with a further 1,279 removed as they reported no liquid slurry or solid manure storage ('Other' in Table 26), leaving 3,590 holding with useable data entries.

Table 26: Manure storage items collected in the 2023 June Agricultural Census used

Storage Type	Unit	Liquid/Solid
Manure solid storage in heaps	%	Solid
Manure stored in compost piles	%	Solid
Manure stored in pits below animal confinement	%	Liquid
Manure stored in deep litter systems	%	Solid
Manure stored in other facilities (not elsewhere classified)	%	Solid
Daily spread	%	Liquid
Other	%	N/A
Liquid manure/slurry storage without cover	%	Liquid
Liquid manure/slurry storage with permeable cover	%	Liquid
Liquid manure/slurry storage with impermeable cover	%	Liquid

6.2.2 Agrecalc data description

107. The Agrecalc data contained information on enterprises' manure storage type and proportion from 2019 to 2025. It had five classifications of manure storage, which are grouped as either solid or liquid (shown in Table 27). The Agrecalc classification differs from both the national inventory manure categories (Table 24 and Table 25) and the JAC categories (Table 26). However, unlike the JAC data, the Agrecalc data contains manure storage details by cattle type, rather than by enterprise. The extent to which farmers differentiate between cattle types should likely be investigated (intra-enterprise variability) in future research.

108. The Agrecalc data contained 5,246 enterprise years. However, 2 enterprise-years were dropped since the managed manure percentages did not sum to 100, and a further 414 enterprise-years were dropped since they had no managed manure (8.8% of beef enterprises). This provided 4,830 enterprise-years for analysis.

Table 27: Entries in Agrecalc data utilised

Storage Type	Unit	Liquid/Solid
Liquid Slurry	%	Liquid
Solid Storage (FYM)	%	Solid
Pit Storage (Slats)	%	Liquid
Deep bedding (retained > 1yr)	%	Solid
Anaerobic digestion)	%	Solid

6.2.3 Manure storage analytic methods

109. The analytic process used to summarise manure storage data followed the following process:

- Let l_i^j and s_i^j be the proportion of *all* manure stored as a liquid or solid system j on enterprise i respectively. For example, l^1 is liquid manure/slurry storage without cover, and s^1 manure in solid storage in heaps. Since these values refer to the percentage of *all* manure on the farm, the liquid and solid storage were normalised separately:

$$\bar{l}_i^j = \frac{l_i^j}{\sum_j l_i^j},$$

$$\bar{s}_i^j = \frac{s_i^j}{\sum_j s_i^j},$$

- Thus $\bar{l}_i^j$ (or $\bar{s}_i^j$) is the proportion of liquid (or solid) system j as a proportion of liquid (or solid) manure only.
- The Agrecalc data collected manure storage for each Agrecalc beef type (b) and the following equations were used to normalise over all beef animals on the enterprise:

$$\bar{l}_i^j = \frac{\sum_b l_i^j(b)}{\sum_b \sum_j l_i^j(b)},$$

$$\bar{s}_i^j = \frac{\sum_b s_i^j(b)}{\sum_b \sum_j s_i^j(b)},$$

- where $l_i^j(b)$ and $s_i^j(b)$ represent the proportion of manure stored as a liquid or solid type j, respectively on enterprise i and beef animal type b. For brevity, the notation retains the distinction between animal types, even for calculations using the JAC data where this information is not collected. In these cases, it was assumed there was only one beef type.
- Let $n_i^l(b)$ and $n_i^s(b)$ be the number of beef animals of type b on farm i which have at least some manure allocated as liquid and solid,

respectively. Then the weighted average of liquid manure stored in a liquid system j was calculated as:

$$\bar{l}^j = \sum_{i=1}^{N} \frac{\sum_b \bar{l}_i^j(b) n_i^l(b)}{\sum_b \sum_{k=1}^{N} n_i^l(b)},$$

- and the weighted average of solid manure stored as solid system j calculate as:

$$\bar{s}^j = \sum_{i=1}^{M} \frac{\sum_b s_i^j(b) n_i^s(b)}{\sum_b \sum_{k=1}^{M} n_i^s(b)},$$

- where N is the number of beef enterprise-years which have at least some liquid storages (995 for the JAC data and 1,549 for the Agrecalc data); and M is the number of beef enterprise-years which have at least some solid storage (3,477 for the JAC data and 4,630 for the Agrecalc data). These calculations assume that all beef animal types produce the same quantity of managed manure.
- The corresponding weighted variances was calculated for liquid system j as:

$$\sigma_{l,j}^2 = \sum_{i=1}^{N} \frac{\sum_b n_i^l(b)\left(\bar{l}_i^j(b) - \bar{l}^j\right)^2}{\sum_b \sum_{k=1}^{N} n_i^l(b)}$$

- and for solid system j as:

$$\sigma_{s,j}^2 = \sum_{i=1}^{N} \frac{\sum_b n_i^s(b)\left(\bar{s}_i^j(b) - \bar{s}^j\right)^2}{\sum_b \sum_{k=1}^{N} n_i^s(b)}$$

6.3 Manure storage results

110. Semantic differences in manure storage classifications made it difficult to compare results from the JAC (Table 28) with values used in the national inventory (Table 24 and Table 25). The national inventory assumes that 60% of solid manure is stored as 'Farmyard Manure Direct Spread'. In this analysis, the 'Daily spread' category in the JAC was classified as a liquid system, Table 26. Additionally, the 'Other' category was excluded from this analysis, since it was not clear if it referred to liquid or solid systems (Table 26), but farmers may have used this to mean they have no manure storage, either from daily spread or because they have entirely pasture-based systems. In the latter case, the approach in the analysis is correct (cattle housing time is dealt with in another analysis), but in the former, the analysis would underestimate the daily spread.

111. When 'Daily Spread' was assumed to be a liquid system, it made up 3% of the liquid storage (see Table 28). This aligns with the national inventory assumptions on the daily spread of liquid (5% 'Slurry Direct Spread', Table 24). However, if the same analysis is performed assuming 'Daily Spread' is a solid storage system, it only makes up 6.8% of solid storage. Therefore, unless the 'Other' category in the JAC was interpreted to include solid manure, which is spread daily, **the conclusion would be that the national inventory model overestimates 'Farmyard Manure Direct Spread' at 60%, and this value should be closer to 6%**[23].

112. The JAC did not differentiate between different types of liquid systems. However, it did suggest that 17% of liquid systems were covered with permeable and impermeable covers, which help to reduce emissions[24].

Table 28: JAC proportions of manure stored as solid and liquid systems. Mean and standard deviations are the proportion of solid/liquid manure stored in the storage type, weighted by the number of animals on the enterprise.

Storage System	Mean (%)	Standard deviation (%)	Number of holdings	Number of cattle
Solid (~66% total manure)				
Manure solid storage in heaps	78	38	3,359	631,951
Manure stored in compost piles	12	30		
Manure stored in deep litter systems	8	23		
Manure stored in other facilities (not elsewhere classified)	2	14		
Liquid (~34% total manure)				
Liquid manure/slurry storage without cover	42	43	1,426	351,767
Liquid manure/slurry storage with permeable cover	8	25		
Liquid manure/slurry storage with impermeable cover	9	26		
Daily spread	3	17		
Manure stored in pits below animal confinement	38	43		

113. The Agrecalc data analysis shows that 90% of solid storage was stored as FYM, and that 65% of liquid slurry storage was stored in pits (see Table 29). No Anaerobic digestion on beef farms was reported in the Agrecalc data. The differences in manure categorisation between data sets makes it difficult to

[23] It also implies that farmyard manure is applied directly without the opportunity to compost and break down in field heaps / middens, or storing to apply at optium time in accordance with best management practices.

[24] See Macleod, et al (2024). Clean Growth through Sustainable Intensification. MACC Fiches. Scotland's Rural College (SRUC). Dataset. https://doi.org/10.58073/SRUC.24974955.v1

compare results to the national inventory model assumptions, and the Agrecalc "Solid storage (FYM)" selection likely includes many of the solid storage options used in the national inventory and JAC.

Table 29: Agrecalc proportions of manure stored as solid and liquid systems. Mean and standard deviations are a proportion of solid/liquid manure stored in the storage type, weighted by the number of animals on the enterprise

Storage System	Mean (%)	Standard deviation (%)	Number of enterprise years	Number of cattle-years
Solid (~74% total manure)				
Solid storage (FYM)	89.9	17.5	4,630	933,211
Deep bedding (retained > 1yr)	10.1	29		
Anaerobic digestion	0	0		
Liquid (~26% total manure)				
Liquid Slurry	35.3	40.8	1,549	337,356
Pit storage (Slats)	64.7	34.4		

114. Spatial variance in solid manure storage methods for beef, based on the JAC 2023 are shown in

115. Figure 21 with spatial variance in liquid storage methods in Figure 22. Holdings in the North East of Scotland (ITL2) reported the highest level of total solid manure stored as "Manure solid storage in heaps" while Argyle and Bute (LADS22) and East Lothian had notably more manure stored as "Manure stored in compost piles" (

116. Figure 21). These differences may reflect different regional terminology/semantics.)

117. There were some noticeable geographical differences in liquid storage systems utilised within the JAC data (see Figure 22). In general, beef holdings in the southwest and west of Scotland were more likely to store liquid manure as "Liquid manure/slurry storage without cover". Shetland had a noticeably higher percentage (~30%) of "impermeable covers", whilst Eastern Scotland had noticeably lower levels of "Manure stored in pits below animal confinement", (which was interpreted by the SAG as liquid storage).

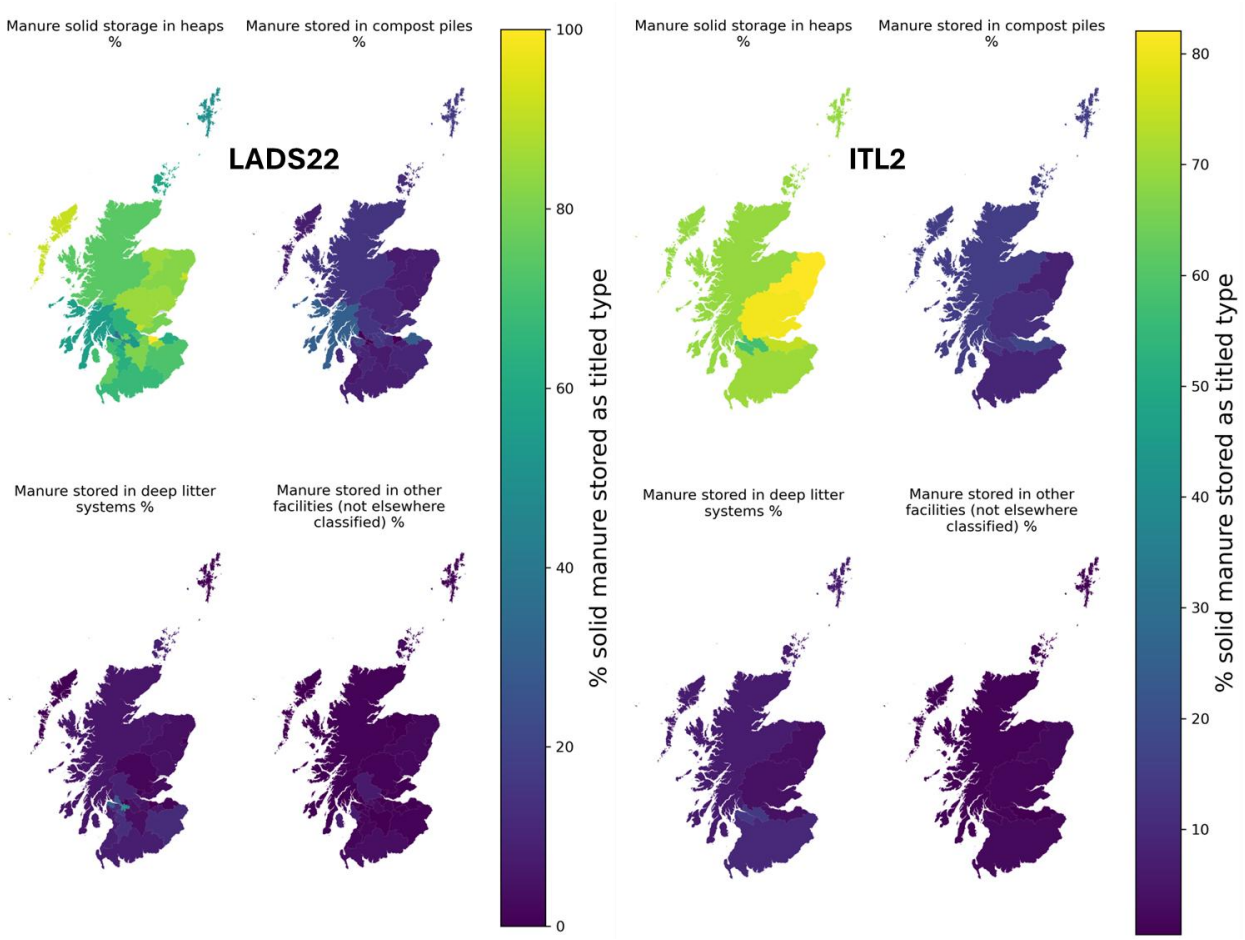


Figure 21 JAC proportion of total solid manure by storage type in each Local authority district (LAD) and International Territorial Level 2 (ITL2) region



Photo: Store beef cattle in shed, Orkney (S Thomson)

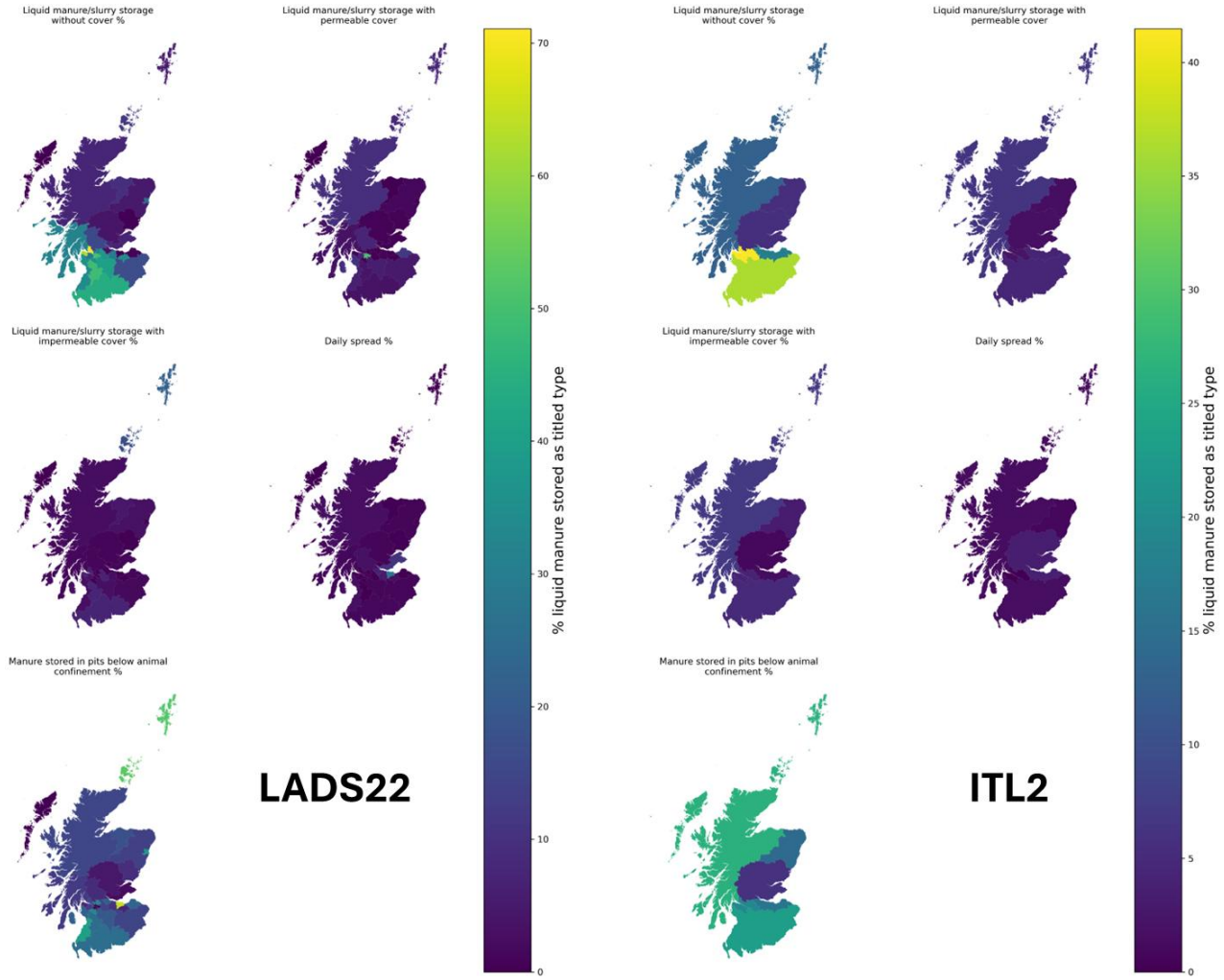


Figure 22: JAC proportion of total liquid manure by storage type in each Local authority district (LAD) and International Territorial Level 2 (ITL2) region

118. Similarly, Figure 23 and Figure 24 show the spatial variation in storage methods for solid and liquid manure storage. As fewer options were available for solid manure storage types within the Agrecalc platform, it made the detection of spatial variation in the data more difficult. However, Figure 23 does show that at the Local Authority District level, the northwest and southwest of Scotland stored more manure as "Deep bedding (retained > 1yr)" compared to other regions. It is worth noting that no beef enterprises in any region/district of Scotland had manure stored as "anaerobic digestion" within the Agrecalc Data.

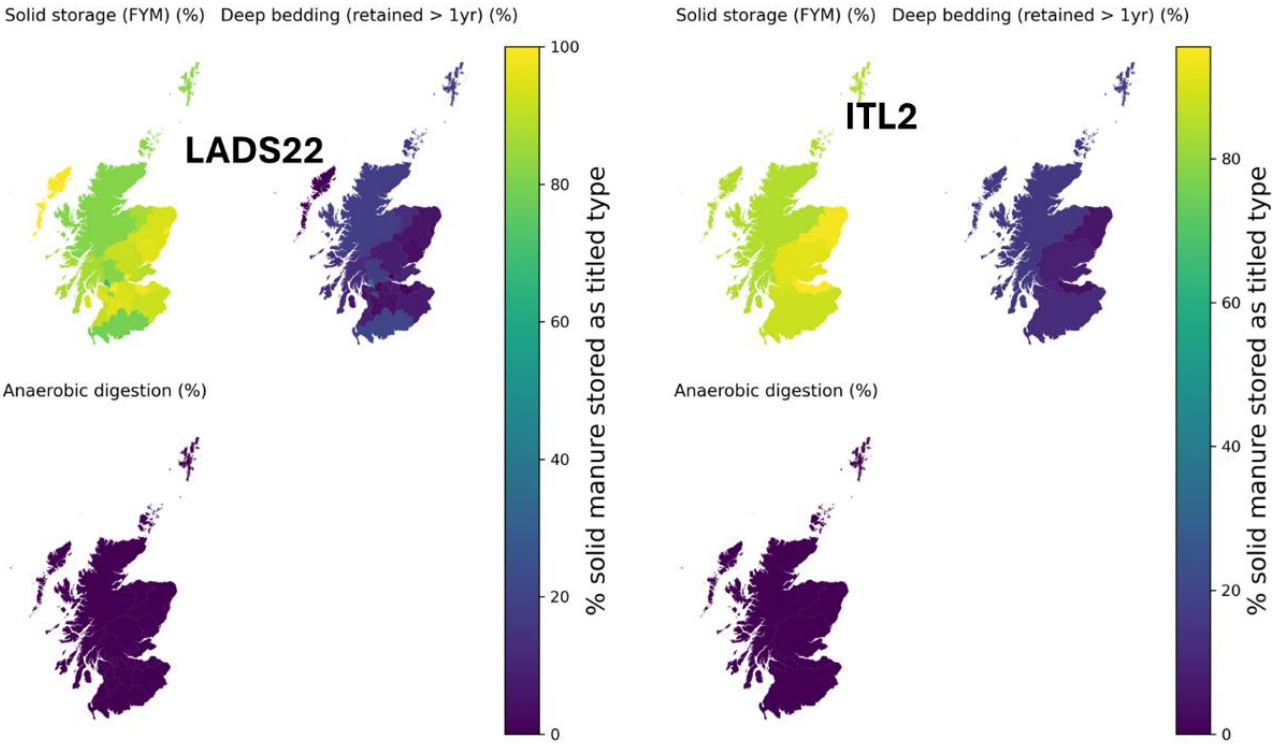


Figure 23: Agrecalc proportion of total solid manure by storage type in each Local authority district (LADS22) and International Territorial Level 2 (ITL2) region

119. For the storage of liquid manure, at the local authority level, the Outer Hebrides stored the highest proportion of liquid manure as "Liquid Slurry" while Angus and Edinburgh had the highest proportion of "Pit Storage Slats" Figure 24. At a coarser resolution (ITL2), the North West had the highest proportion of "Pit Storage Slats" while the West Central belt had the highest proportion of "Liquid Slurry". It is worth reiterating that this represents the proportion of liquid slurry stored, meaning, for example, that it is a small number in absolute terms in the Outer Hebrides, where solid manure systems were more prevalent.

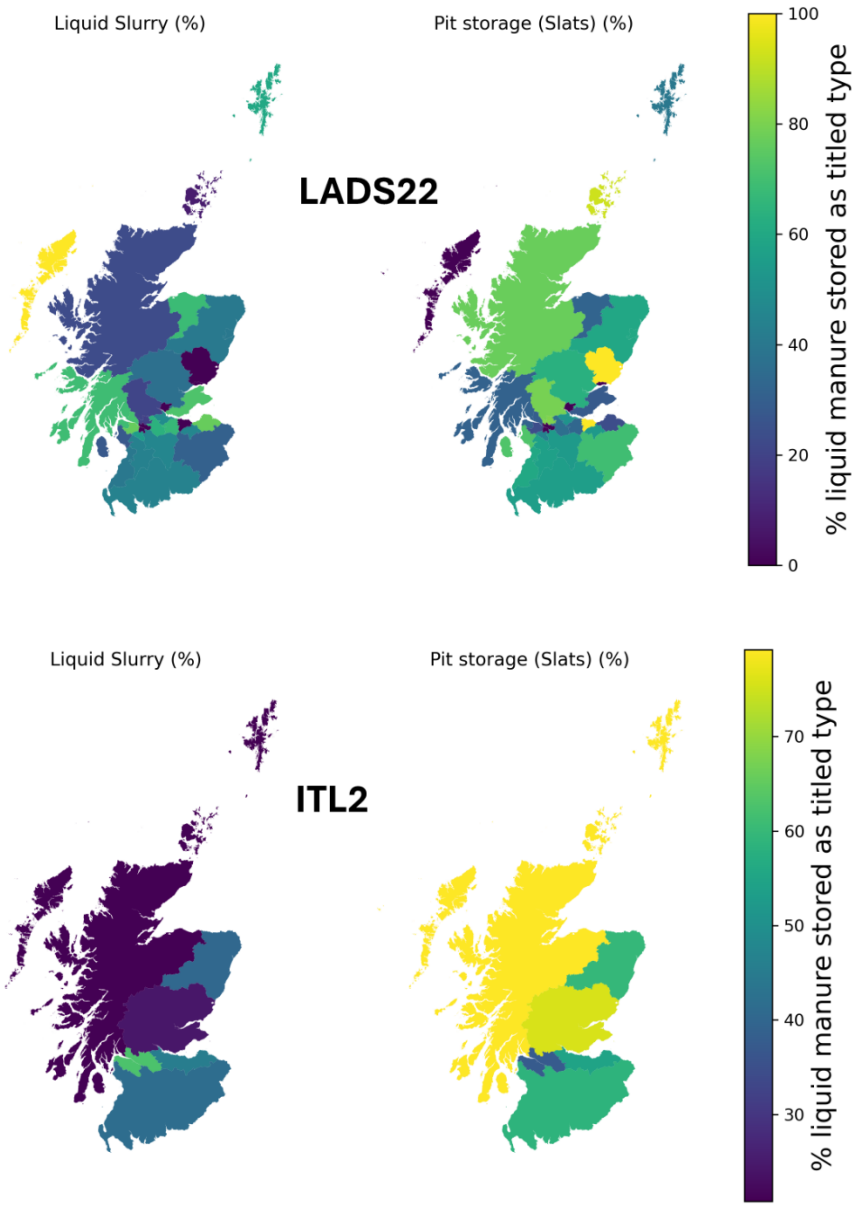


Figure 24: Agrecalc, proportion of total liquid manure by storage type in each Local authority district (LADS22) and International Territorial Level 2 (ITL2) region

120. When comparing the Agrecalc data over time (see Figure 25), it is noticeable that there was an increase in "Liquid slurry" proportions in 2024, followed by a decrease to its lowest value in 2025 (noting that the data extract was up to mid-2025, meaning some enterprises that may conduct audits later in the year would be missing). There was an increase in "Deep bedding (retained > 1yr)" in 2020 at the expense of "Solid Storage (FYM)", but the proportion of solid stored as "Deep bedding (retained > 1yr)" then decreases to below 10%. As previously highlighted, temporal comparisons need to be treated with a degree of caution, as it is not the same population of farms that complete a beef carbon audit each year.

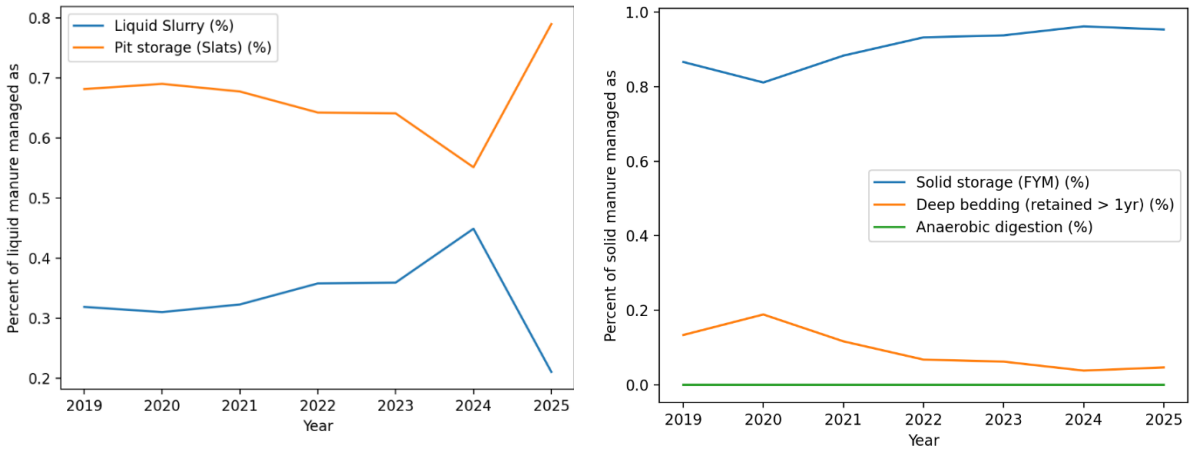
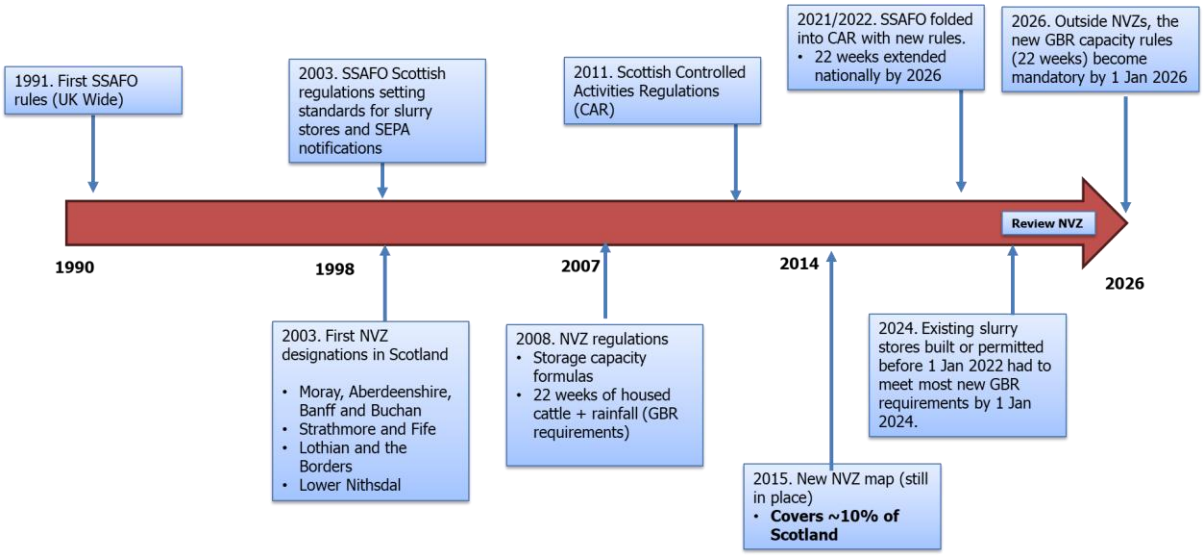


Figure 25: Agrecalc trends in how liquid (left) and solid (right) manure were stored. The percentages in each graph and year sum to 100%

6.4 Manure storage: historic legislative context

121. The history of manure storage regulation in Scotland has likely impacted how beef farmers store and handle liquid and solid manures (see Figure 26 for an illustrative timeline). These rules are enshrined in statute, and since January 1st 2026, all cattle producers must have a minimum of 22 weeks' storage for any slurry produced by cattle on their farm (including outside Nitrate Vulnerable Zones). The extent to which these rules changed on-farm manure and slurry storage behaviours is unknown, but sporadic Scottish Government grants for slurry storage upgrades have been well utilised over the last 30 years.

Figure 26 Key legislative timeline relating to manure storage and handling in Scotland



6.5 Manure storage data comparisons

122. Table 30and Table 31 show the comparisons of the mean proportion of manure storage for the JAC 2023, Agrecalc and national inventory model 2020 assumptions for solid and liquid systems, respectively.

123. The national inventory uniquely uses the "direct spread" category for solid manure, allocating 59% of all managed solid manure to this system (see Table 30). **The Agrecalc and JAC data would therefore be more appropriate evidence bases to justify changes in the national inventory model assumptions.** The use of direct spread of solids leads to an underestimation of other storage systems in the national inventory model compared to the JAC and Agrecalc where 8-10% of solid manure was deep bedding/litter systems, (which are not classified in the national inventory). The Agrecalc data suggested there was no anaerobic digestion of manure on beef enterprises (this does not distinguish between solid and liquid manure), while the national inventory model assumes 2.1% is allocated to this system. Since this is such a small proportion, it may be that these farms do not use the Agrecalc platform.

124. For liquid manure storage (Table 31.), the national inventory model assumptions approximately align with the evidence from JAC on the daily spread of slurry (5% and 3%, respectively). However, compared to the Agrecalc data, the national inventory underestimates the amount of slurry stored below housing ("Pit Storage (Slats)" and "Slurry Below Ground Tank") at the expense of Slurry stored above ground or in lagoons (Table 31). **The JAC results should be used to account for slurry covering in the national inventory**.

6.6 Manure storage back casting

125. The 2010 Survey of Agricultural Production Methods provided an extra data point for back-casting some manure storage parameters. Details of data can be found in Appendix 4: Backcasting data sources. The results show 25% of liquid (slurry) was covered in 2010, Table 41. This is greater than the 17% covered liquid storage found in JAC 2023 (Table 31, permeable + impermeable) suggesting that covering has decreased since 2010. However, data quality may affect results.

Table 30: Comparisons of mean storage proportions for solid manure storage systems between Agrecalc June Agricultural Census (JAC) and National Inventory 2020 (national inventory) assumptions.

Agrecalc System	JAC System	National Inventory System	Agrecalc %	JAC %	National Inventory%
Solid storage (FYM)			**90**		
	Manure solid storage in heaps *Manure stored in compost piles* **JAC Total**			*78* *12* **90**	
		Farmyard Manure Steading Heap *Farmyard Manure Field Heap* **National Inventory Total**			*37* *2* **39**
Deep bedding (retained > 1yr)			**10**		
	Manure stored in deep litter systems			**8**	
		Farmyard Manure Direct Spread (*No Storage)			**59**
Anaerobic digestion			**0**		
		Farmyard Manure Anaerobic Digestion			**2.1**
	Manure stored in other facilities (not elsewhere classified)			**2**	

Table 31: Comparisons of liquid manure storage system mean storage percentages between Agrecalc June Agricultural Census (JAC) and National Inventory 2020 (national inventory) assumptions.

Agrecalc System	JAC System	National Inventory System	Agrecalc %	JAC %	National Inventory%
Liquid			**35**		
	Liquid manure without cover *Liquid with permeable cover* *Liquid with impermeable cover* **JAC Total**			*42* *8* *9* **59**	
		Slurry Above Ground Tank *Slurry Earth Bank Lagoon* **National Inventory Total**			*34.2* *9.8* **44**
Pit Storage (Slats)			**65**		
	Manure stored in pits below animal confinement			**38**	
		Slurry Below Ground Tank			**49**
	Daily Spread			**3**	
		Slurry Direct Spread (*No Storage)			**5**
		Slurry Anaerobic Digestion			**2**

7 Manure storage time in Scottish beef cattle systems

7.1 Introduction

126. The longer manure is stored, the more methane, ammonia, and nitrous oxide it is likely to emit. According to typical inventory models, liquid manure stored for three months can release twice as much methane as manure stored for just one month (Gavrilova et al., 2019). Improving national data on manure storage length can, therefore, make the inventory more representative of Scotland.

7.2 Data and analysis

7.2.1 Scottish Government data description

127. The data source used in this section was the 2023 June Agricultural Census (JAC), which had special entries on manure management (see Table 32). These entries refer to how long managed manure was stored for on a given holding[25], in a given storage system.

128. It is worth noting that the JAC survey did not ask for the storage time of all manure storage items described in Table 26, but following discussion with the SAG (and comparing the total number of holdings responding to the different questions), the length of time for "Manure stored in compost piles" (Table 32) was assumed to cover both "Manure solid storage in heaps" (78% of solid manure storage) and "Manure stored in compost piles" (12% of solid manure storage) in Table 26.

129. Further, the JAC did not distinguish between manure stored by different cattle classifications (beef or dairy), although the number of cattle by type and age was available. To make sure the manure storage time on holdings was representative of beef animals, only JAC holdings that had more than 10 beef animals were included. The averages were also weighted by the proportion of total beef animals on the farm.

Table 32: JAC 2023 modular items relating to manure storage time

Storage Type	Unit
Manure stored in compost piles	Months
Manure stored in pits below animal confinement	Months
Manure stored in deep litter systems	Months
Liquid manure/slurry storage	Months
Manure stored in other facilities (not elsewhere classified)	Months

[25] The JAC modular questions were asked at a holding level – that means respondents (BRNs) with multiple holdings may have had multiple entries based on whether there were beef animals present on the different holdings (that is pre-populated in the JAC by RESAS).

7.3 Manure storage time data and analytic methods

130. After filtering out holdings in the JAC that had less than 10 beef cattle, there was entries for 8,223 holdings. An additional 3,305 holdings were removed since they didn't complete the JAC 2023 modular questions relating farm practices, and therefore, all manure storage time was missing. In agreement with SAG members, a further 47 holdings were removed due to reported storage times of greater than 3 years[26]. This resulted in 4,871 holdings with 810,807 beef animals to analyse. The 3-year storage time cut-off was used so that histograms could be visualised.

131. The analytical approach to estimate the average manure storage length on each holding, weighted by the proportion of beef animals on that farm, was:

- Let m_i^s be the number of months holding i reports they stored manure type s for. The manure storage types (s) can be seen in Table 26.
- Let n_i be the number beef animals on holding i and let N_s be the number of holdings which report storing at least some manure as type s for longer than 0 months
- The weighted mean storage length was calculated as:

$$\overline{m^s} = \sum_{i=1}^{N_s} \frac{m_i^s n_i}{\sum_{k=1}^{N_S} n_k}.$$

- Manure stored for no time (0 months) was excluded as this would fall into the 'daily spread' category in the inventory.
- The weighted variance in storage length was calculated as:

$$\sigma_s^2 = \sum_{i=1}^{N_S} \frac{n_i (m_i^s - \overline{m^s})^2}{\sum_{k=1}^{N_S} n_k}.$$

7.4 Results

132. Table 33 shows the mean and standard deviation for each manure storage type, and Figure 27 shows the corresponding probability density functions. The mean storage length for manure stored in compost piles/heaps was nearly 9 months, and data was reported by 2,355 holdings / main location codes, with 428,000 beef cattle. The average storage time for liquid manure/slurry was 6.6 months and was reported by 1,045 holdings/main location codes that contained 261,000 beef cattle. Whilst only 730 holdings reported storing manure in pits below animal confinement, they accounted for 189,000 beef animals, and the average storage length was 6.3 months.

[26] We do, however, note that some beef farms do, indeed, keep manure heaps for over 3 years.

Table 33: Weighted mean and standard deviation of manure storage length on beef holdings by storage type (2023)

Manure storage type	Mean (month)	Standard deviation (month)	Number of holdings	Number of cattle
Manure stored in compost piles	8.95	4.46	2,355	427,831
Manure stored in pits below animal confinement	6.27	3.00	730	188,695
Manure stored in deep litter systems	5.74	3.57	359	89,673
Liquid manure/slurry storage (months)	6.57	2.76	1,045	260,516
Manure stored in other facilities	8.06	4.11	265	49,815

133. Figure 27 shows that the mode storage length was 6 months for all storage types except the "*manure stored in other facilities*" grouping, which was 12 months. The exaggerated peaks at 6 and 12 months suggest that many farmers only report manure storage length at 6-month resolution (or that this fits within the cropping cycle of livestock farms – e.g. perhaps spreading manure post-silage harvest as fodder crops sown).



Photo: Hill grazing Highland cow and calf, Lurgan farm, Aberfeldy (S Thomson)

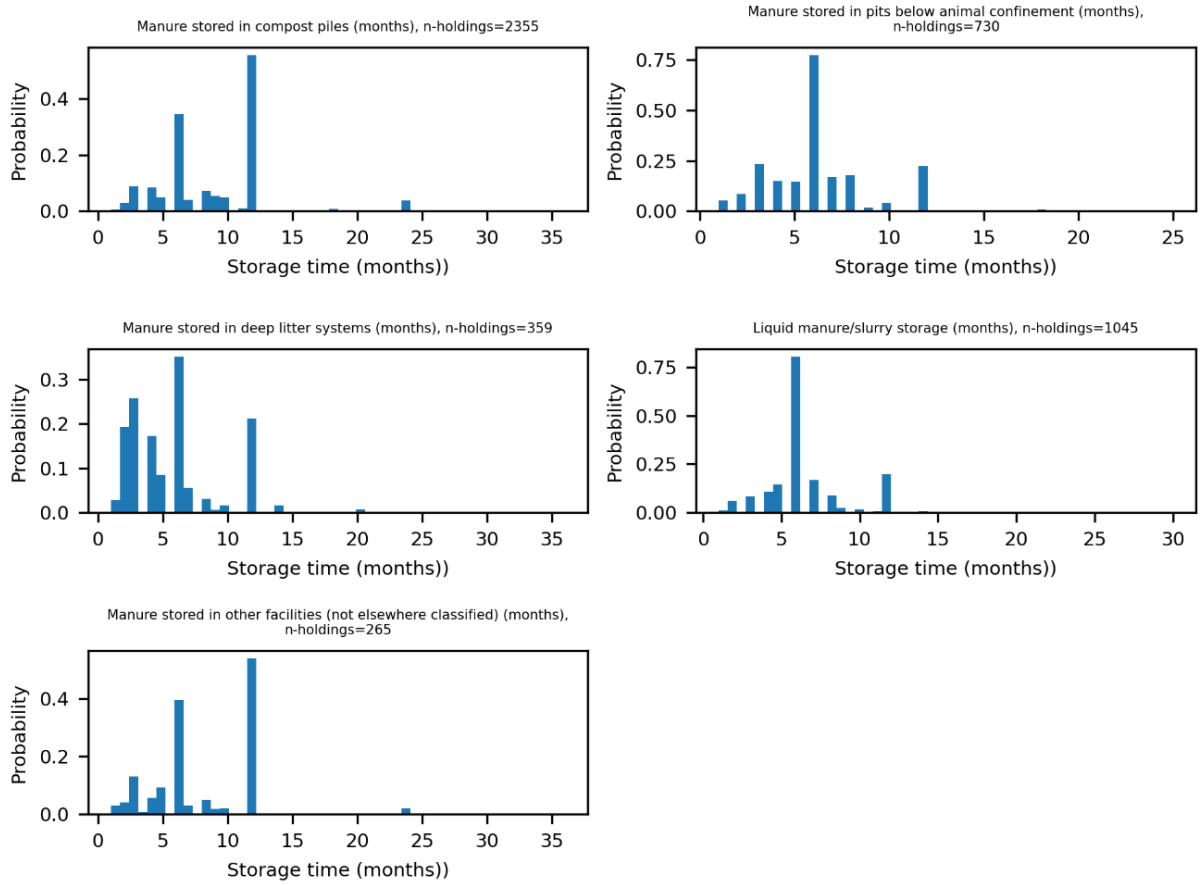


Figure 27: Probability density functions of storage time for each manure storage system in the June Agricultural Census 2023.

134. There was limited spatial variation in manure storage time at the local authority level (Figure 28) and low holding counts in some local authorities made the veracity of results uncertain. At regional (ITL2) level the only noticeable spatial variation was the long storage length for 'Manure stored in other facilities' in West Central Scotland and longer storage lengths for liquid slurry / stored in pits under animals in the Lothians and 'manure stored in compost piles' in Tayside. **Due to this, the use of national averages is recommended.**

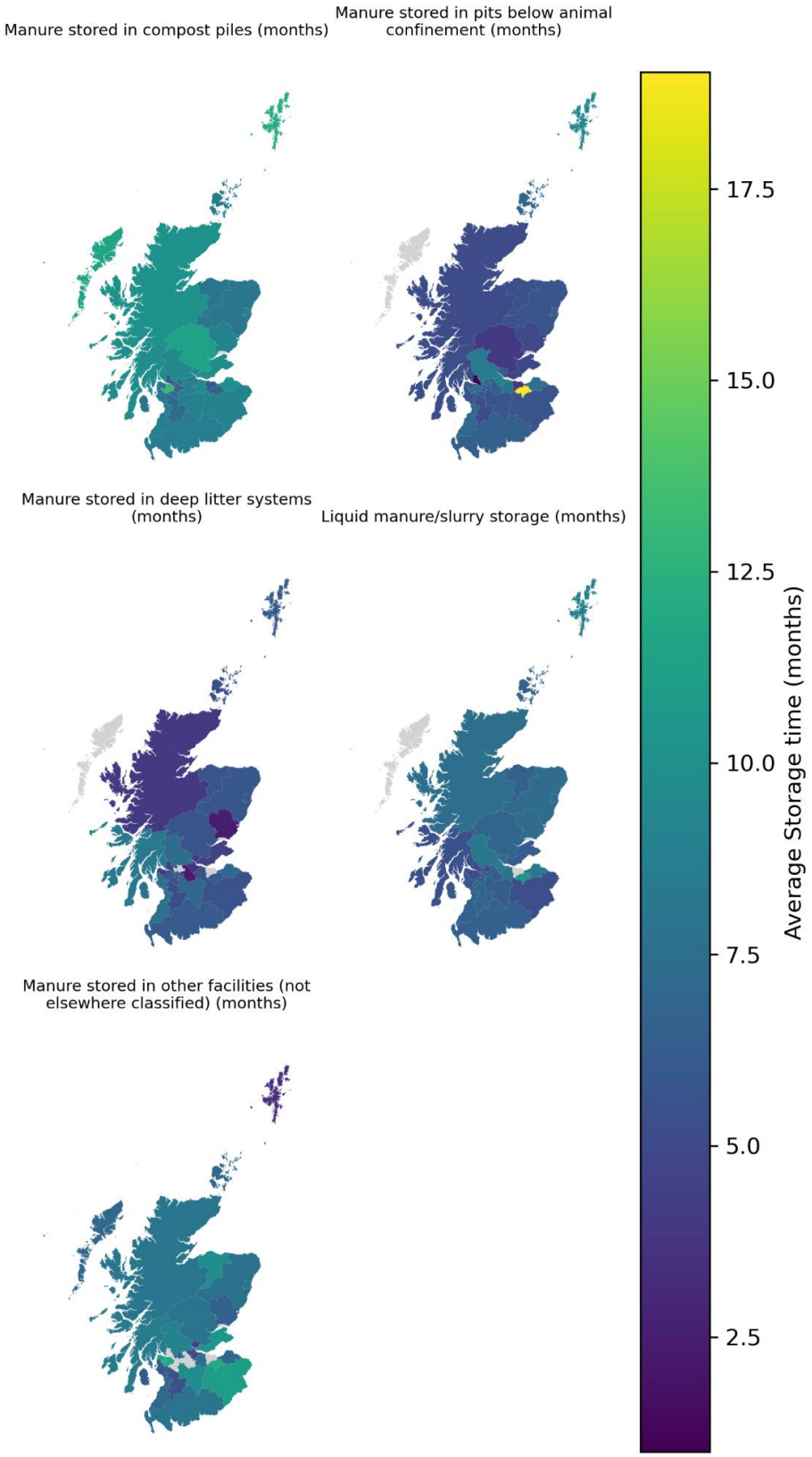


Figure 28: Manure storage length in each Local authority district (2022 boundaries).

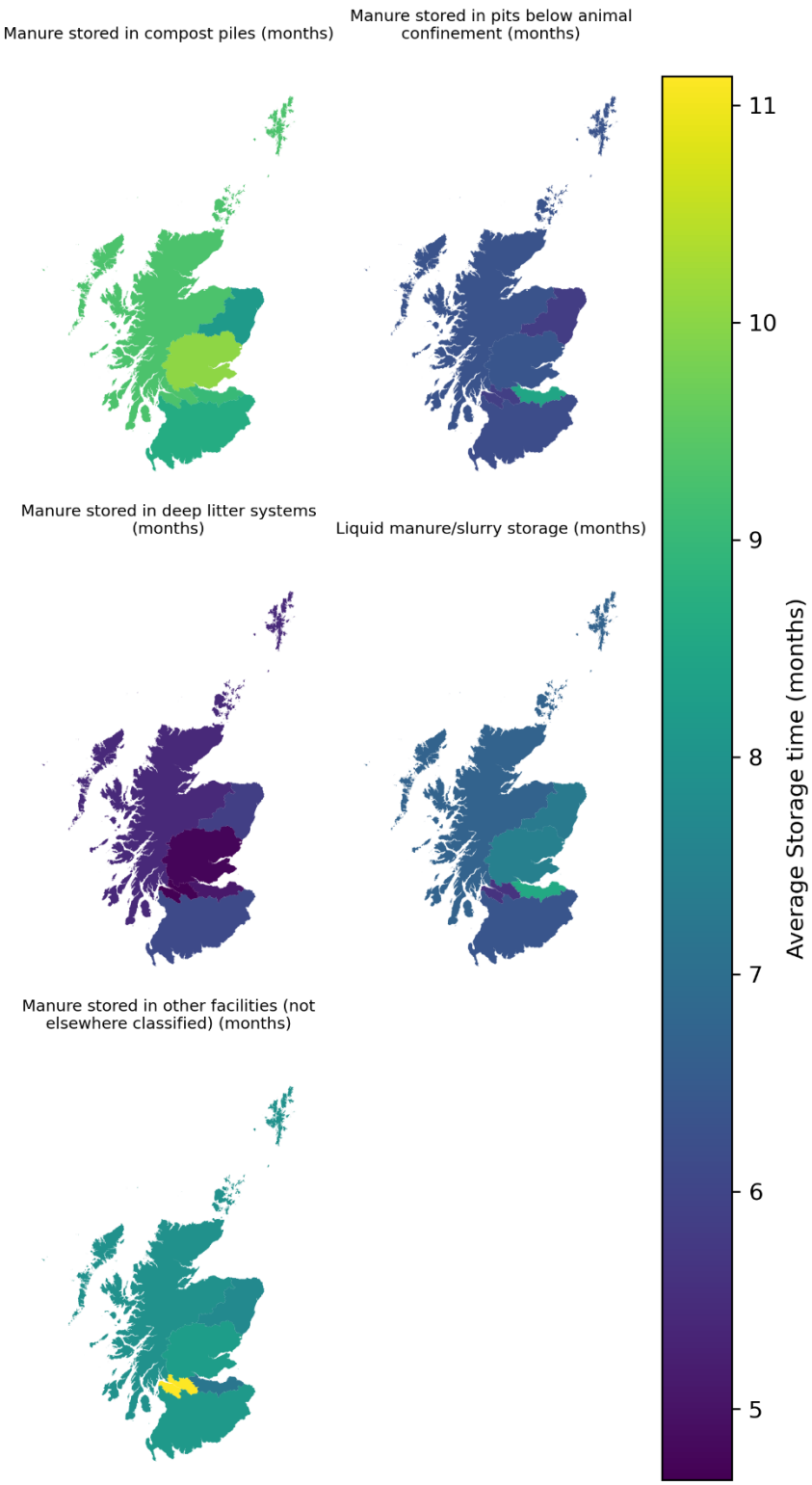


Figure 29: Manure storage length in each International Territorial Level 2 region

Appendix 1: JAC and Agrecalc data representativeness

Figure 30: June Agricultural Census 2023 modular questions

Solid manure use and import/export
(Solid manure: of livestock origin, including composted manure)

		Tonnes
Tonnes of manure used on this holding	4	
Solid manure exported from holding	5	
Solid manure imported to holding	6	

Slurry/liquid manure use and import/export
(Slurry manure: of livestock origin, including anaerobically digested slurry)

		Cubic metres (m^3)
Cubic metres of slurry/liquid manure used on this holding	7	
Slurry/liquid manure exported from holding	8	
Slurry/liquid manure imported to holding	9	

What percentage of the manure/slurry spread on your holding is spread using the following techniques? Please make sure the percentages total to 100.

		Percentage
Broadcast spreader with manure ploughed in within 4 hours of spreading	12	
Broadcast spreader with manure ploughed in 4 or more hours after spreading	13	
Broadcast spreader with manure not ploughed in	14	
Band spreader with a trailing hose	15	
Band spreading with a trailing shoe	16	
Open-slot shallow injection spreader	17	
Closed-slot deep injection spreader	18	
Other	19	

Please indicate the percentage of total manure or slurry stored (including that eventually exported) in the following systems. Please make sure the percentages total to 100.

		Percentage
Manure solid storage in heaps	20	
Manure stored in compost piles	21	
Manure stored in pits below animal confinement	22	
Manure stored in deep litter systems	23	
Liquid manure/slurry storage without cover	24	
Liquid manure/slurry storage with permeable cover	25	
Liquid manure/slurry storage with impermeable cover	26	
Manure stored in other facilities (not elsewhere classified)	27	
Daily spread	28	
Other	29	

Please enter the number of months for which manure produced on the holding can be held, without risk of runoff, and without occasional emptying.

		Month(s)
Manure stored in compost piles	30	
Manure stored in pits below animal confinement	31	
Manure stored in deep litter systems	32	
Liquid manure/slurry storage	33	
Manure stored in other facilities (not elsewhere classified)	34	

Table 34: Total animals, occupiers, workforce, and farmed area on holdings with beef cattle in JAC 2023 and proportion on holdings completing JAC 2023 modular questions, by agricultural region

	Head / HA										
Region	Female beef cattle with offspring aged 2 yrs and over	Total cattle	Beef Cattle	Full time Occupiers	Part time Occupiers (>50%)	Part time Occupiers (<50%)	Regular & Casual Workers	Total Crops	Total Crops & Grass	Rough Grazing	Total Area
Argyll & Bute	**17,821**	**58,526**	**48,279**	**255**	**81**	**113**	**732**	**2,244**	**46,878**	**217,418**	**295,389**
% where cph completed module	64%	64%	64%	65%	62%	67%	77%	52%	66%	81%	77%
Ayrshire	**27,493**	**179,885**	**113,713**	**513**	**77**	**78**	**1,208**	**5,904**	**83,048**	**36,569**	**128,557**
% cph completed module	57%	46%	52%	51%	48%	54%	56%	52%	53%	51%	52%
Clyde Valley	**26,343**	**127,238**	**93,799**	**440**	**84**	**95**	**985**	**4,781**	**67,167**	**36,239**	**110,155**
% where cph completed module	57%	57%	58%	57%	63%	57%	64%	60%	60%	62%	61%
Dumfries & Galloway	**69,408**	**427,350**	**267,449**	**892**	**146**	**148**	**2,844**	**15,755**	**183,493**	**94,479**	**305,766**
% where cph completed module	67%	55%	61%	59%	62%	56%	63%	50%	60%	68%	64%
East Central	**10,959**	**51,066**	**38,148**	**189**	**40**	**38**	**493**	**6,502**	**37,062**	**50,120**	**97,249**
% where cph completed module	60%	59%	58%	61%	75%	53%	69%	67%	67%	83%	76%
Eileanan an Iar	**2,429**	**5,736**	**5,728**	**52**	**82**	**137**	**128**	**114**	**4,782**	**5,423**	**10,430**
% where cph completed module	62%	61%	61%	65%	56%	54%	55%	62%	64%	78%	72%
Fife	**12,226**	**53,171**	**45,651**	**159**	**24**	**24**	**599**	**20,886**	**38,932**	**1,503**	**43,865**
% where cph completed module	52%	54%	54%	60%	46%	50%	57%	56%	58%	68%	59%
Highland	**41,927**	**113,105**	**109,479**	**563**	**307**	**409**	**1,376**	**17,992**	**91,843**	**420,702**	**582,957**
% where cph completed module	68%	65%	67%	66%	64%	63%	69%	62%	67%	61%	63%
Lothian	**12,692**	**45,897**	**42,139**	**125**	**25**	**28**	**476**	**14,551**	**38,032**	**15,778**	**61,222**
% where cph completed module	70%	65%	67%	70%	68%	50%	64%	66%	68%	71%	70%
NE Scotland	**75,583**	**309,475**	**301,557**	**1,045**	**204**	**281**	**2,228**	**85,329**	**196,250**	**99,132**	**321,263**
% cph completed module	59%	53%	54%	62%	57%	55%	66%	60%	60%	66%	62%
Orkney	**24,741**	**75,090**	**72,293**	**292**	**82**	**48**	**501**	**4,082**	**43,876**	**16,074**	**60,416**
% where cph completed module	70%	69%	70%	71%	68%	50%	73%	59%	67%	77%	70%
Scottish Borders	**41,085**	**137,096**	**125,680**	**339**	**61**	**71**	**1,165**	**31,151**	**117,057**	**67,355**	**200,388**
% where cph completed module	72%	69%	69%	72%	67%	69%	77%	72%	72%	68%	71%
Shetland	**1,594**	**4,645**	**4,287**	**40**	**41**	**46**	**130**	**127**	**8,982**	**13,499**	**22,933**
% where cph completed module	60%	57%	59%	55%	66%	61%	63%	27%	60%	75%	69%
Tayside	**30,397**	**94,152**	**89,453**	**362**	**63**	**64**	**1,284**	**38,882**	**91,694**	**138,157**	**255,006**
% where cph completed module	70%	68%	69%	68%	76%	64%	66%	72%	71%	62%	65%

Table 35: Number of holdings with animals, occupiers, workforce, and farmed area on holdings with beef cattle, and the proportion completing JAC 2023 modular questions, by agricultural region

	CPHs										
Region	Female beef cattle with offspring aged 2 yrs and over	Total cattle	Beef Cattle	Full time Occupiers	Part time Occupiers (>50%)	Part time Occupiers (<50%)	Regular & Casual Workers	Total Crops	Total Crops & Grass	Rough Grazing	Total Area
Argyll & Bute	**524**	**580**	**580**	**255**	**81**	**113**	**580**	**106**	**528**	**436**	**545**
% cph completed module	63%	62%	62%	65%	62%	67%	62%	64%	66%	69%	66%
Ayrshire	**582**	**821**	**821**	**513**	**77**	**78**	**821**	**243**	**766**	**310**	**768**
% cph completed module	48%	47%	47%	51%	48%	54%	47%	48%	50%	59%	50%
Clyde Valley	**590**	**765**	**765**	**440**	**84**	**95**	**765**	**191**	**696**	**348**	**701**
% cph completed module	53%	52%	52%	57%	63%	57%	52%	61%	56%	61%	56%
Dumfries & Galloway	**1,085**	**1,462**	**1,462**	**892**	**146**	**148**	**1,462**	**541**	**1,346**	**784**	**1,350**
% cph completed module	58%	54%	54%	59%	62%	56%	54%	57%	58%	64%	59%
East Central	**297**	**362**	**362**	**189**	**40**	**38**	**362**	**107**	**320**	**168**	**323**
% cph completed module	57%	56%	56%	61%	75%	53%	56%	63%	61%	67%	62%
Eileanan an Iar	**322**	**374**	**374**	**52**	**82**	**137**	**374**	**62**	**335**	**175**	**356**
% cph completed module	56%	55%	55%	65%	56%	54%	55%	56%	56%	58%	56%
Fife	**204**	**261**	**261**	**159**	**24**	**24**	**261**	**182**	**239**	**107**	**241**
% cph completed module	54%	54%	54%	60%	46%	50%	54%	62%	58%	60%	58%
Highland	**1,436**	**1,640**	**1,640**	**563**	**307**	**409**	**1,640**	**473**	**1,505**	**1,057**	**1,538**
% cph completed module	60%	58%	58%	66%	64%	63%	58%	64%	62%	67%	62%
Lothian	**190**	**241**	**241**	**125**	**25**	**28**	**241**	**136**	**220**	**111**	**220**
% cph completed module	59%	59%	59%	70%	68%	50%	59%	65%	64%	72%	64%
NE Scotland	**1,326**	**1,879**	**1,879**	**1,045**	**204**	**281**	**1,879**	**1,287**	**1,727**	**1,007**	**1,730**
% cph completed module	54%	54%	54%	62%	57%	55%	54%	59%	58%	60%	58%
Orkney	**425**	**476**	**476**	**292**	**82**	**48**	**476**	**318**	**466**	**328**	**467**
% cph completed module	69%	66%	66%	71%	68%	50%	66%	67%	67%	70%	67%
Scottish Borders	**499**	**594**	**594**	**339**	**61**	**71**	**594**	**340**	**550**	**360**	**551**
% cph completed module	67%	65%	65%	72%	67%	69%	65%	70%	70%	74%	70%
Shetland	**120**	**149**	**149**	**40**	**41**	**46**	**149**	**43**	**146**	**126**	**146**
% cph completed module	62%	60%	60%	55%	66%	61%	60%	56%	60%	62%	60%
Tayside	**527**	**645**	**645**	**362**	**63**	**64**	**645**	**403**	**588**	**344**	**589**
% cph completed module	64%	62%	62%	68%	76%	64%	62%	69%	68%	73%	68%

Table 36: Total animals, occupiers, workforce, and farmed area on holdings with beef cattle in JAC 2023 and proportion on holdings completing JAC 2023 modular questions, by robust farm type

	Head / HA										
Region	Female beef cattle with offspring aged 2 yrs and over	Total cattle	Beef Cattle	Full time Occupiers	Part time Occupiers (>50%)	Part time Occupiers (<50%)	Regular & Casual Workers	Total Crops	Total Crops & Grass	Rough Grazing	Total Area
'Specialist cereals'	**4,450**	**16,359**	**16,114**	**144**	**25**	**31**	**411**	**35,511**	**46,327**	**2,926**	**54,470**
% where cph completed module	64%	63%	64%	67%	68%	55%	70%	64%	64%	90%	66%
'General cropping'	**10,758**	**37,846**	**37,822**	**195**	**30**	**21**	**739**	**50,880**	**67,244**	**4,407**	**80,034**
% where cph completed module	69%	66%	66%	63%	73%	76%	71%	66%	67%	51%	67%
'Specialist horticulture & permanent crops'	**592**	**1,473**	**1,473**	**10**	**-**	**-**	**283**	**1,015**	**1,879**	**-**	**2,208**
% where cph completed module	69%	74%	74%	40%	-	-	16%	49%	63%	-	67%
'Specialist pigs'	**445**	**2,029**	**2,024**	**12**	**-**	**14**	**56**	**994**	**2,053**	**285**	**2,467**
% where cph completed module	93%	87%	87%	67%	-	14%	63%	85%	76%	90%	78%
'Specialist poultry'	**957**	**2,720**	**2,563**	**15**	**-**	**-**	**257**	**1,003**	**3,157**	**1,580**	**5,111**
% where cph completed module	99%	98%	98%	73%	-	-	71%	70%	83%	99%	88%
'Specialist dairy'	**1,702**	**334,346**	**70,141**	**478**	**23**	**19**	**2,102**	**12,630**	**91,375**	**6,448**	**104,438**
% where cph completed module	47%	45%	45%	46%	52%	47%	58%	53%	47%	49%	46%
'LFA Cattle & Sheep'	**283,051**	**874,321**	**835,634**	**3,265**	**968**	**1,192**	**7,311**	**38,697**	**588,102**	**1,169,630**	**1,947,692**
% where cph completed module	67%	65%	66%	65%	65%	62%	71%	64%	66%	67%	67%
'Non-LFA Cattle & Sheep'	**32,759**	**177,537**	**164,825**	**482**	**141**	**175**	**1,111**	**17,586**	**74,933**	**2,999**	**85,270**
% where cph completed module	50%	47%	47%	56%	48%	50%	57%	51%	52%	32%	51%
'Mixed holdings'	**53,646**	**205,336**	**198,489**	**659**	**122**	**115**	**1,865**	**89,983**	**174,027**	**24,036**	**213,907**
% where cph completed module	65%	61%	62%	63%	58%	47%	66%	64%	64%	73%	65%

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Table 37: Number of holdings with animals, occupiers, workforce, and farmed area on holdings with beef cattle, and the proportion completing JAC 2023 modular questions, by robust farm type

	CPHs										
Region	Female beef cattle with offspring aged 2 yrs and over	Total cattle	Beef Cattle	Full time Occupiers	Part time Occupiers (>50%)	Part time Occupiers (<50%)	Regular & Casual Workers	Total Crops	Total Crops & Grass	Rough Grazing	Total Area
'Specialist cereals'	**129**	**234**	**234**	**144**	**25**	**31**	**234**	**234**	**234**	**125**	**234**
% cph completed module	64%	64%	64%	67%	68%	55%	64%	64%	64%	62%	64%
'General cropping'	**197**	**290**	**290**	**195**	**30**	**21**	**290**	**290**	**290**	**156**	**290**
% cph completed module	63%	67%	67%	63%	73%	76%	67%	67%	67%	68%	67%
'Specialist horticulture & permanent crops'	**10**	**13**	**13**	**10**	**-**	**-**	**13**	**13**	**13**	**-**	**13**
% cph completed module	50%	46%	46%	40%	-	-	46%	46%	46%	-	46%
'Specialist pigs'	**18**	**33**	**33**	**12**	**-**	**14**	**33**	**14**	**30**	**11**	**32**
% cph completed module	28%	30%	30%	67%	-	14%	30%	43%	30%	45%	31%
'Specialist poultry'	**16**	**21**	**21**	**15**	**-**	**-**	**21**	**11**	**20**	**13**	**20**
% cph completed module	81%	81%	81%	73%	-	-	81%	73%	80%	77%	80%
'Specialist dairy'	**254**	**587**	**587**	**478**	**23**	**19**	**587**	**339**	**585**	**283**	**587**
% cph completed module	43%	45%	45%	46%	52%	47%	45%	48%	45%	47%	45%
'LFA Cattle & Sheep'	**5,638**	**6,380**	**6,380**	**3,265**	**968**	**1,192**	**6,380**	**2,076**	**6,269**	**4,210**	**6,353**
% cph completed module	64%	63%	63%	65%	65%	62%	63%	65%	63%	67%	63%
'Non-LFA Cattle & Sheep'	**688**	**966**	**966**	**482**	**141**	**175**	**966**	**488**	**963**	**275**	**966**
% cph completed module	49%	50%	50%	56%	48%	50%	50%	54%	50%	57%	50%
'Mixed holdings'	**736**	**1,035**	**1,035**	**659**	**122**	**115**	**1,035**	**966**	**1,027**	**584**	**1,029**
% cph completed module	60%	60%	60%	63%	58%	47%	60%	62%	60%	63%	60%

- disclosive

Appendix 2: Dry Matter Yield and Feed Assumptions

Table 38: Feeds in the Agrecalc dataset, how they are classified in this analysis (Category) and the assumed Dry Matter Yield as a proportion of fresh weight, Metabolizable Energy (ME), Gross Energy (GE) and Crude Protein (CP) Feeds with the suffix "_hg" are homegrown.

Category	Feed	Dry matter yield	ME (MJ/kgDM)	GE (MJ/kgDM)	CP (% DM)
Concentrate	Barley (grain)	0.88	13.2	18.4	11
Concentrate	Barley (grain) commercial urea treatment	0.88	13.2	18.4	11
Concentrate	Barley (grain) urea treated	0.88	13	18.5	15
Concentrate	Barley (moist)	0.85	13.2	18.4	11
Concentrate	Crimped Barley	0.85	13.2	18.4	11
Concentrate	Feed winter barley - Grain_hg	0.88	13.2	18.4	11
Concentrate	Feed spring wheat - Grain_hg	0.88	13.4	18.5	12
Concentrate	Feed winter wheat - Grain_hg	0.88	13.4	18.5	11.5
Concentrate	Feed wheat (all) - Grain_hg	0.88	13.4	18.5	11.5
Concentrate	Malting spring barley (all) - Grain_hg	0.88	13.2	18.4	10.5
Concentrate	Malting winter barley - Grain_hg	0.88	13.2	18.4	10.5
Concentrate	Spring brewing malting barley - Grain_hg	0.88	13.2	18.4	10.5
Concentrate	Spring distilling malting barley - Grain_hg	0.88	13.2	18.4	10
Concentrate	Spring feed barley - Grain_hg	0.88	13.2	18.4	11
Concentrate	Oats (grain)	0.88	12	19.5	11
Concentrate	Wheat (grain)	0.88	13.4	18.5	11.5
Concentrate	Wheat (grain) caustic soda	0.88	13.4	18.5	11.5
Concentrate	Wheat (grain) commerical urea treatment	0.88	13.2	18.6	16
Concentrate	Wheat (grain) urea	0.88	13.2	18.6	16
Concentrate	Maize (grain)	0.88	14	18.8	9
Concentrate	Minor cereals - Grain_hg	0.88	12.8	18.2	11
Concentrate	Winter rye - Grain_hg	0.88	13	18.2	11
Concentrate	Spring oats - Grain_hg	0.88	12	19.5	11
Concentrate	Winter oats - Grain_hg	0.88	12	19.5	11
Concentrate	Milling wheat (all) - Grain_hg	0.88	13.6	18.5	12.5
Concentrate	Bread milling winter wheat - Grain_hg	0.88	13.6	18.5	12.5
Concentrate	Beef nuts (16% protein)	0.9	12	18.5	16
Concentrate	Dairy Heifer rearing Nuts	0.9	11.5	18.2	18
Concentrate	Dairy and calf nuts (12.5 ME, 16% protein)	0.9	12.5	18.5	16
Concentrate	Dairy and calf nuts (13ME,18% protein)	0.9	13	18.8	18
Concentrate	Ewe nuts (12.5 ME, 18% protein)	0.9	12.5	18.5	18
Concentrate	Lamb Finisher nuts (12.5 ME, 15% protein)	0.9	12.5	18.5	15
Concentrate	Other beef blends	0.9	12	18.5	16
Concentrate	Other dairy blends (13.5ME, 20% protein)	0.9	13.5	19	20

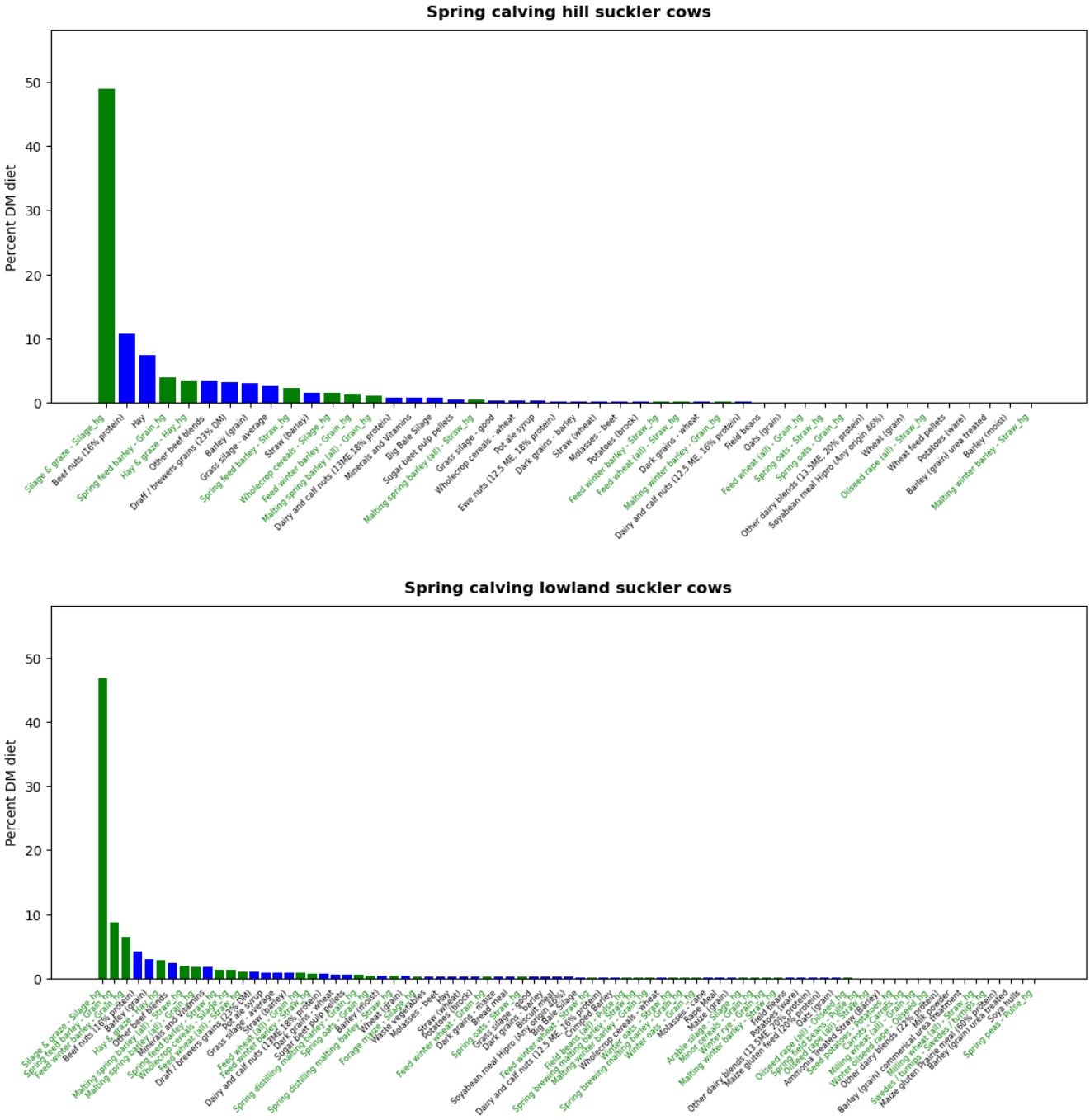
Category	Feed	Dry matter yield	ME (MJ/kgDM)	GE (MJ/kgDM)	CP (% DM)
Concentrate	Other dairy blends (22% protein)	0.9	12.8	18.8	22
Concentrate	Wheat feed pellets	0.9	11.5	18.5	17
Concentrate	Milk powder	0.9	18	21	25
Concentrate	Soyabean meal Hipro (Any origin 46%)	0.9	13.8	19.5	46
Concentrate	Soyabean meal Hipro (Brazilian 48%)	0.9	13.9	19.5	48
Concentrate	Soyabean Full Fat	0.9	15.5	23.5	38
Concentrate	Lo Pro Soyabean meal (40%)	0.9	13	19.5	40
Concentrate	Rapeseed - full fat	0.9	20	27	20
Concentrate	Rape Meal	0.9	12	19.5	35
Concentrate	Rape Meal - expeller	0.9	12.8	21	34
Concentrate	Expelled Rapseed meal (Neopro)	0.9	12.8	21	34
Concentrate	Cold Pressed Rapeseed Treated (Neolac)	0.9	13.5	22	32
Concentrate	Palm Kernel expeller	0.9	11.5	20.5	16
Concentrate	Vegetable protein concentrate	0.9	13	19.5	50
Concentrate	Fishmeal	0.9	14.5	21.5	68
Concentrate	Maize gluten feed (20% protein)	0.9	12	19	20
Concentrate	Maize gluten Prairie meal (60% protein)	0.9	14.2	21	60
Concentrate	Soya hulls	0.9	11.5	18.5	12
Concentrate	Oilseed rape (all) - Oilseed_hg	0.88	20	27	20
Concentrate	Winter oilseed rape - Oilseed_hg	0.88	20	27	20
Concentrate	Field beans	0.88	13.5	19	26
Concentrate	Field beans (all) - Pulse_hg	0.88	13.5	19	26
Concentrate	Spring peas - Pulse_hg	0.88	13.5	18.5	24
Concentrate	Winter field beans - Pulse_hg	0.88	13.5	19	26
Concentrate	Spring field beans - Pulse_hg	0.88	13.5	19	26
Concentrate	Peas	0.88	13.5	18.5	24
Concentrate	Dark grains - barley	0.9	11.5	20	24
Concentrate	Dark grains - maize	0.9	13.5	21.5	27
Concentrate	Dark grains - wheat	0.9	13	21	28
Concentrate	Draff / brewers grains (23% DM)	0.23	11.5	19.5	24
Concentrate	Biscuit meal	0.95	14.5	20	10
Concentrate	Bread meal	0.95	14	19.5	12.5
Concentrate	Confectionery by-product	0.9	15	21	8
Concentrate	Pot ale syrup	0.9	14	20	35
Concentrate	Molasses - beet	0.9	12.5	15	10
Concentrate	Molasses - cane	0.9	12.5	15	4.5
Concentrate	Citrus pellets	0.9	12.5	18	6.5
Concentrate	Sugar beet pulp pellets	0.9	12.5	18.2	10
Silage	Arable Silage	0.25	9	18.5	12
Silage	Arable silage - Silage_hg	0.25	9	18.5	12
Silage	Big Bale Silage	0.25	10	18.2	13
Silage	Silage & graze - Silage_hg	0.25	10.5	18.5	14
Silage	Red clover silage	0.25	10.5	18.5	18
Silage	Red clover - Silage_hg	0.25	10.5	18.5	18
Silage	Grass silage - average	0.25	10.5	18.5	14
Silage	Grass silage - good	0.3	11.5	18.5	16
Silage	Grass silage - poor	0.2	9	18	11

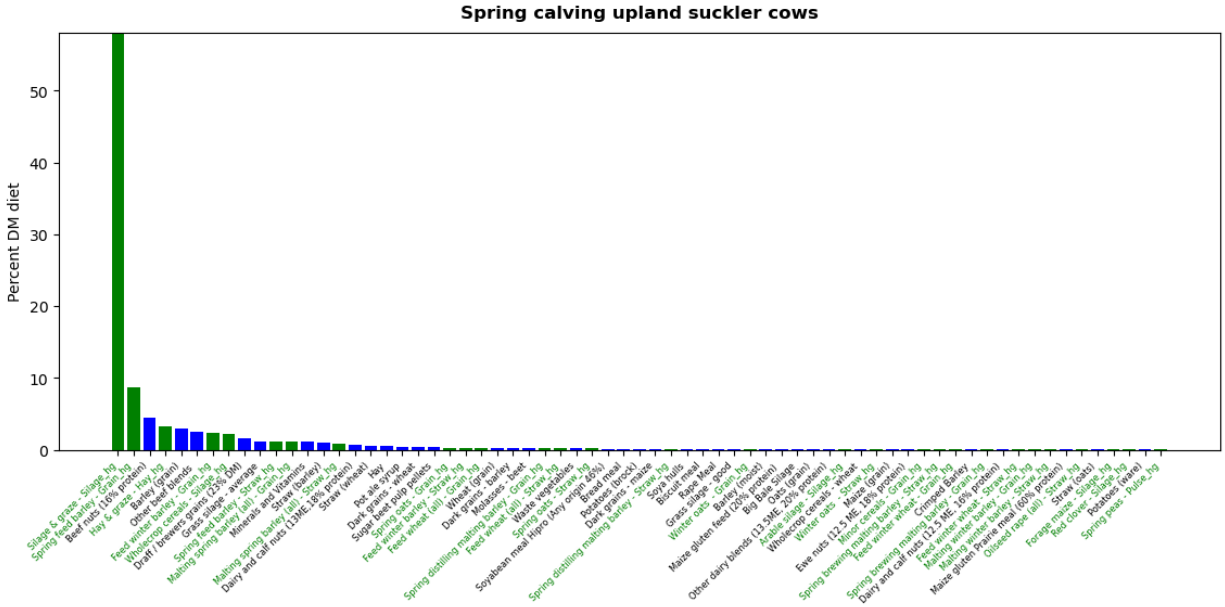
Category	Feed	Dry matter yield	ME (MJ/kgDM)	GE (MJ/kgDM)	CP (% DM)
Maize Silage	Maize silage	0.25	11.2	18.8	8.5
Maize Silage	Forage maize - Silage_hg	0.25	11.2	18.8	8.5
Hay	Hay	0.9	8.8	18	9
Hay	Hay & graze - Hay_hg	0.9	8.8	18	9
Hay	Dried Grass	0.9	10.5	18.2	16
Hay	Dried Lucerne	0.9	10	18	18
Straw	Ammonia Treated Straw (Barley)	0.9	8.5	18.2	9
Straw	Straw (barley)	0.85	6.5	18	3.5
Straw	Straw (oats)	0.85	6.5	18	3.5
Straw	Straw (wheat)	0.85	6	18	3
Straw	Bread milling winter wheat - Straw_hg	0.85	6.5	18	3.5
Straw	Feed spring wheat - Straw_hg	0.85	6.5	18	3.5
Straw	Feed wheat (all) - Straw_hg	0.85	6.5	18	3.5
Straw	Feed winter barley - Straw_hg	0.85	6.5	18	3.5
Straw	Feed winter wheat - Straw_hg	0.85	6.5	18	3.5
Straw	Field beans (all) - Straw_hg	0.85	7	18	6
Straw	Malting spring barley (all) - Straw_hg	0.85	6.5	18	3.5
Straw	Malting winter barley - Straw_hg	0.85	6.5	18	3.5
Straw	Spring brewing malting barley - Straw_hg	0.85	6.5	18	3.5
Straw	Spring distilling malting barley - Straw_hg	0.85	6.5	18	3.5
Straw	Spring feed barley - Straw_hg	0.85	6.5	18	3.5
Straw	Spring oats - Straw_hg	0.85	6.5	18	3.5
Straw	Spring peas - Straw_hg	0.85	7	18	6
Straw	Winter field beans - Straw_hg	0.85	7	18	6
Straw	Winter oats - Straw_hg	0.85	6.5	18	3.5
Straw	Winter rye - Straw_hg	0.85	6	18	3.5
Straw	Soft milling winter wheat - Straw_hg	0.85	6.5	18	3.5
Straw	Minor cereals - Straw_hg	0.85	6.5	18	3.5
Straw	Oilseed rape (all) - Straw_hg	0.85	5.5	18	4
Straw	Winter oilseed rape - Straw_hg	0.85	5.5	18	4
Straw	Milling wheat (all) - Straw_hg	0.85	6.5	18	3.5
Whole Crop	Wholecrop cereals - Silage_hg	0.4	10.5	18.5	10
Whole Crop	Wholecrop cereals - barley	0.88	10.5	18.5	10
Whole Crop	Wholecrop cereals - wheat	0.88	10.5	18.5	10.5
Forage roots	Fodder beet (bulb)	0.12	13	17.5	7
Forage roots	Sugar beet roots	0.12	13.2	17.5	7
Forage roots	Swedes	0.12	13	17.5	11
Forage roots	Swedes / turnips - Swedes / turnips_hg	0.12	13	17.5	11
Forage roots	Turnips (bulbs)	0.12	12.5	17.5	12
Forage roots	Carrots	0.12	13	18.2	10

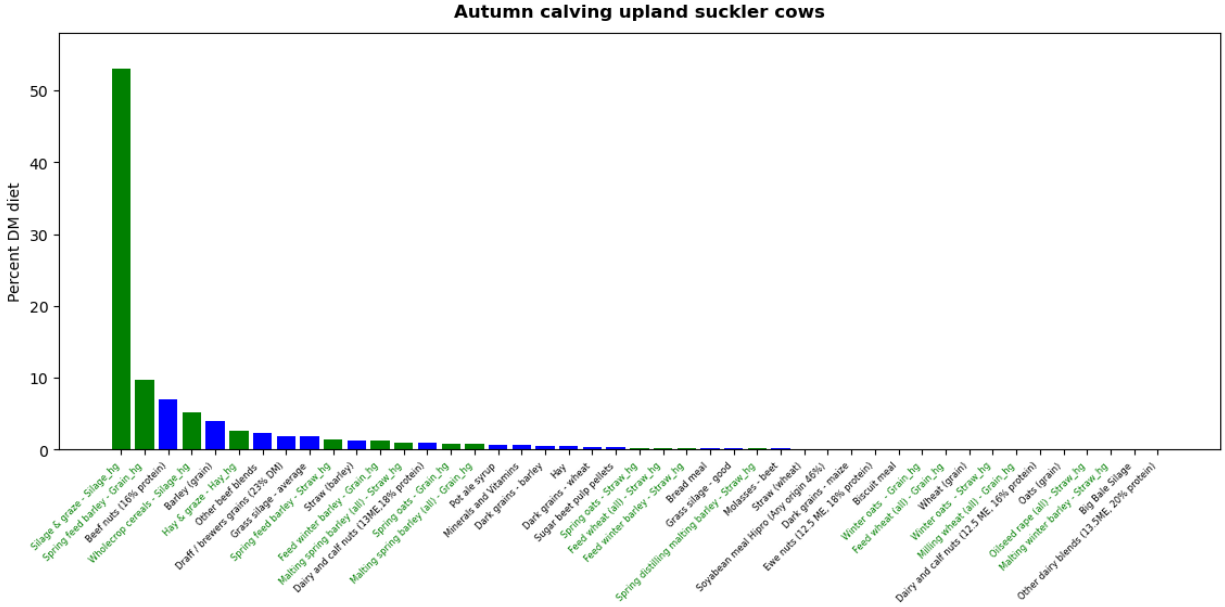
Category	Feed	Dry matter yield	ME (MJ/kgDM)	GE (MJ/kgDM)	CP (% DM)
Forage roots	Carrots - Carrots_hg	0.12	13	18.2	10
Forage roots	Potatoes (ware)	0.2	13.2	17.5	10
Forage roots	Potatoes (brock)	0.2	13.2	17.5	10
Forage roots	Early potatoes - Potatoes_hg	0.2	13.2	17.5	10
Forage roots	Maincrop processing potatoes - Potatoes_hg	0.2	13.2	17.5	10
Forage roots	Maincrop ware potatoes - Potatoes_hg	0.2	13.2	17.5	10
Forage roots	Seed potatoes - Potatoes_hg	0.2	13.2	17.5	10
Forage roots	Waste vegetables	0.12	12	17.5	15
Additives	Additives	1	0	0	0
Additives	Calcium carbonate	1	0	0	0
Additives	Limestone flour	1	0	0	0
Additives	Urea	1	0	0	287
Additives	Lysine	1	16	19	90
Additives	Methionine	1	20	24	58
Additives	Monocalcium phosphate	1	0	0	0
Additives	Magnesium chloride	1	0	0	0
Additives	Minerals and Vitamins	1	0	0	0
Additives	Pre-mix	1	0	0	0
Additives	Salt	1	0	0	0
Additives	Seaweed Meal	1	6	12	10
Additives	Protected palm oil	1	35	39	0
Additives	Soya Bean oil	1	37	39.5	0
Other	Other brassica veg - Brassica_hg	0.12	12.5	18	18
Other	Brussel sprouts - Brassica_hg	0.12	12.5	18	20
Other	Cabbages - Brassica_hg	0.12	12.5	18	18

Appendix 3: Full diet breakdown figures

Figure 31: Full housed diet breakdown of Agrecalc beef animals on each enterprise types. Homegrown feeds are coloured green while bought feeds are blue. Each sub figure is ordered by largest to smallest feed.




Spring calving upland suckler cows
Percent DM diet
0
10
20
30
40
50
Silage & graze - Silage_hg
Spring feed barley - Grain_hg
Beef nuts (16% protein)
Hay & graze - Hay_hg
Barley (grain)
Other beef blends
Feed winter barley - Grain_hg
Wholecrop cereals - Silage_hg
Dreff / brewers grains (23% DM)
Grass silage - average
Spring feed barley - Straw_hg
Malting spring barley (all) - Grain_hg
Minerals and Vitamins
Straw (barley)
Malting spring barley (all) - Straw_hg
Dairy and calf nuts (13ME,18% protein)
Straw (wheat)
Hay
Pot ale syrup
Dark grains - wheat
Sugar beet pulp pellets
Spring oats - Grain_hg
Feed wheat (all) - Straw_hg
Wheat (grain)
Dark grains - barley
Molasses - beet
Spring distilling malting barley - Grain_hg
Feed wheat (all) - Grain_hg
Waste vegetables
Soyabean meal Hipro (Any origin 46%)
Spring oats - Straw_hg
Spring distilling malting barley - Straw_hg
Bread meal
Potatoes (brocx)
Dark grains - maize
Soya hulls
Biscuit meal
Rape Meal
Grass silage - good
Winter oats - Grain_hg
Barley (mixed)
Maize gluten feed (21% protein)
Big Bale Silage
Other dairy blends (13.5ME, 20% protein)
Oats (grain)
Arable silage - silage_hg
Wholecrop cereals - wheat
Winter oats - Straw_hg
Ewe nuts (12.5 ME, 18% protein)
Maize (grain)
Minor cereals - Grain_hg
Spring brewing malting barley - Grain_hg
Feed winter wheat - Straw_hg
Crimped Barley
Spring brewing malting barley - Straw_hg
Dairy and calf nuts (12.5 ME, 16% protein)
Feed winter wheat - Grain_hg
Feed winter wheat - Straw_hg
Malting winter barley - Grain_hg
Malting winter barley - Straw_hg
Maize gluten prairie meal (60% protein)
Oilseed rape (all) - Straw_hg
Straw (oats)
Forage maize - silage_hg
Red clover - silage_hg
Potatoes (were)
Spring peas - Pulse_hg


Autumn calving upland suckler cows
Percent DM diet
0
10
20
30
40
50
Silage & graze - Silage_hg
Spring feed barley - Grain_hg
Beef nuts (16% protein)
Wholecrop cereals - Silage_hg
Barley (grain)
Hay & graze - Hay_hg
Other beef blends
Dreff / brewers grains (23% DM)
Grass silage - average
Spring feed barley - Straw_hg
Feed winter barley - Grain_hg
Straw (barley)
Malting spring barley (all) - Straw_hg
Dairy and calf nuts (13ME,18% protein)
Spring oats - Grain_hg
Malting spring barley (all) - Grain_hg
Pot ale syrup
Minerals and Vitamins
Dark grains - barley
Hay
Dark grains - wheat
Sugar beet pulp pellets
Spring oats - Straw_hg
Feed wheat (all) - Straw_hg
Feed winter barley - Straw_hg
Bread meal
Grass silage - good
Spring distilling malting barley - Straw_hg
Soyabean meal Hipro (Any origin 46%)
Molasses - beet
Straw (wheat)
Dark grains - maize
Ewe nuts (12.5 ME, 18% protein)
Biscuit meal
Winter oats - Grain_hg
Feed wheat (all) - Grain_hg
Wheat (grain)
Winter oats - Straw_hg
Milling wheat (all) - Grain_hg
Dairy and calf nuts (12.5 ME, 16% protein)
Oats (grain)
Oilseed rape (all) - Straw_hg
Malting winter barley - Straw_hg
Other dairy blends (13.5ME, 20% protein)
Big Bale Silage

Appendix 4: Backcasting data sources

135. The 2010 Survey of agricultural production methods[27] was identified as an auxiliary data source to inform back casting. It provides survey data on housing types and manure storage. Data is only subdivided as Dairy vs non-Dairy and not by enterprise type or animal type as in Agrecalc and JAC data sources. This data source introduces yet another system of agri-semantics which makes it difficult to compare to other data sources an NI typologies.

136. The data source captures 21.5% of CPH with beef cattle representing 30.2% of the beef herd, Table 39. Questions were not asked to be mutually exclusive so results do not sum to 100% since questions were not mutually exclusive.

137. Summary results for housing types (Table 40) and manure storage (Table 41) in beef holdings are shown.

Table 39: "Non-dairy" (interpreted as beef) holdings (CPH) and animals which are represented in the 2010 survey of agricultural production methods.

	Non-Dairy		Non-Dairy	
Housing	**CPH**	**% sample**	**Cattle**	**% sample**
Loose housing with dung and manure	1,813	81.6%	215,398	49.5%
Stanchion tied stable with dung and manure	176	7.9%	5,502	1.3%
Loose housing with slurry	659	29.7%	93,210	21.4%
Other housing	241	10.8%	9,770	2.2%

Table 40: Results of housing questions from the 2010 Survey of agricultural production methods. Results do not sum to 100% since questions were not mutually exclusive.

2010 respondents	Non-Dairy	% population
Total CPH population with cattle	**10,338**	
Total Cattle population	**1,439,402**	
Respondent CPHs with cattle	2,222	21.5%
Total Cattle on Respondent CPHs	435,061	30.2%

[27] Available: Statistical Publication: Agriculture Series - Results From the Scottish Survey of Agricultural Production Methods, 2010

Table 41: Results of manure storage questions from the 2010 Survey of agricultural production methods. Results do not sum to 100% since questions were not mutually exclusive.

Manure Storage	Non-Dairy Cattle	% sample
Storage facilities for solid dung	236,652	54%
Covered storage for solid manure	31,393	7%
Storage facilities for slurry	199,149	46%
Storage facilities for slurry (slurry tank)	181,091	42%
Storage facilities for slurry (lagoon)	45,504	10%
Covered storage for slurry	107,275	25%



Photo: Hill suckler cows, Breakachy farm, Laggan, Highlands (S Thomson)



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