Pure

Scotland's Rural College

Greenhouse gas emissions from Scottish farming: an exploratory analysis of the Scottish Farm Business Survey and Agrecalc

Barnes, AP; Bevan, KR; Moxey, Andrew P; Grierson, SG; Toma, L

Print publication: 01/05/2022

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

Link to publication

Citation for pulished version (APA):
Barnes, AP., Bevan, KR., Moxey, A. P., Grierson, SG., & Toma, L. (2022). *Greenhouse gas emissions from Scottish farming: an exploratory analysis of the Scottish Farm Business Survey and Agrecalc*. Scotland’s Rural College 2022 on behalf of ClimateXChange. https://www.climatexchange.org.uk/research/projects/greenhouse-gas-emissions-from-scottish-farming-an-exploratory-analysis-of-the-scottish-farm-business-survey-and-agrecalc/

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

• Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
• You may not further distribute the material or use it for any profit-making activity or commercial gain
• You may freely distribute the URL identifying the publication in the public portal ?

Take down policy
If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Download date: 12. Jul. 2022

Scotland's centre of expertise connecting climate change research and policy

Greenhouse gas emissions from Scottish farming: an exploratory analysis of the Scottish Farm Business Survey and Agrecalc

Andrew Barnes^, Kev Bevan±, Andrew Moxey~, Sascha Grierson≠, Luiza Toma^

^ Department for Rural Economy, Environment and Society, SRUC, ± KBevan Consulting, ~ Pareto Consulting, ≠ SAC Consulting

March 2022

DOI: http://dx.doi.org/10.7488/era/2223

1 Executive summary

The Scottish Government has set ambitious targets for reducing greenhouse gas (GHG) emissions from Scottish agriculture; in 2018[1] these emissions represented 16% of the nation's total. As part of a commitment to reach net-zero emissions by 2045, the Climate Change Plan update[2] requires the equivalent of a 31% reduction in agricultural emissions by 2032 from 2018 levels. However, between 1990 and 2019 Scottish agriculture's emissions decreased by only 13%.

Various options have been proposed for reducing GHG emissions in Scottish agriculture. The sector is characterised by a large array of farming systems; it is not yet clear how emissions are distributed within the farm population, for example, across different types of livestock and arable farms.

We need a better understanding of how GHG emissions vary across farms to help us understand the scope for emission reductions and the potential impacts on farm incomes. Generating metrics can support our understanding by providing baselines and accommodating wider goals for future Scottish agricultural policy development, monitoring and evaluation.

---

[1] see: https://uk-air.defra.gov.uk/reports/cat09/2106240841_DA_GHGI_1990-2019_Final_Issue1.2.xlsx and https://www.gov.scot/publications/securing-green-recovery-path-net-zero-update-climate-change-plan-20182032/
[2] https://www.gov.scot/publications/securing-green-recovery-path-net-zero-update-climate-change-plan-20182032/

This report explores how data on emissions and nitrogen from the Scottish Farm Business Survey, using Agrecalc, can be used to help design policies aimed at reducing emissions in a sustainable way. Agrecalc[3] is a farm carbon calculator developed by SRUC and used widely within Scotland.

1.1 Background

- Farm-level emissions can be estimated using carbon calculators, such as Agrecalc.
- Although carbon calculator estimates for an individual farm are a useful guide to how that farm could reduce its emissions, cross-farm comparisons are hampered by inconsistency in the quality of data used by individual farmers for their own purposes.
- More reliable cross-farm comparisons can, however, be facilitated through the use of farm-specific data collected in a consistent way by trained investigators.
- The Scottish Farm Business Survey (SFBS)[4] is one such survey. It is a long-standing annual survey of farms in Scotland, which collects detailed financial and production data used primarily to underpin government estimates of farm incomes.
- As a pilot exercise, the SFBS was used in conjunction with Agrecalc to estimate emissions for around 400 Scottish farms for crop year 2019. Particular benefits of the SFBS dataset include a consistent baseline meaning cross-farm comparisons can be made with good confidence and that economic information is available for the same farms. This economic information offers a unique opportunity to explore how estimated emissions vary jointly with farm economic performance; for example, to explore whether best practice can deliver emission savings without incurring significant financial performance penalties.

1.2 In this project

- Gross emission and production intensities[5] were used instead of total emissions and total output to allow for comparisons between farms of different sizes. There are many ways to present emissions intensity that offer different perspectives and can give different impressions under certain circumstances. To relate this to the wider literature on emissions intensity, we examined GHG emissions in kg per ha[6] against agricultural product in kg per ha[7].

[3] The Agricultural Resources Calculator - https://www.agrecalc.com

[4] https://www.sruc.ac.uk/business-services/help-in-your-sector/farm-business-management/scottish-farm-business-survey/

[5] Emissions intensity in kilograms of carbon dioxide equivalent emissions per hectare and production intensity in kilograms of output per hectare

[6] These are the total emissions (that is direct, indirect, methane and NO_x) per farm measured in CO_2e[6]. When divided by hectare this provides a comparative metric between farms. To accommodate the range of farms in the Scottish FBS, i.e., those with large areas of rough grazing land, we take the total utilised agricultural area adjusted for forage quality as the per ha metric.

[7] This is the sum of agricultural production in livestock (meat), livestock products (milk, wool, eggs) and crops (including straw) on the farm divided by the total utilised agricultural area adjusted for forage quality. This reflects the level of production on the farm.

- Different farm types were found to be characterised by different emissions profiles related to their main activity types. Variation in emission intensities were also found within farm types.
- We used cluster analysis, a statistical technique, to group farms with similar emission and production intensities. This enabled us to explore whether there are differences between high emitters (farms with high emission intensity) and low emitters (farms with low emission intensity) in the SFBS.

1.3 Findings and recommendations

- For dairy farms a linear relationship was found between production and GHG emissions intensity– in other words, as milk production per ha increases, GHG emissions per ha increase[8]. High intensity emitters were characterised as the most intensive farms, having a higher stocking density and a smaller area. They were also found to have larger expenditure on feed per animal.
- Other farm types showed no clear linear trends between production and emissions. We found a large variation in the mix of enterprises across farms. Those enterprises which are dominated by cattle production demonstrate higher emission intensities compared to those with mostly arable enterprises. This is predominantly due to differences in enterprise mixes.
- Emissions intensity varied both between and within farm types. Variation between farm types largely reflects differences in enterprise mix. For example, ruminant livestock enterprises are intrinsically more intense emitters than arable enterprises.
- Variation within a given farm type can also be due to farm classification, which is based on the predominant enterprise, but other enterprises can also be present.
- Variation within a given farm type can also reflect how enterprises are managed; for example, through adoption of innovations and best practice. The results show some evidence for this, although the patterns are neither linear nor consistent.
- We find little evidence of a clear relationship between lower emissions and stronger economic performance. In some sectors, the lowest emitters do show better financial returns, but in others the reverse is true, and in most sectors only a small number of financial indicators are significantly different.
- We did not find clear evidence for the effects of managerial efficiency. This may reflect limits to win-win mitigation options that improve profitability whilst lowering emissions intensity. However, it may reflect the sample sizes which were relatively small and related only to one year.
- We found that Nitrogen Use Efficiency (NUE) is a potentially useful agri-environmental metric, as this provides a proxy for farm level efficiency of nutrient use. However, the NUE values calculated from the current SFBS dataset omit important input information, such as legumes (e.g. percentage of clover planted in a sward, and contribution from the amount of atmospheric N). Therefore, its value should be further assessed and measured before potential use as a farm performance metric.

[8] kilograms per hectare and GHG emissions (kilograms CO2e per hectare).

- We found farms with similar structural characteristics have different emissions intensities. Collection of additional SFBS data items could improve subsequent analysis. For example, indication of uptake of major practices and innovations such as nitrogen management planning, covered slurry storage and (in future) use of methane inhibitors, would help to identify differences in emissions performance within farm types.
- Some of the resulting sub-sample sizes are quite small. Moreover, because the SFBS sampling frame is based on farm types and size rather than emission profiles, its representativeness of emissions is assumed rather than guaranteed. Both factors may reduce the statistical significance of results presented, but do not necessarily reduce their value as illustrative case-studies (with the consistent measurement basis and overall sample size of the SFBS offering advantages over smaller and more *ad hoc* case studies).
- Although the focus here has been on gross emissions, the approach could usefully be extended to consider net emissions. In particular, sequestration into farm soils and woodland. This may, however, need to await further refinements to Agrecalc and collection of additional SFBS variables, such as hedgerow quality.
- We did not explore all of the data available within the SFBS as part of this project. Further analysis may inform understanding of environmental performance (e.g. input usage rates such as synthetic nitrogen, diesel, electricity and lime; areas of woodland planted). There may also be opportunities to gather additional environmental data through the survey in a cost-effective manner.

Contents

Abbreviations

CO_2	Carbon Dioxide
CH_4	Methane
EU	European Union
EI	Emissions intensity
FBI	Farm Business Income
GHG	Greenhouse Gas
GWP	Global Warming Potential
kg/ha	Kilograms per Ha
$kgCO_2e$	Kilogram per Carbon Dioxide Equivalent
LCA	Life Cycle Analysis,
LFA	Less Favoured Area
LULUCF	Land Use, Land Use Change and Forestry
MACC	Marginal Abatement Cost Curve
Mt	Million tonnes
N_2O	Nitrous oxide
NFI	Net Farm Income
NUE	Nitrogen Use Efficiency
SAOS	Scottish Agricultural Organisation Society
SDA	Severely Disadvantaged Areas
SFBS	Scottish Farm Business survey
T	Tonnes

Glossary

Agrecalc	Carbon calculator developed by SAC Consulting
Carbon Dioxide equivalent (CO_2e)	A measure used to compare the emissions from various greenhouse gases based on their global-warming potential (GWP), by converting amounts of other gases to the equivalent amount of carbon dioxide with the same global warming.
Direct Emissions	Emissions that are owned or controlled by the farmer, e.g., diesel use, electricity use.
Drystock	A name to group meat producing livestock, namely beef cattle and meat-sheep
Farm Business Income (FBI)	The total income available to all unpaid labour and their capital invested in the business. It covers income from both agricultural activity and farm diversification (i.e., enterprises using farm resources).
Farmer Led Groups (FLG)	Sectoral groups formed by the Scottish Government which the remit of focusing on how each sector can mitigate greenhouse gases.
GHG emissions	Emissions of greenhouse gases to atmosphere, including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydro fluorocarbons, perfluorocarbons, and sulphur hexafluoride
Gross Margin	This is the total output from an enterprise less the variable costs to those enterprises.
Global Warming Potential (GWP)	Global warming potentials. Units of different greenhouse gas emissions are multiplied by factors to provide a harmonised unit of Carbon equivalents
Greenhouse Gas Inventory (GHG)	A list of emission sources and the associated emissions quantified using standardized methods.
Indirect Emissions	The consequences of another activity, e.g., fertiliser use, production of feed etc.
K-Means Clustering	An approach which finds groups in data. The approach finds a number of clusters (k) on which each observation belongs to the cluster with the nearest mean.
Land Use, Land Use Change and Farming (LULUCF)	UN Climate Change classification of activities. Mitigation can be achieved through activities in the LULUCF sector that increase the removals of GHGs from the atmosphere or decrease emissions by halting the loss of carbon stocks.
Net Margin	The total output less variable and fixed costs for the farm.

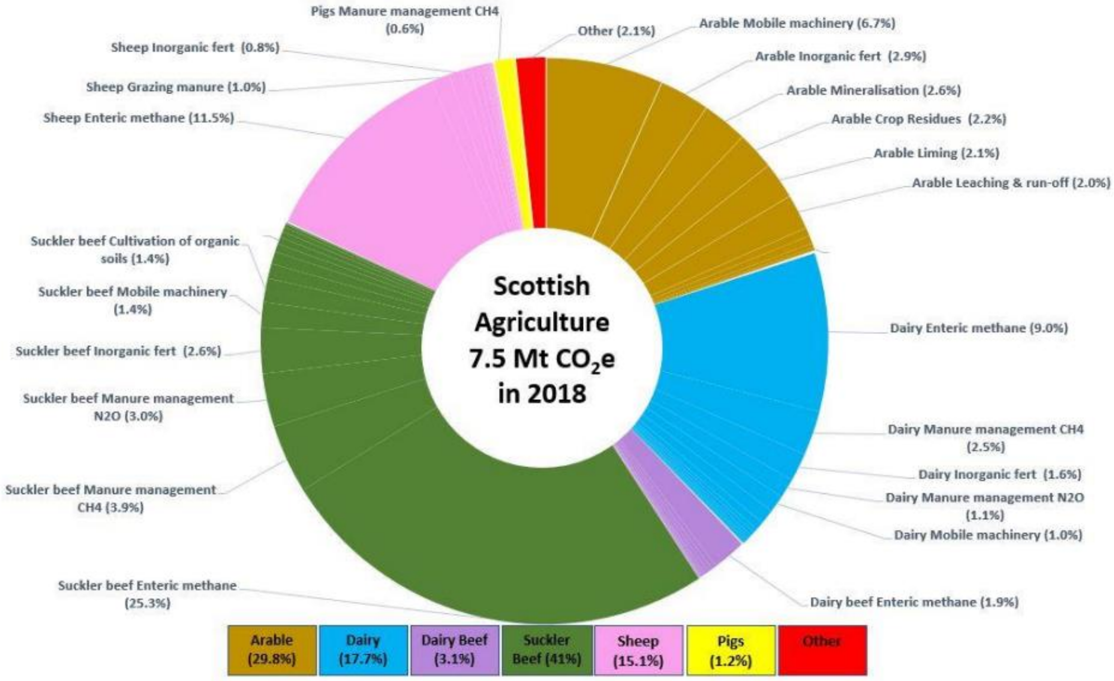
Nitrogen Use Efficiency (NUE)	Used as an intensity metric, indicating how closely nitrogen inputs and outputs are balanced, where 100% being perfectly balanced between nitrogen inputs and outputs, below 100% there is a surplus, and above 100% in deficit.
Operating Profit	The total earnings from agricultural operations, excluding deductions of interest and tax. Provides a proxy reflective of management efficiency.
Output to input ratio	This is a proxy for farm productivity as it represents the ratio of the value of output without subsidies to the cost of inputs, with higher ratios representing higher levels of productivity.
Smart Inventory	The GHG Inventory methodology for agricultural emissions in the UK (United Kingdom), implemented in 2018, which contains UK specific, detailed (known as Tier 3) level emission calculations
Total Adjusted Area	Agricultural area is adjusted to represent grazing quality. This applies to land under Less Favoured area.

2 Introduction

Agriculture represented 16% of Scotland's emissions in 2018[9]. The Scottish Government has committed to reaching net zero emissions by 2045, including a reduction of 75% by 2030. The Climate Change Plan update[10] requires the equivalent of a 31% reduction in agricultural emissions by 2032 from 2018 levels, but between 1990-2019 Scottish agriculture's emissions decreased by only 13%. Recent and ongoing work with farmers suggests that future policy will have to be supported by enhanced monitoring of land management practices and environmental performances, including through on-the-ground surveys.[11]

Following the UK's withdrawal from the EU, a replacement policy for agriculture within the next five years will need to embed both the needs of Scottish agriculture and the wider goal of achieving net zero. Understanding environmental performance and the financial capacity to adapt can inform policy development. Generating metrics can provide baselines and accommodate wider goals for future Scottish agricultural policy development, monitoring and evaluation.

Figure 1: estimated sector by category share of overall total emissions in 2018 (%)



Source: Moxey and Thomson (2021)[12]

[9] see: https://uk-air.defra.gov.uk/reports/cat09/2106240841_DA_GHGI_1990-2019_Final_Issue1.2.xlsx and https://www.gov.scot/publications/securing-green-recovery-path-net-zero-update-climate-change-plan-20182032/

[10] https://www.gov.scot/publications/securing-green-recovery-path-net-zero-update-climate-change-plan-20182032/

[11] see https://www.gov.scot/policies/agriculture-and-the-environment/farmer-led-climate-change-groups/

Enteric methane dominates emissions from the Scottish agricultural sector (Figure 1). It accounts for almost half of all emissions and highlights that ruminant livestock sectors are key to tackling emissions. Other sectors and other gases also have roles to play. For example, carbon dioxide from on-farm machinery and nitrous oxide from fertiliser applications.

However, it is important to note four points in relation to interpretation of agricultural emissions as reported above:

- Emissions associated with farming activities are not only reported in the agriculture section of the Inventory. Most importantly, carbon losses from or sequestration into soils under agricultural management are (mostly) reported in the parallel but separate Land Use, Land Use Change and Forestry (LULUCF) section of the Inventory. For example, 1.7MT CO2e emissions from drained grassland and 2.2MT CO2e from cropland. Similarly, transport emissions from moving agricultural products, generating electricity for on-farm usage and manufacturing nitrogen fertilisers are also reported elsewhere in the Inventory. This means that although emission reduction targets have been set in relation to the agriculture total, changes to farm management may also reduce emissions reported elsewhere.
- Whereas the Inventory splits agricultural-related emissions into separate sections, farm-level carbon calculators such as Agrecalc take a different (Life Cycle Analysis, LCA) perspective that aggregates all sources together. This is helpful in indicating to a farmer where there is scope for reducing their emissions but assigning savings to particular Inventory sections can require an extra step.
- The calculation processes for the Inventory and for farm-level carbon calculators are not necessarily identical. For example, they may use different assumptions and data, reflecting differences in the availability of information or just different points in the cycle of methodological improvements (e.g., recent revisions to the methodology for the Agriculture and LULUCF sections of the Inventory have yet to be reflected in Agrecalc).[13]
- Different carbon calculators, even those accredited under PAS2050[14] or the ISO14000[15] series, can generate different emission estimates from the same data. This hinders cross-farm comparisons unless the same carbon calculator is used. Moreover, it also means that absolute levels of estimated emissions are of less interest than changes in them attributable to variation in farm management and economic performance.

---

[12] Available at: https://www.gov.scot/binaries/content/documents/govscot/publications/research-and-analysis/2021/12/disaggregating-headline-smart-inventory-figures/documents/disaggregating-headline-smart-inventory-figures-scottish-agriculture/disaggregating-headline-smart-inventory-figures-scottish-agriculture/govscot%3Adocument/disaggregating-headline-smart-inventory-figures-scottish-agriculture.pdf

[13] Although there is currently much discussion about the adoption of GWP* rather than GWP100 in order to better reflect global warming differences between methane and carbon dioxide, GWP100 remains the basis for reporting in both the Inventory and Agrecalc.

[14] See: http://www.carbonconstruct.com/pdf/pas_2050.pdf

[15] See: https://www.iso.org/iso-14001-environmental-management.html

Whilst targets are set in terms of absolute emissions, comparisons between farms need to be expressed in relative terms to account for differences in scale. This requires use of emissions-intensity metrics, of which two are used here: emissions per hectare[16] and emissions per kilogram of output.

2.1 Policy towards Scottish agriculture and emissions

Reports by the Suckler Beef Climate Group[17] and other Farmer-led Groups[18] acknowledged the challenge of meeting emission reduction targets and identified a range of management changes that could be implemented to make progress. These included wider adoption of best practice. For example, better storage and handling of manure, more efficient use of fuel, feed and fertilisers, and improved animal health. The potential for innovation was also noted, for example, electric-powered machinery, dietary methane inhibitors, and accelerated genomic breeding selection.

Many of these possibilities had been previously identified for inclusion in Marginal Abatement Cost Curve (MACC) analysis of Scottish agriculture. This ranks practices and technologies in terms of the cost of implementation and the emissions reduction from their implementation. This has been shown to have potential for making progress towards targets. However, such analysis suggests that achievement of stated targets will require increased rates of adoption and/or further policy efforts.[19,20]

Understanding the current variation in emissions across farms can help to show whether best practice – in terms of overall management efficiency – can deliver emission savings without incurring significant financial performance penalties, and hence could be adopted more widely.

The Scottish Farm Business Survey (SFBS) offers micro-economic and biophysical data on a number of farm businesses. Collected yearly, the SFBS data provides a critical pillar to ongoing progress reporting within the Scottish agricultural economy. The SFBS has a detailed core of indicators related to activities at the whole farm level but also has linked modules that focus on particular activities e.g., quantities of carcase weight sold, categories of land use (including non-agricultural land) and the tonnage of pure N, P and K purchased.

Recent analysis of SFBS farms through Agrecalc offers an opportunity to explore environmental indicators, linking these to national targets (e.g., via the Agriculture and LULUCF Inventory chapters), as well as economic and biophysical performance (e.g.,

---

[16] All our calculations per hectare are based on adjusted agricultural area. Adjusted hectares is a standard approach to put rough grazing on an equivalent basis to better quality grazing – normally at a ratio of between 6:1 and 3:1. In this report when we use per Ha we are referring to per adjusted Ha.

[17] https://www.gov.scot/groups/suckler-beef-climate-group/

[18] https://www.gov.scot/policies/agriculture-and-the-environment/farmer-led-climate-change-groups/#:~:text=Farmer%20led%20groups%20were%20established,upland%20farming%2Fcrofting)%20sectors

[19] see Eory et al (2020) https://www.climatexchange.org.uk/media/4612/cxc-marginal-abatement-cost-curve-for-scottish-agriculture-august-2020.pdf

[20] https://www.wwf.org.uk/sites/default/files/2021-10/Ricardo%20GHG%20mitigation%20WWF%20Scotland%2017Oct21.pdf

via on-farm calculators and decision tools, such as the nascent Nature Scot/Iceni App[21] or the SAOS Livestock Performance Programme)[22].

2.2 SFBS data and Agrecalc tools

The combination of Agrecalc results with SFBS data offers an opportunity to explore how emissions vary between – and within – different farm types according to their enterprise mix and financial performance. Using the SFBS as the basis to estimate farm-level emissions gives confidence that emission and financial data have been reported in a consistent manner for all farms and are based on high quality data.

The Agricultural Resources Calculator (Agrecalc) is a farm-level tool developed by SRUC for measuring resource efficiency to improve profitability and environmental impact. As with other farm-level tools, it requires reasonably detailed information of farming activities and deploys a range of assumptions and (e.g.) emission factors to estimate the effects of management changes.[23] It has over 3,000 registered users and, having been developed in Scotland, is well suited to running with Scottish farming systems. For example, it is able to estimate the effects of changes on fertiliser application rates, livestock diets and daily growth rates – all of which were identified by Farmer Led Groups as areas for best practice adoption.

The SFBS has been in operation since the 1930s. Its main purpose is to collect detailed structural and financial data from a sample of Scottish farms to estimate average farm income by farm type and size. The annual sample of around 400 farms does not necessarily represent all farming systems or management practices. The survey is intended to represent the majority of economic output from the sectors in Scottish farming that are in receipt of CAP and other support payments.[24] Most of the participating farms are retained year-on-year in the SFBS sample, allowing identification of long-term trends. Data are collected using a consistent and rigorous methodology that allows for robust comparisons between farms and over time[25]. It is this detail and consistency which supports the use of Agrecalc as a means of estimating emissions from each SFBS farm alongside financial performance metrics such as operating profit.

---

[21] see: https://www.nature.scot/professional-advice/social-and-economic-benefits-nature/natural-capital/pilot-programme/ncapp-farmer-led-projects

[22] see: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwjZiKeMieH1AhVThlwKHaveCLMQFnoECAMQAQ&url=https%3A%2F%2Fec.europa.eu%2Feip%2Fagriculture%2Fen%2Ffind-connect%2Fprojects%2Flivestock-performance-programme&usg=AOvVaw2EcEq1Q1Swy-DONvZBbsqj

[23] see https://www.sruc.ac.uk/business-services/what-is-your-goal/sustainability/Agrecalc/ and https://www.climatexchange.org.uk/research/projects/comparative-analysis-of-farm-based-carbon-audits/

[24] The SFBS only includes full time farms with economic activity of at least €25,000 (equivalent to around £23,000 in September 2019). Full time farms are considered to be those with a Standard Labour Requirement (SLR) of more than 0.5. Standard Labour Requirements represent the approximate average labour requirement for a livestock or crop enterprise. The annual hours of a full-time worker is 1,900 hours.

[25] see https://www.sruc.ac.uk/business-services/help-in-your-sector/farm-business-management/scottish-farm-business-survey/ and https://www.gov.scot/collections/scottish-farm-business-income-fbi-annual-estimates/

Emissions for SFBS farms were estimated by inputting SFBS physical data (e.g., areas of crops, number of livestock, quantities of feed, fertiliser and fuel used) into Agrecalc.

Similarly, farm-level Nitrogen Use Efficiency (NUE) is also used as an intensity metric, indicating how closely nitrogen inputs and outputs are balanced (100% being perfectly balanced between nitrogen inputs and outputs, below 100% there is a surplus, and above 100% in deficit).

2.3 Aims and objectives

The purpose of this report is to develop and apply a methodology for analysis of the SFBS. It has four objectives:

- to explore the potential of new SFBS environmental indicators to provide robust evidence to inform policy development and monitor uptake of cost-effective and sustainable climate mitigation measures.
- to investigate the potential of a nitrogen use efficiency indicator for understanding and monitoring changes in how nitrogen is being used in Scottish agriculture.
- to build on pilot Scottish Government analysis of carbon audit information to outline a data analysis methodology, and
- to provide recommendations for future collection, estimation, and analysis of SFBS environmental variables.

3 Methods and approach

The 2019/20 (2019 crop year) survey produced a physical, economic and environmental data set for 403 farms that forms the basis of this study.

Farms are typed based on that farm's main enterprise activity[26]. We applied our analysis to Specialist Cereals, General Cropping, Specialist Dairy, Drystock (composed of both cattle and sheep farms[27]), and Mixed farming types. The spread of direct GHGs and the distribution of GHG emissions are shown in figures 2 and 3. In this context direct emissions are those that are owned or controlled by the farmer, e.g., diesel use, electricity use, and indirect emissions are the consequences of another activity, e.g. fertiliser use, production of feed etc.

[26] Farms are classified based on the how much of their standard output (the estimated worth of crops and livestock) is from the crop and livestock enterprises on each farm. Farm types contain farms where more than two-thirds of standard output comes from the specified enterprise. Mixed farms are those where no enterprise contributes more than two-thirds of the total.

[27] LFA farms will have a mixture of sheep and cattle under similar management and produce a relatively similar output, hence the three farm types were merged.

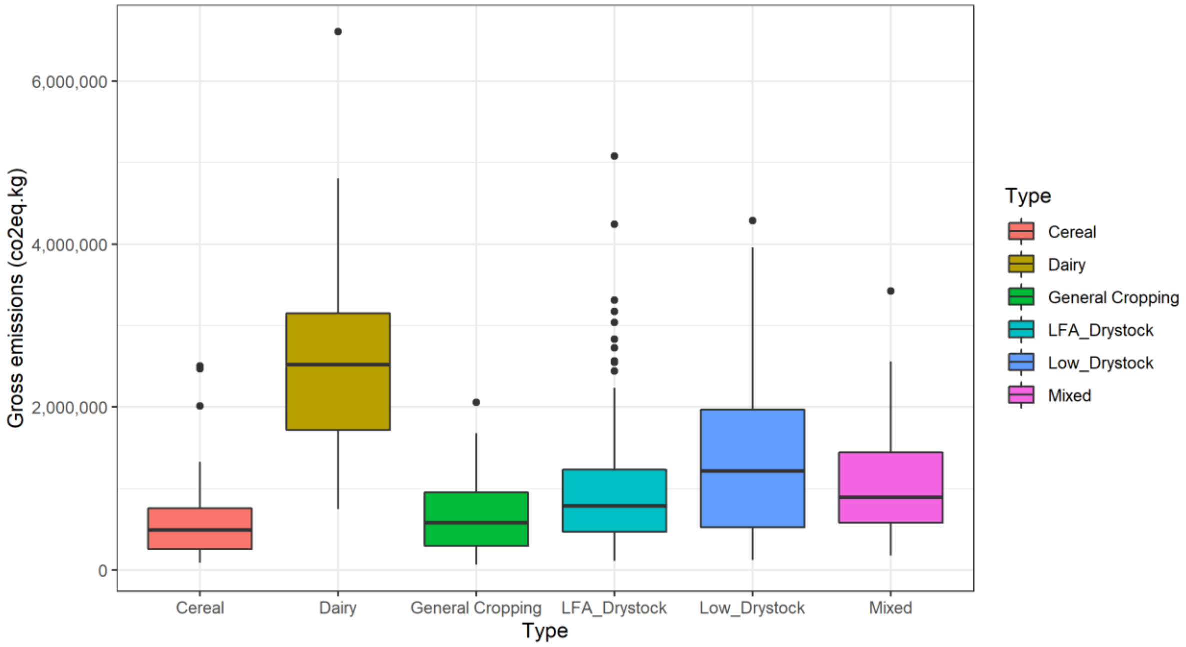


Figure 2. Gross emissions in Kg CO2e of farms in the SFBS, by farm type

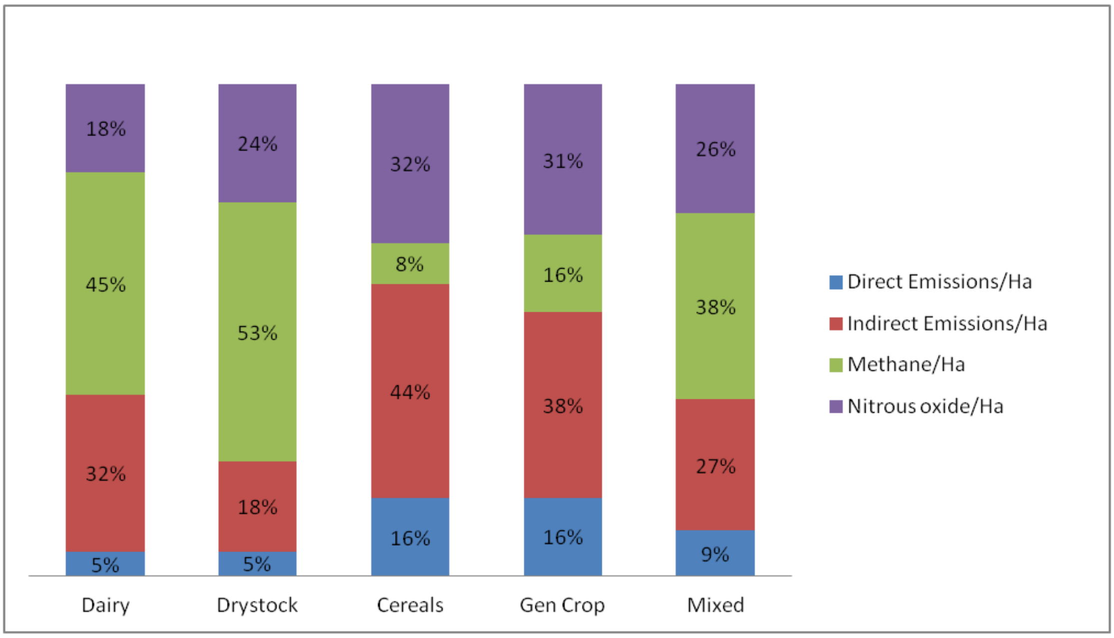


Figure 3. Distribution by type of Emission, proportion of GHG by Farm Type

The benefit of the SFBS is that it offers detailed information at a farm level. The spread of GHG emissions per ha are shown in Figure 4 for all farms in the SFBS. These are shown against the total kg of product produced per ha.

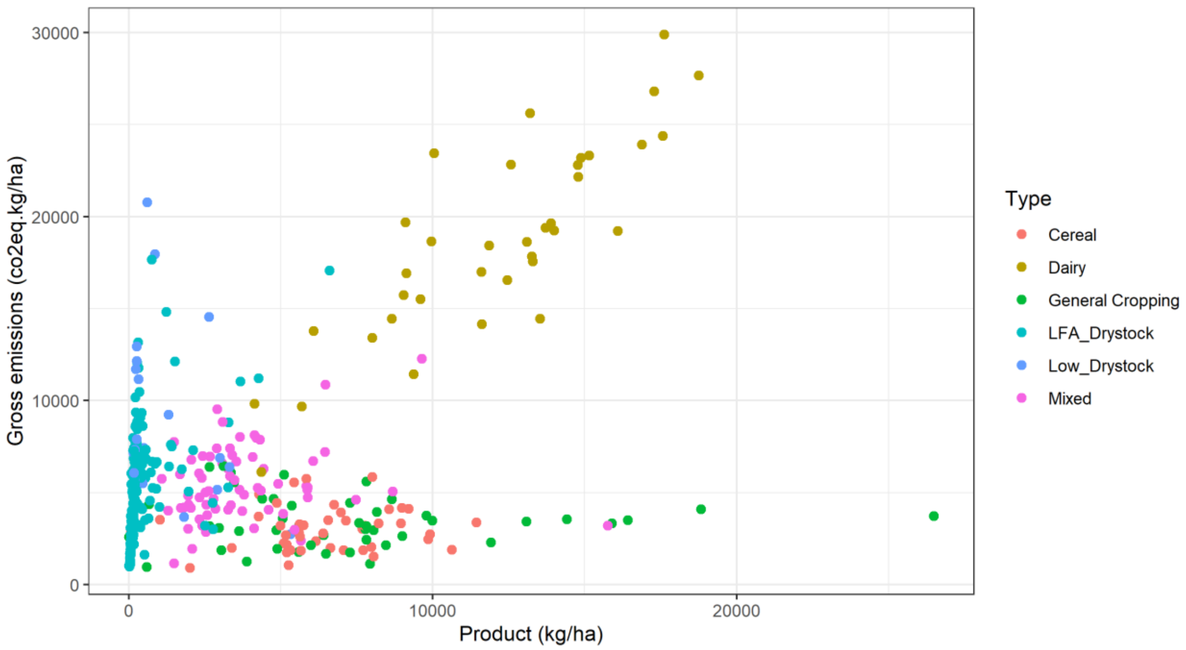


Figure 4 Gross GHG emissions by product produced for all farm types, Kg and kgCO_2e per ha

Given this variation within and between farms in the SFBS, we applied a clustering approach to these farms. This also helped to maximise the information available.

Farms are grouped into clusters based on the average that best fits the characteristics of each cluster[28,29] (see Appendix 1). The most straightforward approach is the K-means clustering approach.

In order to be consistent, we took the same indicators for each farm type to allow some comparison with national reporting. The pilot study, conducted on a smaller sample from the 2018-2019 SFBS, examined greenhouse gas emissions per ha against the ratio of output to input value less subsidies, which infers efficiency of resource use. We firstly explored greenhouse gas emissions per ha against operating profit per ha. The latter provides a proxy for management efficiency and reflects the return to on-farm practices. However, to relate this to the wider literature on emissions intensity we examined Greenhouse gas emissions in kg per ha[30] against agricultural product in kg per ha[31].

---

[28] A simple guide to K-means clustering can be found at: https://www.analyticsvidhya.com/blog/2020/10/a-simple-explanation-of-k-means-clustering/

[29] There are a number of model-based approaches available, however K-means is the most common approach used in the literature.

[30] These are the total emissions (that is direct, indirect, methane and NO_x) per farm measured in CO_2e[30]. When divided by hectare this provides a comparative metric between farms. To accommodate the range of farms in the Scottish FBS, i.e., those with large areas of rough grazing land, we take the total utilised agricultural area adjusted for forage quality as the per ha metric.

[31] This is the sum of agricultural production in livestock (meat), livestock products (milk, wool, eggs) and crops (including straw) on the farm divided by the total utilised agricultural area adjusted for forage quality. This reflects the level of production on the farm.

4 Results

4.1 Specialist Dairy farms

Dairy farming is one of the most specialised production types in Scotland, with the majority of farms in SFBS producing mostly milk. Figures 5a and 5b show the relationship between production of product by kg/ha and GHG emissions at kg CO_2e/ha. The clusters are also shown within the scattergraph.

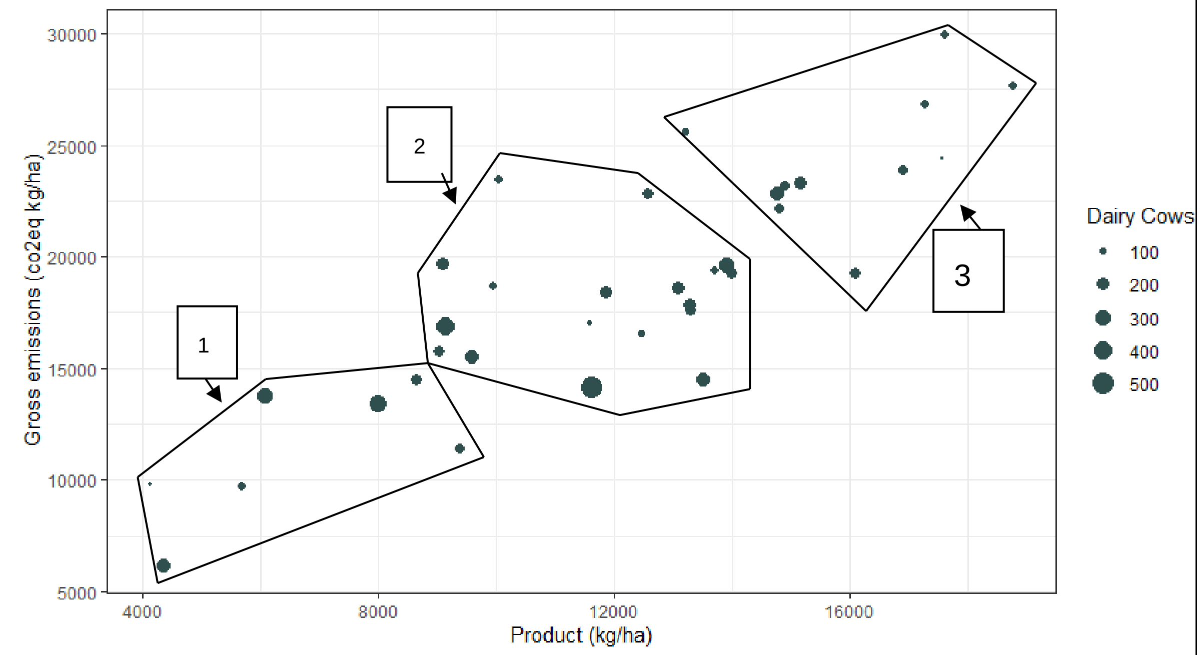


Figure 5a. This shows total product sold in kg/ha, the bulk of which will be from milk sales in this sector, against total direct greenhouse gas emissions (direct and indirect CO_2, NO_x and CH_4). All in kg of CO2e per ha. This shows a clear positive linear trend, as milk production per ha increases the GHG emissions per ha increase.

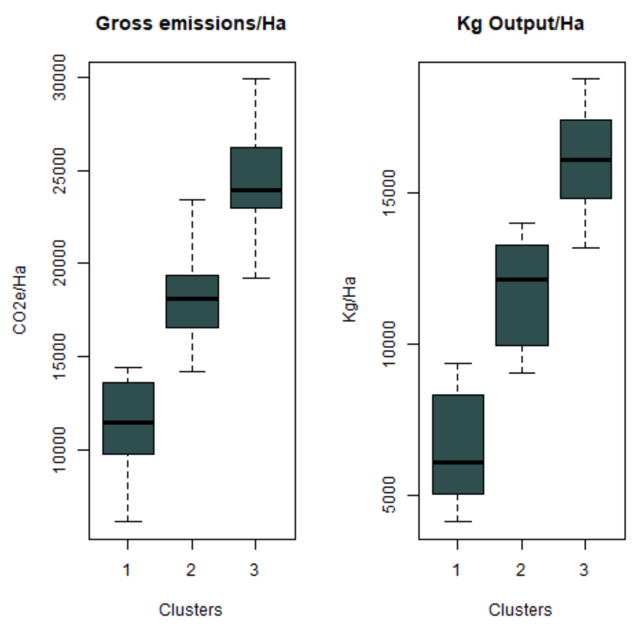


Figure 5b. The figure shows the same two variables grouped into 3 clusters as box plots. These indicate the median, the upper and lower quartile within the box and the ranges, in terms of the whiskers[32].

These show cluster 1 (N=7) with the lowest relative GHG emissions and lowest product per ha, a second group (C 2) (N=18) with mid-level GHG/ha and mid-level production, and a final group (C 3) (N=11) with the highest production and highest GHG emissions per ha. This clearly reflects the linear trends observed above but does show, at the whiskers, the range of emissions and production within each cluster.

Table 2 (a,b,c) shows the main descriptive statistics, showing the level and types of emission (Table 2a), the relationship to economic indicators (Table 2b) and structural indicators (Table 2c) of the clusters. The final column shows whether there is a significant difference between the clusters (performed through the Kruskal-Wallis test described in Appendix 1).

Key findings

- For SFBS dairy farms, a clearly positive linear trend was found between milk production in kilograms per hectare and GHG emissions in kilograms CO2e per hectare. This would mean that, on the whole, as production per ha of milk increases, we would expect GHG emissions per ha to also increase.
- These farms can be classified into three different groups (C1,C2,C3) that have significant differences between both their emission intensity (kg CO2e/ha) and production intensity (kg/ha). Hence, we find for dairy farms that high emitters are also the most intensive.
- High (C3) emitters were found to be more intensive. They have a higher stocking density and a smaller area.
- High emitters were found to have larger expenditure of feed per animal and no reliance on home-produced feed.
- There were no significant differences between standard economic indicators of productivity (output/input ratio) and farm business income. However, gross and net margins were significantly different. This indicates that the low emitting group will have lower gross margins per ha (returns to the enterprise) than those in the high emitting group.

[32] The median is the halfway point between the observations; The upper quartile is the median of the upper half of observations, whereas the lower quartile is the median of the lower half of the observations. The whiskers in a boxplot indicate the spread of the data. Outliers are unique values that fall outside the spread of the data.

Table 2a. Greenhouse gas emissions for SFBS dairy farms

	C.1. (n=7)		C.2 (n=18)		C3 (n=11)		
	mean	sd	mean	sd	mean	sd	sig.
Product (kg/ha)	6,614	*2,084*	11,761	*1,820*	16,088	*1,665*	***
Gross emissions (kg/ha)	11,254	*2,947*	18,097	*2,497*	24,457	*2,921*	***
Direct emissions (kg/ha)	574	*234*	845	*201*	1,272	*344*	***
Indirect emissions (kg/ha)	2,803	*1,227*	5,559	*1,046*	8,668	*1,914*	***
CH_4 emissions (kg/ha)	5,736	*1,386*	8,220	*1,046*	10,665	*1,485*	***
N_{ox} emissions (kg/ha)	2,141	*664*	3,473	*1,896*	3,853	*827*	**
Net emissions (kg/ha)	11,124	*2,999*	17,710	*2,528*	24,271	*2,920*	***

Significantly different at ***0.001; **0.01; *0.05

Table 2b. Economic indicators of the dairy farm clusters

	C.1. (n=7)		C.2 (n=18)		C3 (n=11)		
	mean	sd	mean	sd	mean	sd	sig.
Operating profit (£/ha)	259	*385*	328	*511*	(303)	*1,057*	
Variable cost (£/ha)	1,163	*440*	1,916	*430*	2,871	*530*	***
Gross margin (£/ha)	1,387	*601*	1,927	*450*	2,174	*534*	*
Net margin (£/ha)	29	*406*	79	*516*	(609)	*755*	**
FBI (£/ha)	361	*440*	318	*551*	203	*440*	
Output/Input^	1.06	*0.23*	1.05	*0.16*	1.00	*0.09*	

^less subsidies Significantly different at ***0.001; **0.01; *0.05

Table 2c. Farm structural indicators for the dairy farm cluster

	C.1. (n=7)		C.2 (n=18)		C3 (n=11)		
	mean	sd	mean	sd	mean	sd	sig.
Adj. Ag. Area	213	*128*	171	*93*	87	*37*	**
Stocking density	1.59	*0.34*	2.05	*0.33*	2.52	*0.39*	***
Livestock Specialisation	0.98	*0.03*	0.93	*0.11*	0.93	*0.05*	
Feed (£/livestock unit)	467	*216*	629	*162*	817	*157*	**
Homefeed used (%)	6%	*7%*	5%	*7%*	0%	*0%*	*
Nitrogen Use Efficiency	20%	*8%*	20%	*7%*	16%	*2%*	

Significantly different at ***0.001; **0.01; *0.05

4.2 Less Favoured Area (LFA) Drystock farms

Whereas dairy farming tends to represent specialised and increasingly homogenous activities, drystock farms will be a combination of cattle and sheep production and be managed in quite different ways according to farm circumstances. Figure 6(a,b) shows the relationship between production – which will be mostly sheep or beef meat - by kg/ha and GHG emissions at kg CO_2e/ha. As these show more variance they were clustered into 5 groups, with cluster 2,3 and 4 reflecting the bulk of these farms.

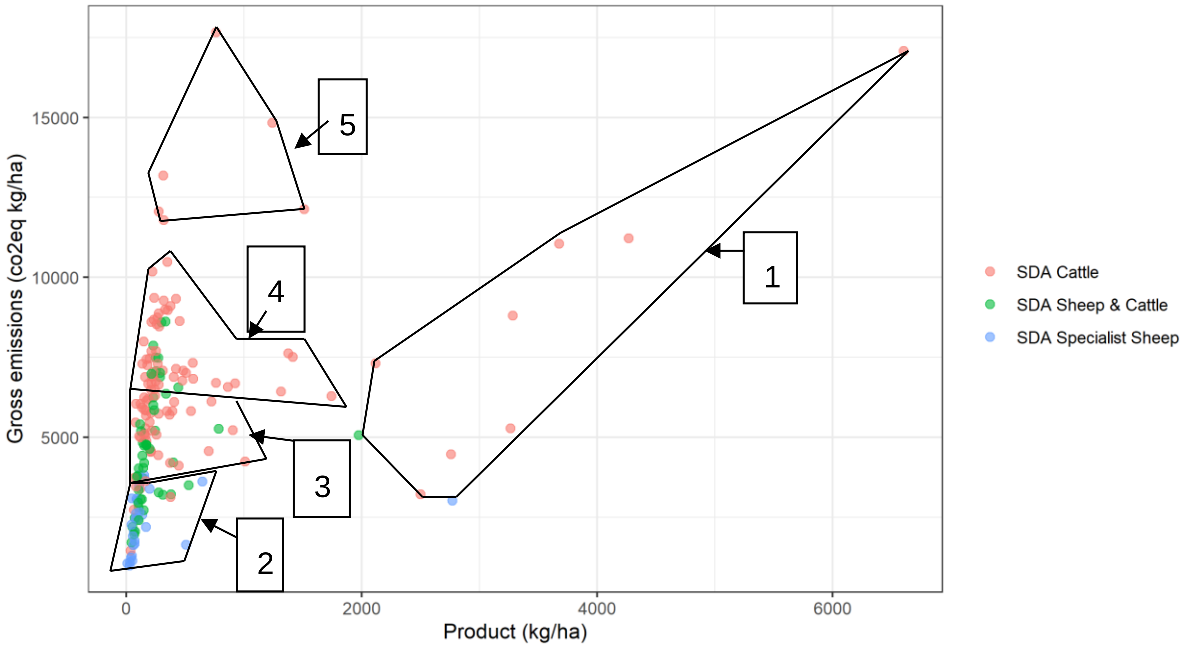


Figure 6a. The figure shows the large amount of variance between production and GHG emissions. A steep positive trend can be observed but this is skewed by a number of farms with distinctly high values for emissions or production, which would reflect a non-typical drystock system.

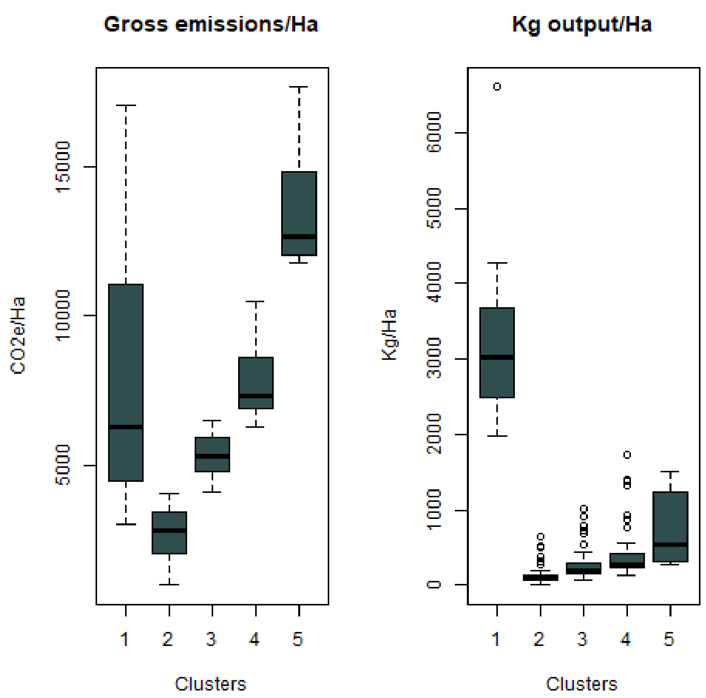


Figure 6b. Given the variance observed in the data the most robust fit resulted in 5 clusters. Cluster 1 (n=10) captured those with very high agricultural production and cluster 5 (n=6) captured those with very high emissions. This may be a result of a higher mixture of other activities that are not clearly measured in the FBS. Hence, the bulk of 'standard' production and emissions in the drystock sector are shown in clusters 2(n=57), 3 (n=56), and 4 (n=56).

The tables below show the relative spread of emissions, economic indicators and structural characteristics of the farms along with an indication of whether these clusters are unique. As noted, a small number of farms in clusters 1 and 5 reflected either higher levels of emissions or much higher amounts of production than would be expected for this farm type. Cluster 1 seems the most mixed in terms of production as it has dairy cattle, and the production of milk is affecting both the emissions and kg production figures. This cluster also produces the highest amount of crop activity leading it to have the lowest level of livestock specialisation. Cluster 5 is the most specialised in beef-meat production, which may explain the high GHG emissions. Farms in this cluster also have a very high farm nitrogen surplus, indicating overuse of inputs.

The SFBS also collects information on lowland cattle and sheep farms. A cluster analysis including these alongside the LFA drystock farms is included in Appendix 1.

Key findings

- For SFBS LFA Drystock farms, there is a wide variation in kilograms production per hectare and GHG emissions in kilograms CO2e per hectare.
- These farms can be classified into five different groups that have significant differences between both their emission intensity (kg CO2e/ha) and production intensity (kg/ha). We find that two clusters (Cluster 1 and Cluster 5), have extreme values and should be discounted as outliers to the analysis.
- Cluster 2 has the lowest emissions per ha but also the lowest level of production per ha, leading to the worst emissions intensity (gross emissions by production). This cluster is potentially the result of the lowest productivity and the lowest NUE. This cluster is composed of wholly specialist sheep producers.
- Clusters 3 and 4 have higher emissions and production per ha and relatively similar emissions intensity. These are composed of either specialist cattle (Cluster 3) or are more mixed with cattle and sheep (Cluster 4).
- There were some significant differences between operating profit (which reflect some management efficiency differences), net margins as well as productivity. But no differences in gross margins, farm business income or operating profit. Generally, the lowest emitting cluster (C2) tends to have higher net margins compared to other clusters (though only through making a lower financial loss). However, the majority of these are only weakly significant, whereas other non-financial factors seem significant at higher levels of confidence.

Table 3a. Greenhouse gas emissions for the drystock farm clusters*

	C 1(n=10)		C2(n=57)		C3(n=56)		C4(n=56)		C5(n=6)		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	sig.
Product (kg/ha)	3,320	1,349	130	127	268	203	406	339	734	533	***
Gross emissions (kg/ha)	7,658	4,451	2,704	880	5,353	683	7,670	1,016	13,614	2,281	*
Direct emissions (kg/ha)	434	152	150	90	264	106	378	110	580	77	
Indirect emissions (kg/ha)	1,905	1,397	368	227	910	303	1,296	521	2,905	1,309	
CH_4 emissions (kg/ha)	3,659	2,115	1,593	497	2,890	469	4,130	642	6,468	882	*
N_{ox} emissions (kg/ha)	1,660	944	593	210	1,289	249	1,866	395	3,660	1,417	*
Net emissions (kg/ha)	7,425	4,162	1,228	5,684	5,229	716	7,475	1,126	13,437	2,076	*

* C1 and C5 represent extreme values and are excluded from the analysis

Significantly different at ***0.001; **0.01; *0.05

Table 3b. Economic indicators of the drystock farms clusters*

	C 1(n=10)		C2(n=57)		C3(n=56)		C4(n=56)		C5(n=6)		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	sig.
Operating profit (£/ha)	36	314	(77)	233	(106)	257	(141)	361	(587)	558	**
Variable cost (£/ha)	667	410	207	96	385	111	543	174	1,006	361	
Gross margin (£/ha)	910	363	428	170	639	222	836	302	1,027	413	
Net margin (£/ha)	(146)	247	(127)	240	(185)	227	(198)	341	(487)	495	*
FBI (£/ha)	197	216	88	180	96	154	149	220	71	347	
Output/Input^	0.95	0.19	0.63	0.24	0.76	0.15	0.81	0.16	0.82	0.17	**

^less subsidies; * C1 and C5 represent extreme values and are excluded from the analysis

Significantly different at ***0.001; **0.01; *0.05

Table 3c. Farm structural indicators for the drystock farm clusters*

	C 1(n=10)		C2(n=57)		C3(n=56)		C4(n=56)		C5(n=6)		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	sig.
Adj. Ag. Area	186	163	257	172	201	135	155	93	66	24	
Stocking density	1.13	0.56	0.63	0.21	0.92	0.16	1.27	0.21	1.97	0.42	***
Livestock Specialisation	0.92	0.13	0.97	0.07	0.97	0.08	0.98	0.04	0.99	0.01	**
Feed (£/livestock unit)	303	104	146	80	180	84	192	82	269	114	
Homefeed used (%)	16%	29%	3%	12%	19%	25%	17%	22%	25%	35%	
Nitrogen Use Efficiency	35%	26%	14%	12%	17%	14%	16%	11%	12%	7%	**

* C1 and C5 represent extreme values and are excluded from the analysis

Significantly different at ***0.001; **0.01; *0.05

4.3 Specialist Cereal farms

The majority of activity of these farms will be focused on arable activity, the production of cereals. However, some farms will have a wider mix of crops and also livestock production. The results of the clustering exercise are shown below. The observations are shaded with respect to their level of crop specialisation, which is the proportion of revenue from cropping activities to total agricultural revenue.

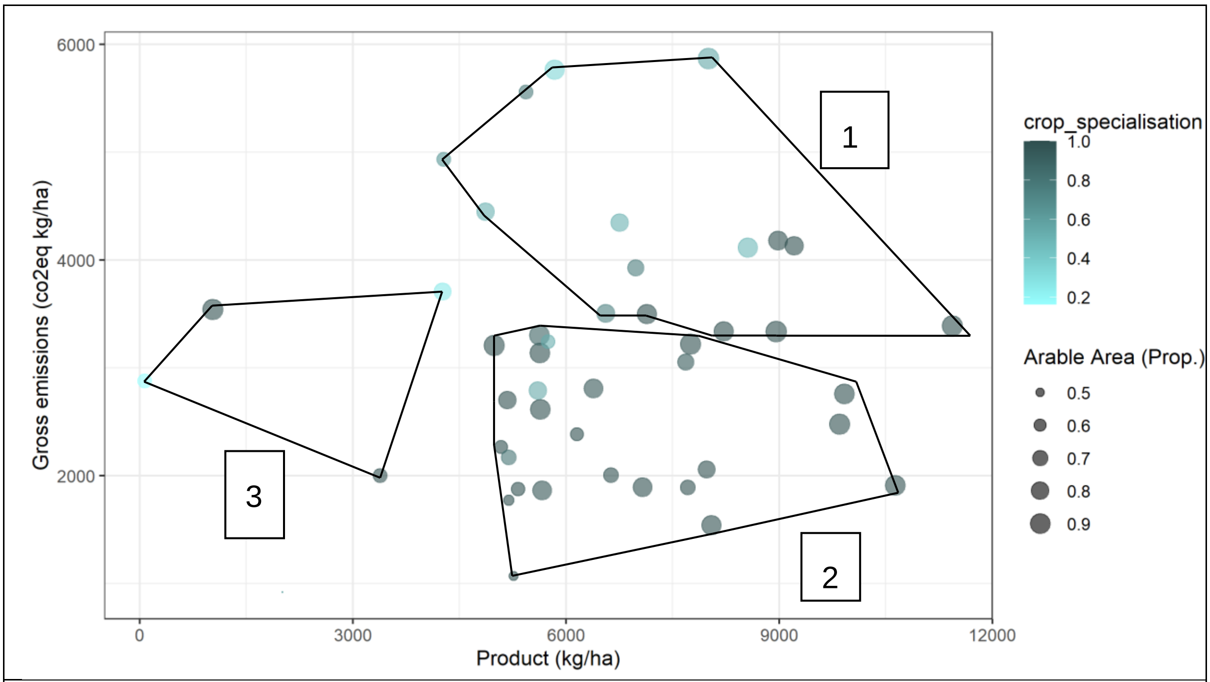


Figure 7a. The figure shows the lack of a clear linear relationship between the emissions of GHG per ha and product of kg per ha. This may be because some cereal farmers have livestock whereas others do not. This is shown in terms of crop specialisation, namely the rate of crop revenue to total agricultural revenue. For the majority of farms in cluster 2 there is a higher level of crop specialisation (the darker shade) than the high emitter cluster 3. Whilst there are some farms with high levels of crop specialisation, Cluster 3 is mostly dominated by farms with a greater mix of livestock and crop activity.

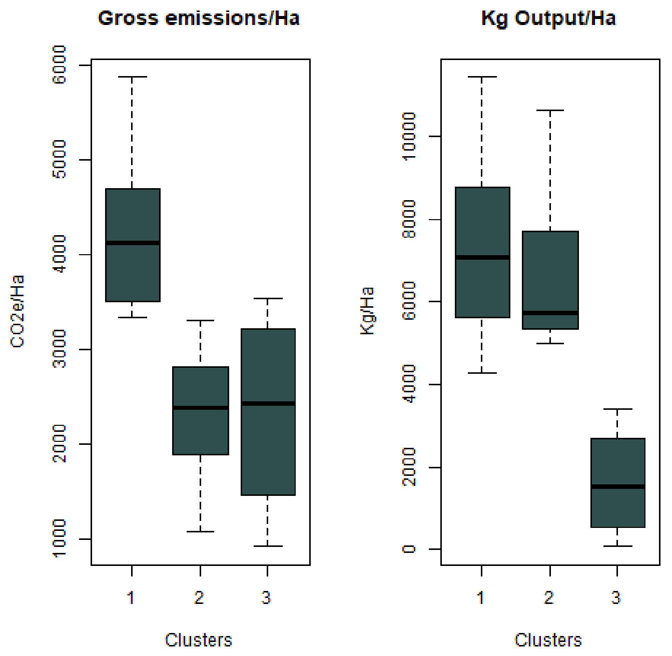


Figure 7b shows a 3-cluster solution where C1 (n=16) has a distinctly high level of emissions per ha, and C3 (n=4) has a distinctly lower level of production per ha. Cluster 2 (n=25) seems to have the medium level of emissions but has a level of production which compares with the high emitting group (C1).

The tables show the various indicators and differences between clusters. Cluster 2 is the most specialised for cereal production, has the highest nitrogen use efficiency, at 99.5% and lowest nitrogen surplus compared to other clusters. Cluster 3 has an amount of sheep production compared to the other clusters and is the less specialised of the three clusters, though this only represents 4 farms. Cluster 1 has the highest level of cattle production compared to the other clusters. This leads to much higher methane emissions compared to other clusters.

Key findings

- There is no clear relationship between emissions and production per ha. Cluster 1 has the highest amount of production per ha and almost double the kg/ha compared to other clusters. Cluster 2 has high levels of production per ha and low levels of emissions, leading to much lower emissions intensity. Cluster 3 has a similar level of emissions as Cluster 2 but as much lower production.
- The only economic indicator that shows a significant difference is variable costs, however other economic indicators are not significant.
- Cluster 2, the specialised cereals cluster, has NUE at 100%. This shows potential mining of soil, i.e., non replacement of nutrients extracted, and, consequently, could affect soil fertility in the long term.

Table 4a. Greenhouse gas emissions for the cereal farm clusters

	C1(n=16)		C2(n=25)		C3(n=4)		
	Mean	*SD*	Mean	*SD*	Mean	*SD*	sig.
Product (kg/ha)	7,217	*2,000*	6,637	*1,655*	1,623	*1,415*	**
Gross emissions (kg/ha)	4,255	*860*	2,401	*612*	2,334	*1,135*	***
Direct emissions (kg/ha)	549	*130*	464	*97*	368	*66*	**
Indirect emissions (kg/ha)	1,871	*382*	1,060	*386*	848	*698*	***
CH_4 emissions (kg/ha)	533	*509*	57	*143*	379	*566*	**
N_{ox} emissions (kg/ha)	1,301	*187*	820	*229*	739	*512*	***
Net emissions (kg/ha)	4,186	*862*	2,078	*752*	2,334	*1,135*	***

Significantly different at ***0.001; **0.01; *0.05

Table 4b. Economic indicators of the cereal farm clusters

	C 1(n=16)		C2(n=25)		C3(n=4)		
	Mean	*SD*	Mean	*SD*	Mean	*SD*	sig.
Operating profit (£/ha)	71	258	19	244	(508)	1,124	
Variable cost (£/ha)	635	164	373	78	308	61	***
Gross margin (£/ha)	946	288	905	226	738	175	
Net margin (£/ha)	(83)	284	(104)	179	(576)	824	
FBI (£/ha)	175	286	220	267	398	750	
Output/Input^	0.99	0.18	1.01	0.23	1.10	0.46	

^less subsidies

Significantly different at ***0.001; **0.01; *0.05

Table 4c. Farm structural indicators for the cereal farm clusters

	C 1(n=16)		C2(n=25)		C3(n=4)		
	Mean	*SD*	Mean	*SD*	Mean	*SD*	sig.
Adj. Ag. Area	218	*132*	171	*93*	139	*118*	
Crop specialisation	0.73	*0.26*	0.95	*0.13*	0.68	*0.40*	*
Fertiliser (£/ha)	216	*32*	155	*41*	84	*49*	***
Nitrogen Use Efficiency (%)	75%	*13%*	100%	*39%*	37%	*29%*	**

Significantly different at ***0.001; **0.01; *0.05

4.4 General Cropping farms

Compared to more specialised farm types we would expect general cropping to have higher mixes of intensive cropping practices, e.g., potatoes and vegetables, but also more animals which would distort any linear relationship between production and GHG emissions. This is shown through the crop specialisation scale, with darker shades denoting higher levels of crop to total revenue.

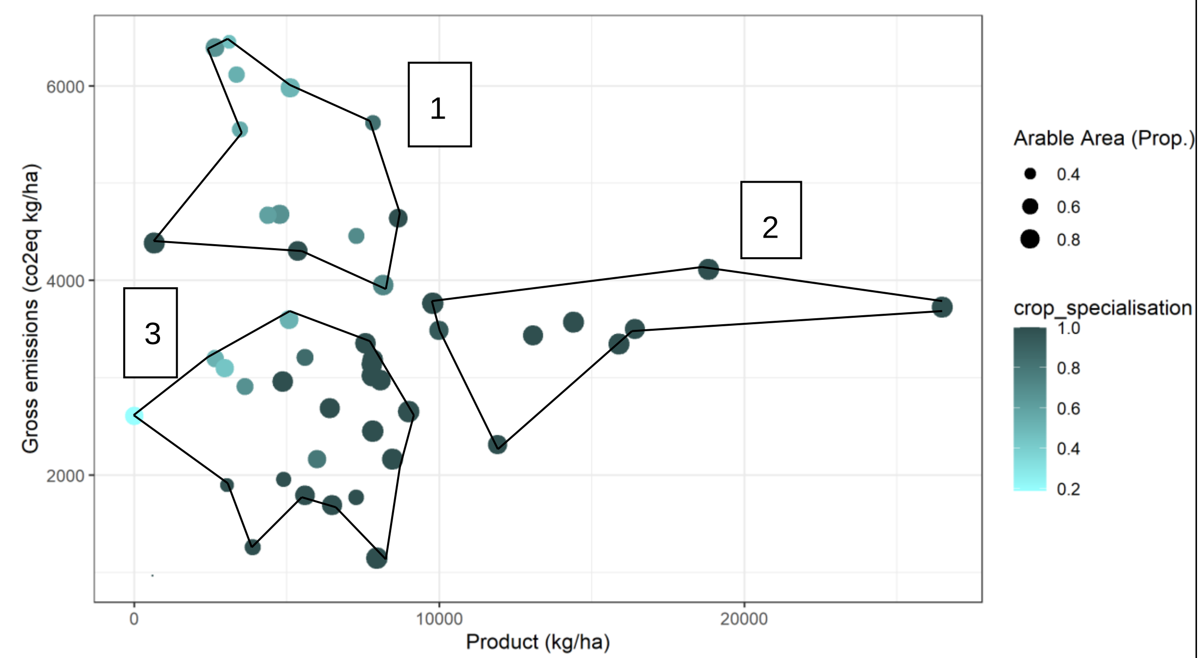


Figure 8a. The figure fails to show a clear linear relationship between production and greenhouse gas emissions. The high emitting group (C1) shows more of a mix of activities, indicating the presence of both livestock and crops on these farms, compared to the low emitting C3.

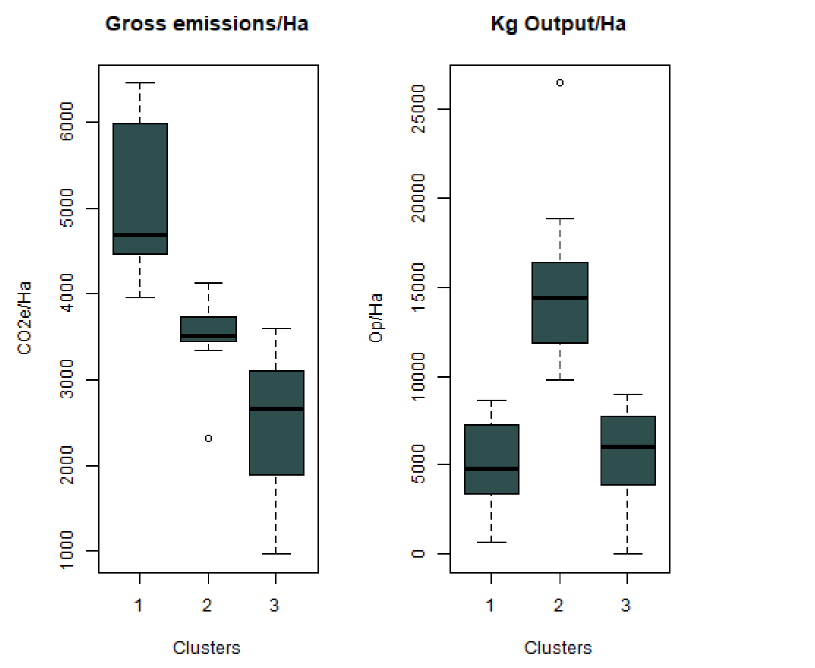


Figure 8b. The final clustering solution found 3 clusters with cluster 1 (n=13) with the highest emissions, cluster 3 (n=25) with the lowest emissions but with similar levels of production.

Cluster 2 (n=9) has a medium level of GHGs but the highest amount of production, cluster 2 also identifies an outlier with very high production and low GHGs. This was removed from further analysis and described below.

The general indicators are shown in the tables below. The outlier in cluster 2 (shown in figure 8b) is a significantly larger producer, with no animal products, producing around 5 times as many potatoes and a much higher fertiliser intensity per ha compared to others in cluster 2. The tables below show the descriptive statistics with this outlier removed, as it will have the effect of misrepresenting the true mean and variance in cluster 2. Appendix 5 shows the results with the outlier included for completeness.

Cluster 1 produces the highest level of cattle meat as well as sheep meat compared to other clusters. This leads to its high emitter status, with much higher rates of methane emitted compared to the other clusters. Cluster 2 is the most specialised (at 99% crop specialisation) with a very small amount of cattle-meat produced. Though it produces potatoes, the cluster produces the highest amount of wheat, barley and OSR. Cluster 3 farms produce around half the cattle meat compared to C1 but has a lower spread of emissions.

Key findings

- There is no clear linear relationship between production intensity and greenhouse gas emissions.
- The largest emitting group (C1) produces at a similar level to C3 which is the lowest emitting group.
- Even with the outlier removed Cluster 2 produces a significantly higher amount of output at only average emission status. Cluster 2 has the lowest emissions per product and the highest productivity rate. This cluster represents the closest to a general cropping farm in terms of output.
- All economic variables were significantly different across the clusters. Cluster 2 has the highest Farm Business Income, Gross and Net Margins compared to the other clusters. The high emitting cluster (C1) has the lowest productivity, lowest NUE, negative net margins and the lowest operating profits, representing low management efficiency, compared to the other clusters.

Table 5a. Greenhouse gas emissions for the general cropping farms (with outlier removed)

	C1(n=13)		C2(n=8)		C3(n=25)		
	Mean	*SD*	Mean	*SD*	Mean	*SD*	sig.
Product (kg/ha)	4,982	*2,416*	13,787	*3,199*	5,645	*2,463*	***
Gross emissions (kg/ha)	5,170	*873*	3,443	*515*	2,477	*747*	***
Direct emissions (kg/ha)	547	*176*	775	*266*	431	*132*	**
Indirect emissions (kg/ha)	1,649	*330*	1,615	*305*	997	*406*	***
CH_4 emissions (kg/ha)	1,418	*921*	17	*47*	265	*461*	***
N_{ox} emissions (kg/ha)	1,557	*275*	1,037	*196*	783	*268*	***
Net emissions (kg/ha)	5,109	*854*	3,323	*506*	2,358	*894*	***

Significantly different at ***0.001; **0.01; *0.05

Table 5b Economic indicators of the general cropping farms (with outlier removed)

	C1(n=13)		C2(n=8)		C3(n=25)		
	Mean	*SD*	Mean	*SD*	Mean	*SD*	sig.
Operating profit (£/ha)	9	*332*	648	*389*	164	*398*	**
Variable cost (£/ha)	609	*198*	837	*195*	347	*101*	***
Gross margin (£/ha)	1,006	*223*	1,787	*507*	1,168	*660*	**
Net margin (£/ha)	(183)	*272*	401	*327*	39	*355*	**
FBI (£/ha)	177	*210*	671	*358*	343	*285*	**
Output/Input^	0.97	*0.13*	1.29	*0.15*	1.08	*0.24*	*

^less subsidies

Significantly different at ***0.001; **0.01; *0.05

Table 5c. Farm structural indicators for the general cropping farms (with outlier removed)

	C1(n=13)		C2(n=8)		C3(n=25)		
	Mean	*SD*	Mean	*SD*	Mean	*SD*	sig.
Adj. Ag. Area	216	*87*	223	*122*	163	*76*	
Crop specialisation	0.71	*0.19*	0.99	*0.02*	0.88	*0.23*	**
Fertiliser (£/ha)	199	*39*	265	*130*	126	*49*	***
Nitrogen Use Efficiency	59%	*12%*	94%	*29%*	95%	*34%*	***

Significantly different at ***0.001; **0.01; *0.05

4.5 Mixed farms

Mixed farms comprise both crop and livestock activities. These are identified within the SFBS as not having any enterprise above two/thirds of total income. Figure 9a below shows the spread of production and GHG emissions intensities, with the observation shaded to represent the level of crop specialisation (to remain consistent with the previous figures). Also, the size of the observation reflects the total adjusted area, namely the amount of land adjusted for forage quality.

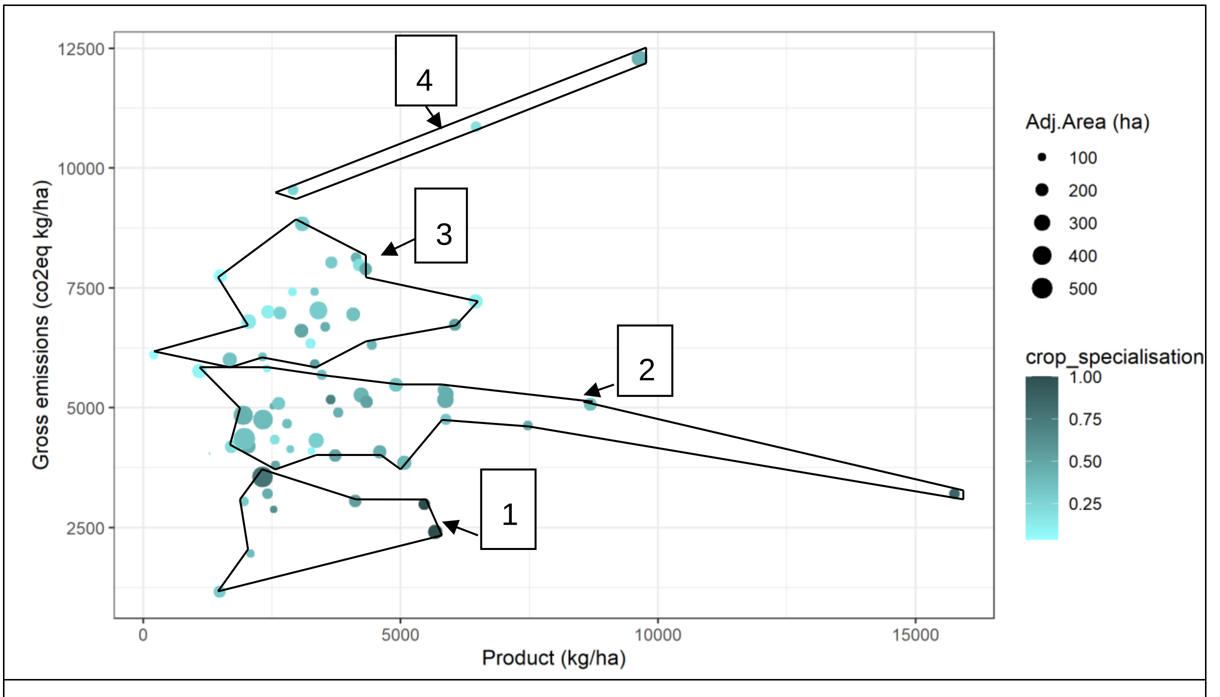


Figure 9a. The relationship between GHG emissions per ha and the amount of product per ha is distorted by the differing mixtures of livestock to cropping activities. A lower emitter group (C1) shows a higher proportion of farms generating more crop than livestock revenue.

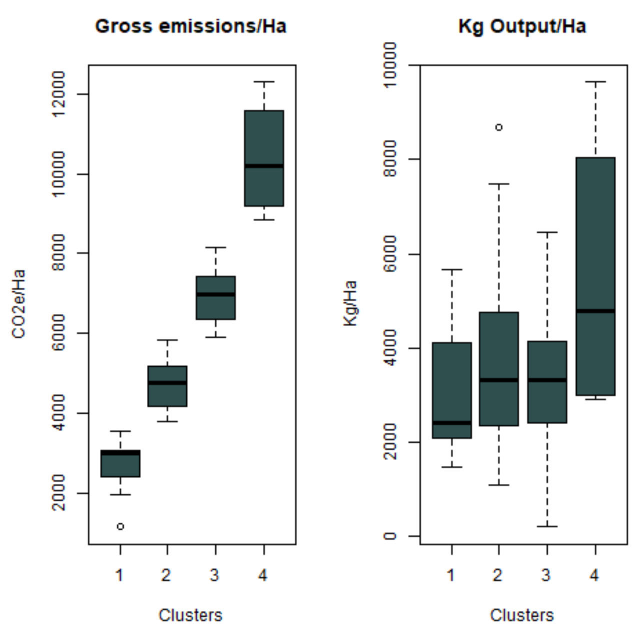


Figure 9b cluster 1(n=9) with the lowest level of emissions, and cluster 4(n=4) with the highest levels of emissions.

The remainder (Cluster 2(n=32) and Cluster 3(n=22) show that there are distinct differences in emissions from the bulk of mixed farms. Notably, perhaps due to the mix of enterprises, there are only slight differences in the median of output produced across the four clusters, though the lowest emitter (C1) has a lower median value, and the highest emitter (C4) has the highest median value.

The tables show the descriptive statistics across environmental, economic and structural indicators. Clusters 3 and 4 have the highest levels of livestock specialisation (at around 70% of total revenue) compared to the other clusters. Though cluster 4 has much higher levels of output from cereals and beef meat compared to the other clusters, this cluster has only 4 observations and consequently represents outliers to this farming type. Cluster 1 is the most specialised in terms of cropping outputs (around 60% of total revenue), it has the smallest amount of beef meat sold (less than a fifth compared to the highest emitter (C4)) and, despite being more specialised, only half the total crop output of the highest emitter. Cluster 1 also has the best nitrogen use efficiency measure at 83%, whereas cluster 4 is at 39%.

Cluster 2 is less specialised in livestock (around 63% of total revenue), and cluster 3 the most specialised (71% of total revenue). The differences between these two clusters tends to pivot on the amount of beef meat sold - cluster 2 sells around half that of cluster 3 but sells the highest amount of lamb meat and wool within the sample. Cluster 2 also sells more crop output compared to cluster 3 and has a higher nitrogen use efficiency and lower nitrogen surplus than cluster 3.

Key findings

- There is no linear relationship between emissions and production intensity for the mixed farming type. Whilst most clusters maintain a relatively similar level of production, their emissions vary significantly.
- Cluster 4 has the highest emissions intensity but only represents four farms, which indicates these farms are outliers. Cluster 1 has the lowest emissions. This only has 9 observations. Most farms tend to be in Clusters 2 and Clusters 3.
- Cluster 2 has much lower greenhouse gas emissions to production compared to Cluster 3. This is driven by lower levels of livestock specialisation, lower fertiliser per ha costs and a higher Nitrogen Use Efficiency.

- Economic indicators are relatively similar between clusters 2 and 3, with cluster 3 generating higher Farm Business Income per ha. However, there is a great deal of variance in economic performance between clusters.

Table 6a. Greenhouse gas emissions for the mixed farms

	C 1(n=9)		C2(n=32)		C3(n=22)		C4(n=4)		
	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*	sig.
Product (kg/ha)	3,113	*1,562*	3,640	*1,817*	3,316	*1,406*	5,525	*3,192*	***
Gross emissions (kg/ha)	2,700	*740*	4,735	*591*	6,973	*697*	10,385	*1,522*	***
Direct emissions (kg/ha)	402	*132*	447	*150*	548	*111*	997	*862*	**
Indirect emissions (kg/ha)	1,059	*498*	1,156	*344*	1,737	*453*	3,510	*2,463*	***
CH_4 emissions (kg/ha)	559	*533*	1,837	*509*	2,850	*393*	3,557	*1,532*	***
N_{ox} emissions (kg/ha)	680	*275*	1,294	*219*	1,838	*293*	2,320	*627*	***
Net emissions (kg/ha)	2,356	*746*	4,359	*1,150*	6,747	*764*	10,371	*1,517*	***

Significantly different at ***0.001; **0.01; *0.05

Table 6b Economic indicators of the mixed farms

	C 1(n=9)		C2(n=32)		C3(n=22)		C4(n=4)		
	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*	sig.
Operating profit (£/ha)	(160)	*193*	(172)	*343*	(70)	*181*	(100)	*245*	
Variable cost (£/ha)	344	*80*	511	*151*	739	*286*	1,277	*875*	***
Gross margin (£/ha)	576	*261*	770	*359*	878	*254*	1,820	*764*	**
Net margin (£/ha)	(257)	*151*	(242)	*305*	(207)	*155*	(169)	*263*	
FBI (£/ha)	(51)	*153*	75	*226*	94	*251*	263	*150*	*
Output/Input^	0.72	*0.19*	0.88	*0.18*	0.90	*0.16*	1.01	*0.04*	*

^less subsidies

Significantly different at ***0.001; **0.01; *0.05

Table 6c. Farm structural indicators for the general cropping farms

	C 1(n=9)		C2(n=32)		C3(n=22)		C4(n=4)		
	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*	sig.
Adj. Ag. Area	190	*125*	197	*112*	180	*65*	203	*71*	
Livestock Specialisation	0.40	*0.28*	0.64	*0.14*	0.71	*0.16*	0.70	*0.11*	*
Fertiliser (£/ha)	89	*37*	137	*39*	175	*44*	218	*119*	***
Feed (£/livestock unit)	310	*197*	262	*145*	330	*226*	1,107	*1,766*	
Homefeed used (%)	0.21	*0.29*	0.48	*0.27*	0.47	*0.19*	0.12	*0.13*	*
Nitrogen Use Efficiency (%)	84%	*49%*	65%	*29%*	51%	*14%*	39%	*9%*	*

Significantly different at ***0.001; **0.01; *0.05

5 Discussion

5.1 How should we measure emissions intensity to compare farms?

Analysing current emissions variation across SFBS farms helps to show whether best practice – in terms of overall management efficiency - can deliver emission savings without incurring significant financial performance penalties. This helps to understand whether the option might be adopted more widely.

Emissions per farm are not particularly helpful as a comparator between farms, given the variation in farm types and sizes within the SFBS. As an alternative, emissions-intensity allows for comparisons across different farm scales and has been used here.

However, there are two ways to present intensity – per kg of output or per ha of land. Both are legitimate metrics but offer different perspectives and can give different impressions under certain circumstances. For example, intensive beef rearing can have high output and high emissions per ha but low emissions per kg of output.

Although this can cause confusion, it is not a reason to use only one metric – they both offer useful insights. Specifically, the purpose of the analysis is to explore how emissions-intensity varies across different farms and whether such variation can be linked to explanatory variables, including enterprise mix and production efficiency. That is, the policy interest is in whether emissions-intensity is susceptible to management changes and therefore could be reduced through wider diffusion of best practice.

5.2 What are the implications of finding variances within farming sectors?

At the national level, emission reduction targets are set in absolute terms as a specific volume of carbon dioxide equivalent (CO_2e) to be avoided. There are various pathways to achieving specified reductions, including changes to the mix of activities undertaken and/or the manner in which they are undertaken. For example, producing less ruminant meat and/or improving the efficiency with which it produced.

Indeed, a key pattern confirmed by the analysis presented here is that emissions-intensity varies significantly across farm types, or more subtly across enterprise mixes. That is, due to fundamental differences in their underlying production processes and the volume of output generated, different enterprises have very different emission profiles. For example, most notably, ruminant livestock compared to cereals, but also root crops compared to cereals.

This has implications for how results should be interpreted (discussed in the next sections), catered for here via clustering. It also has potential implications for how policy might treat different enterprises. For example, if carbon pricing were applied to agricultural output, higher emission-intensity enterprises would be affected more – suggesting that low emission activities would be preferred.

Yet farmland management also delivers other ecosystem service benefits, including landscapes and semi-natural habitats for biodiversity. If these were also accounted for, it is not certain that higher emission-intensity enterprises would necessarily be less socially desirable than lower-emission activities. That is, there is a balance to be struck.

Such issues are beyond the scope of this report, but it is suggested that results presented here should not be interpreted as evidence of the relative desirability of different farm types or enterprise mixes but only more narrowly as evidence of the potential to reduce emissions arising from a given enterprise or enterprise mix. That is, attention is focused on the scope for reducing the emissions intensity of activities, not changing the mix of enterprises.

5.3 What are the inconsistencies with the smart inventory and other approaches?

As noted in the introduction, the LCA perspective of Agrecalc (and other farm-level carbon calculators) is different from the sectoral perspective of the National Inventory. For example, sequestration into soils or woodland is in the LULUCF rather than Agriculture chapter of the Inventory. This means that overall Agrecalc emission estimates need to be disaggregated into their component elements if they are to be compared with figures reported in the Inventory. This is not overly burdensome but is a further complication. In addition, emissions arising downstream of farms will appear in the Inventory but are not covered by Agrecalc which only covers up to the farmgate.

This difference has been catered for here by

- focusing on gross rather than net emissions, and
- the reality that the bulk of gross emissions associated with farming arise from on-farm rather than off-farm activities.

Nevertheless, the difference in perspectives is a potential source of confusion for farm managers and in policy design, and needs to be acknowledged explicitly. Future analysis could usefully extend to consider sequestration effects, to make fuller use of the information generated by Agrecalc. Critically, to help policy makers nudge farmers to meet climate change targets, farm level carbon audits based on net emissions would appear essential to encourage and reward farmers for desired actions.

However, following revisions to the methodologies used in both the Agriculture and LULUCF sections of the Inventory, Agrecalc is not currently aligned perfectly with the Inventory in terms of assumptions and data. Whilst this is unlikely to materially affect the general patterns revealed by the analysis presented here, future analysis would benefit from methodologies being more fully aligned.

Better use of nitrogen information gathered via the SFBS, would also provide an opportunity to crosscheck the Scottish Nitrogen Balance Sheet. At the very least it would provide simple metrics on nitrogen usage (e.g., N per ha) by farm type that would aid discussion. Nitrogen use efficiency (NUE) is a potentially useful agro-environmental metric that can be relatively easily extracted from the SFBS dataset, though extra input is required to capture N supplied by, for example, legumes and crop residues and some further checking of the calculation is required. Moreover, the cluster achieving best emissions efficiency for the specialist cereals type averaged 100% NUE and so requires more qualification: at this level, soil “mining” is occurring which is not positive in terms of soil health.

To sum up, NUE is a useful but single metric that should be used in combination with other indicators in assessing farm performance.

5.4 What are the implications of not covering some farm types?

The SFBS excludes specialist pig, poultry and horticulture farms. Collectively, these sectors account for only a small fraction of total greenhouse gas emissions from Scottish agriculture (see Figure 1). Yet each sector is expected to play its part in helping to reduce emissions and hence there may be merit in applying the SFBS methodology to a sample of such farms. In particular, given the Farmer Led Group report on the pig sector[33], this might be a sensible first extension to the analysis presented here. However, the practicalities of this would require further consideration, including the treatment of pig production within Agrecalc.

5.5 What is the relationship between emissions and economic performance?

We find little evidence of a clear relationship between lower emissions intensity and stronger economic performance. In some sectors, the lowest emitters do show better financial returns, but in others the reverse is true, and in most sectors only a small number of financial indicators are significantly different. This may reflect unexplored interactions between, for example economies of scale (or scope) and the costs vs. productivity effects of investment in equipment and training required to increase efficiency of variable input usage. However, we must emphasise that the analysis was focused on a single crop year and repeating this exercise over a number of years would provide a more robust assessment of this relationship.

6 Conclusions and recommendations

Although only an exploratory analysis of the potential insights obtainable from combining SFBS data with Agrecalc, the results presented above allow the following conclusions:

- The combined data do reveal variation across farms. Moreover, the patterns revealed are broadly as expected in terms of how farm type and enterprise mix affect emissions-intensity. There is some, though hardly compelling, evidence of variation in managerial efficiency consistent with aspirations to promote wider adoption of best practice, for example, improved utilisation of feed, fertiliser and fuel through better planning and targeting to simultaneously lower costs and emissions.

- Whilst the use of cluster analysis helps to isolate differences in enterprise mix and managerial efficiency, some of the resulting sub-sample sizes are quite small. Moreover, because the SFBS sampling frame is based on farm types and size rather than emission profiles, its representativeness of emissions is assumed rather than guaranteed. Both factors may reduce the statistical significance of results presented, but do not necessarily reduce their value as illustrative case studies (with the consistent measurement basis and overall sample size of the SFBS offering advantages over smaller and more *ad hoc* case studies). That is, the analysis is still powerful in helping to reveal patterns and potential for emission reductions.

- While there may be benefits in adjusting the sample size and/or sampling frame of the SFBS, we do not think this is feasible (although a bespoke, parallel study of pig

[33] See: https://www.gov.scot/publications/pig-sector-flg-climate-change-greenhouse-gas-evidence/pages/1/

farms might be desirable[34]). Collection of some additional data items could nonetheless be valuable, for example, animal health data which has been found to have a significant influence on GHG emissions[35]. In addition, some simple categorical variables around uptake of major practices and innovations, e.g. use of nitrogen management planning and cover for slurry storage, could be added with minimal impact on surveying time. This would provide considerable understanding to the differences between farms of similar structural characteristics but with significantly different emissions intensities. Moreover, whilst this is an exploratory analysis and we use common indicators of performance, e.g. farm business income, the SFBS could be explored further to establish other metrics which may explain differences, e.g. debt ratios may indicate attitudes to investment.

- Although the focus here has been on gross emissions, the approach could usefully be extended to consider net emissions, in particular, sequestration into farm soils and woodland. However, this might need to await revisions to Agrecalc considering recent methodological changes to the LULUCF section of the Inventory relating to (in particular) peatlands. Equally, the SFBS might need to collect additional information on, for example, the presence and condition of hedges and peatlands. The breaking down of gross emissions as an indicator of total emissions across different types of farming would be useful for reporting and give some indication of the balance between gross compared to net emissions.

- Separately, policy deliberations around the scope for farmers' self-reporting of management actions and environmental conditions (e.g. soil carbon, estimated emissions) can be informed by the feasibility and limitations of the analysis presented here, namely the depth of reporting required for accurate measurements. Whilst the consistency and accuracy of self-reported data provided by individual farmers would be expected to be lower than obtained via the SFBS, the data requirements and analytical limitations could be similar.

- Whilst we provide an indication of emissions intensity this only covers one year of data. In order to assess the robustness of our estimates we recommend this exercise be repeated for a number of years. Refinements could help increase estimates' accuracy. In particular, we suggest the SFBS supports additions to N, P, K[36](Kg) measurements; type of fertiliser used and its method of application; that crop residues are accurately recorded; and tonnage and type of organic manures also be recorded. From a livestock perspective, death rates and scanning rates, amongst other information, would help produce more robust emissions' estimates.

- We also note that methods for weighting of different greenhouse gases into composite metrics have been challenged, in particular, the use of GWP* rather than GWP100 to express the impacts of methane emissions. The combination of different metrics with SFBS data would yield different results to those presented here. Emissions from methane are driven mainly by ruminant livestock, and therefore farms with more cattle and sheep enterprises will have markedly different rankings if GWP*, compared to GWP100, were used.

---

[34] Pig production is an important part of the red meat sector, but pig manure contributes towards greenhouse gas emissions and also raises issues for nutrient management more broadly. Gaining an understanding of variation and scope for improvements via SFBS data would be helpful.

[35] see Eory et al (2020) https://www.climatexchange.org.uk/media/4612/cxc-marginal-abatement-cost-curve-for-scottish-agriculture-august-2020.pdf

[36] Nitrogen, Phosphorus, Potassium

Appendix

Analysis methodology

Data used

In 2019, a pilot study successfully integrated Agrecalc into the Scottish Farm Business Survey (the survey) to provide a carbon audit for each farm surveyed. A subsequent investigation also found that the survey could be used to calculate Nitrogen Use Efficiency (NUE) for each farm. Consequently, the 2019/20 (2020 crop year) survey produced a physical, economic, and environmental data set for 403 farms that forms the basis of this study. Table 1 summarises the key statistics for each farm type.

Table A1. Descriptive statistics by main farming type, with observation numbers for the 2020 crop year

	Dairy		Drystock*		Cereals		General Cropping		Mixed	
	(n=36)		(n=207)		(n=45)		(n=47)		(n=68)	
	mean	*sd*	mean	*sd*	mean	*sd*	mean	*sd*	mean	*sd*
Total area (ha)	158	*103*	427	*674*	188	*111*	195	*95*	194	*96*
Adjusted area (ha)	153	*98*	196	*146*	185	*111*	191	*92*	190	*97*
Farm Woodland Area (ha)	2	*8*	4	*21*	0	*0*	1	*3*	1	*4*
Total wooded area (ha)	4	*9*	7	*24*	3	*5*	2	*5*	6	*17*
Gross GHG emissions (kgCo2e per farm)	2,571,188	*1,212,628*	1,040,996	*816,000*	621,177	*559,085*	698,448	*487,879*	1,052,170	*632,307*
Gross GHG emissions (kgCo2e per ha)	18,710	*5,352*	5,992	*3,218*	3,054	*1,165*	3,413	*1,372*	5,499	*2,008*
Of which										
Direct CO2 (kgCo2e per ha)	923	*359*	301	*166*	486	*119*	545	*254*	507	*260*
Indirect CO2 (kgCo2e per ha)	5,973	*2,493*	1,101	*955*	1,329	*577*	1,285	*480*	1,472	*873*
Methane (kgCo2e per ha)	8,484	*2,129*	3,150	*1,504*	255	*416*	536	*804*	2,077	*1,004*
Nitrous Oxide (kgCo2e per ha)	3,330	*1,548*	1,441	*872*	984	*340*	1,047	*418*	1,444	*515*
Net emissions (kgCo2e per ha)	18,434	*5,362*	5,471	*4,652*	2,850	*1,289*	3,310	*1,434*	5,203	*2,198*
NUE (% per farm)	19%	*6%*	18%	*18%*	86%	*36%*	85%	*32%*	64%	*37%*
FBI (£ per ha)	291	*490*	110	*220*	220	*330*	353	*316*	79	*229*
Operating profit (£ per ha)	122	*744*	(123)	*337*	(9)	*408*	232	*466*	(132)	*272*

*Drystock farms are composed of all cattle and sheep farms, namely LFA Cattle, LFA Sheep, Lowland Cattle and LFA Cattle and Sheep farm types

Note the following when viewing farming types:

- Each farm is “typed” based on the contribution of that farm’s main enterprises to overall economic output.
- The drystock (beef and sheep) farm type is the most common in Scotland and mainly covers livestock rearing and finishing farms in the less favoured area (LFA)[37].
- The other farm types range from purely cropping farms to mixed farms where a significant part of output is generated from livestock.
- Scottish dairying covers farms located in both the LFA and non-LFA.
- Farms where pigs, poultry or specialist horticultural crops predominate, are not covered by the survey.
- There are just 3% of the sample in some form of organic production or conversion in the survey, a number that does not allow meaningful separate analysis, so these farms are combined with conventional farms for GHG emissions. These farms have been excluded from NUE calculations.
- The overall size of each farm, the area of farmed land and total fenced off woodland is shown. Adjusted area excludes areas not used for grass or crops (woodland, roads, buildings), and also adjusts rough grazing to equivalent in-bye (improved) grassland based on pasture productivity (typically at a ratio of 3 to 1). The “per ha” figures used throughout the report are all based on adjusted hectares unless otherwise stated.

Gross GHG emissions are expressed on both per farm and per hectare basis in $kgCO_2e$. The latter is then split into the sub-categories recorded by Agrecalc, based on the main greenhouse gases.

- Direct CO_2 covers the emissions from energy value of oil, diesel, petrol, electric and the share of domestic heating fuel allocated against the business.
- Indirect CO_2 covers the energy embedded in producing and hauling the remaining key inputs (purchased feed, fertiliser, lime, and agrichemicals) used to produce crops, milk, livestock (meat) and wool.
- Most methane (CH_4) is a by-product of ruminant digestion with the balance coming from manure.
- Nitrous oxide (N_2O) is emitted from applied synthetic nitrogen fertiliser and organic manure plus the dung excreted by animals. Volatilisation, leaching, and run-off are key processes in the release of this potent gas.

Identifying high and low emitters

Based on the literature, emissions intensity (EI) was the obvious choice for identifying the low and high emitters. That is for each farm (i),

$$EI_i = \frac{GHG_{kgCO_2e_i}}{Output_{kg_i}}$$

Comparison between enterprises and farm types, however, is not possible on this basis because of the physical (e.g., energy, nutritive value) differences between commodities, e.g., units of milk, meats, grains, oilseeds and straws. Also, emissions intensity does not

[37] Scotland's LFA's are defined by: (i) The presence of poor land of poor productivity, which is difficult to cultivate and with a limited potential which cannot be increased except at excessive cost, and which is mainly suitable for extensive livestock farming. (ii) lower than average production, compared to the main indices of economic performance in agriculture. (iii) a low or dwindling population predominantly dependent on agricultural activity, the accelerated decline of which could cause rural depopulation

measure the absolute level of emissions. Lowering total emissions is, ultimately, the critical metric though emissions intensity is also an important measure to guide decision making at the farm level.

Clearly outliers are a problem. For example, where a drystock farm sells even a small amount of crop the output of that farm becomes atypical compared to most drystock farms that sell no hay or forage. Removing outliers at some determined threshold is one way to deal with this, however given the low observation numbers an alternative approach is to group individual farms based on their similarity within production and GHG emissions. This allows us to maximise the information available from a small data set and speaks to a farm management agenda as we generate peer farms to understand common characteristics of low or high emissions.

In order to maximise the information available, we applied a K-Means clustering. This is a simple approach which groups farms into clusters based on the group average that best fits the characteristics of each cluster[38]. This requires that the number of clusters are firstly identified, and this was conducted mostly through observation of cluster grams (See Appendix 1), to understand whether the clusters were distinctly capturing the variance in production and GHG's.

To cluster these farms, we used two variables:

i) *Gross emissions per ha*. These are the total emissions (that is direct, indirect, methane and NO_x) per farm measured in CO_2e[39]. When divided by hectare this provides a comparative metric between farms. To accommodate the range of farms in the Scottish FBS, i.e., those with large areas of rough grazing land, we take the total utilised agricultural area adjusted for forage quality as the per ha metric.

ii) *Agricultural product in Kg per ha*. This is the sum of agricultural production in livestock (meat), livestock products (milk, wool, eggs) and crops (including straw) on the farm divided by the total utilised agricultural area adjusted for forage quality. This reflects the level of production on the farm.

A first stage in clustering is to standardise these variables to put them on the same scale[40]. A cluster analysis was conducted on each farm type based on visual inspection of these clusters[41], but in the case of mixed and drystock farms - where there was more variance - we validated the choice of clusters based on statistical criteria[42].

Once clusters were finalised, then characteristics of these clusters could be examined. In the tables below we present the mean and standard deviations of each cluster per farm type. To assess whether these characteristics are significantly different we ran a Kruskal-Wallis test on each variable. This compares the mean values of each cluster to assess whether they are significantly different. This test is appropriate when sample sizes are small which applies to our data.

---

[38] A simple guide to K-means clustering can be found at: https://www.analyticsvidhya.com/blog/2020/10/a-simple-explanation-of-k-means-clustering/

[39] The Carbon dioxide (CO2e) equivalent is a measure of how much a gas contributes to global warming, relative to carbon dioxide. Factors are used to convert greenhouse gases, such as methane or nitrate oxide into a common equivalent metric.

[40] See: https://cran.r-project.org/web/packages/standardize/vignettes/using-standardize.html

[41] The R code created for this analysis has been supplied to the SFBS analysts.

[42] There are a number of model-based approaches to determine optimal clusters, but essentially focus on clustering data and basing the decision on the number of clusters based on the lowest Bayesian information criterion (BIC) value.

Main characteristics of clusters

In order to be consistent, we took the same indicators for each farm type to allow some comparison with national reporting. The tables below show characteristics in terms of

i) *Greenhouse gas emissions:* GHG's as explained above but with the addition of net emissions. Net emissions show gross GHG emissions less $kgCO_2e$ sequestered (e.g., woodland, renewables) by that farm over the year surveyed.

ii) *Economic indicators*: Farm Business Income (FBI) is the main income measure used by the Scottish Government and covers income from both agricultural activity and farm diversification (i.e., enterprises using farm resources). Operating profit measures the income generated from agricultural operations. Besides the usual business accounting costs (e.g., feed, fertiliser, fuel, and depreciation) it notably includes the market cost of unpaid family labour but excludes the cost of funding (i.e., interest). In addition, we include variable costs and gross margins, as well as net margins - which includes fixed costs, which equates to a 'partial budget' of these clusters[43]. Finally, an output to input ratio is shown. This is a proxy for farm productivity as it represents the ratio of the value of output without subsidies to the cost of inputs, with higher ratios representing higher levels of productivity.

iii) *Farm structural indicators*: We present the common indicator for farm size, adjusted for forage quality, stocking density - which measures the amount of livestock activity per area, specialisation which represents the proportion of income from either livestock or cropping enterprises. This helps to understand how diversified or specialised some of these clusters may be. Feed and Fertiliser use per livestock unit or ha are common indicators of intensity of activity. In addition, we add an indicator of home feed produced (e.g., the amount of straw produced) to represent internal transfer of inputs, and consequently this may reflect less demand for external inputs.

Calculating nitrogen use efficiency

NUE is a relatively new environmental indicator that measures the nitrogen exported from a farm in its outputs relative to the nitrogen used in producing those outputs. Expressing it as a percentage is preferred given that "per ha" figures are subject to variation in land quality. Crop farms typically return a high NUE (60-80%) with livestock farms generally low at less than 30%.

We followed methodology from EUNEP guidance for assessing NUE at farm level[44] and extracted data from the SFBS Agrecalc and economic datasets. A key assumption in the use of the EUNEP tables is that N is constant in each variable. This is not the case in practical terms. This study is a tier 1 approach.

There were 15 farms that were organic or in conversion and their data was removed from the NUE dataset. All organic farms or those in conversion typically use clover planting to build soil fertility, regardless of their farm type, unless they are a hard hill farm where planting on rough grazing is not possible.

For example, a standard rotation is 6 years for a mixed organic farm: 3 years of grazing in each field followed by 3 years of cropping. This may vary between farms and within years, but the principle is embedded in organic farming due to clover's potential to fix nitrogen into soils. The last year of cropping in the rotation requires clover under sowing to build the sward for the following 3-4 years of grass, but each year there is residual

[43] Gross and Net Margins are reported for all farm types here: https://www.fas.scot/publication/fmh2022/
[44] See: http://www.eunep.com/wp-content/uploads/2019/09/NUE-Guidance-Document.pdf

clover seed in the soil so that it continues to grow underneath whichever crop is planted in any year.

Furthermore, clover for building soil fertility is not restricted to organic farms but is widely used in pasture farms to reduce levels of artificial fertiliser required for grass. There is a forage legume category for plantings of clover / lucernes etc. in the carbon footprint however gathering this level of detail from the farmer is challenging and, inconsistent. In a consistent approach to the issue of clover plantings and residual clover in grass swards, we have therefore left this data point out of the data analysis.

Estimating clover planting in a field newly sown is relatively straightforward, however estimating sward coverage of the field is a challenge. The area of crop cover can look high, but as a percentage of the sward it can be deceptively low due to the nature of the plant. Clover grows up and then spreads out horizontally. This is an area of suggested further work.

As a further footnote, different species of clover fix nitrogen at different levels into the soil (1). Also, the increased use of multi species grass seed mixes in rotational grazing and other types of mob grazing practices can further complicate this picture.

The SFBS does not go into this level of detail with its farms.

The main outputs from the NUE analysis are

NUE: expressed as a percentage of total kg N output / total kg N input and in total kg / Ha,

N Farm Surplus expressed in kg / ha. There is a second line for each farm data point that expresses this accurately, and

Total N Input, Total N output and their associated input and output variables.

Area Used (Ha): EUNEP guidance suggests expressing N inputs and outputs per unit of planted agricultural area. We have used TOTAL FARM AREA (ha), which includes total planted crops and grass. We also include permanent pasture. Total farm area does not include roads and buildings, fallow land, rough grazing, or land let to other businesses. This means that farms in this dataset with large areas of rough grazing may have artificially low NUE.

In the SFBS Agrecalc reports in kgCO2e / Ha adjusted farm area. We have therefore run a supplementary dataset using total adjusted area to align this data with the carbon footprint data. This data can be ready within the next 10 days.

The total adjusted area does vary considerably from the guidance as it includes total crops and grass, both temporary and permanent pasture, and land let to other businesses. It also includes an adjustment for rough grazing areas. This adjustment is a subjective judgement made by each FBA depending on the quality of the land in each farm in this dataset.

Most of the farms with very low NUEs in this dataset have high fertiliser applications over an apparent small land area. This is because we have used Total Farm Area, and the farms have large areas of rough grazing.

All potential output from farming activity that contained N were used. All crops harvested and harvest residues (straw) are entered for sales off farm only and standard coefficients for cattle, sheep, pig, poultry meat, and eggs sold off farm were used to calculate N outputs.

Some farms have sales of fodder (straw, hay, silage) which has the impact of raising the NUE.

N fertilizer There is no information about the type of fertilizer applied on the farms in this dataset.

Amount of N in imported feed and fodder

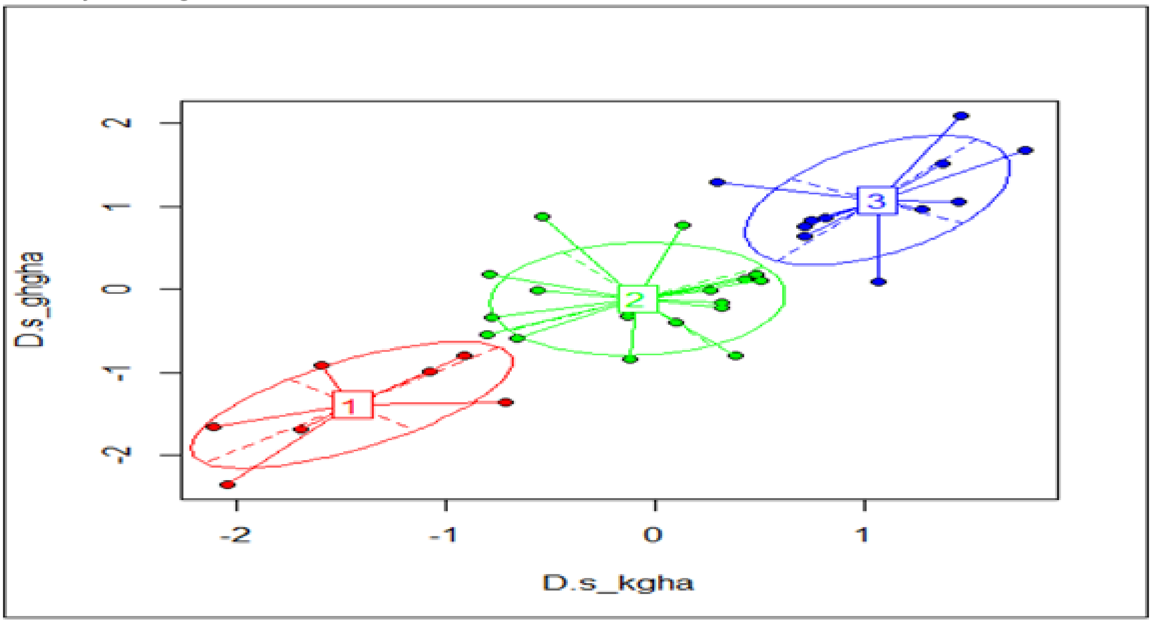
The N is calculated for bought in feeds and fodder only. N in home grown feed and fodder which is fed to animals is not part of this calculation.

Results from the cluster analysis

The clustering analysis was conducted using the built-in k-means clustering within R and clusters were visualised using the ade4 package[45] . A range of different clustering algorithms are available, but the K-means method was chosen as it is a relatively simple and common approach to clustering data.

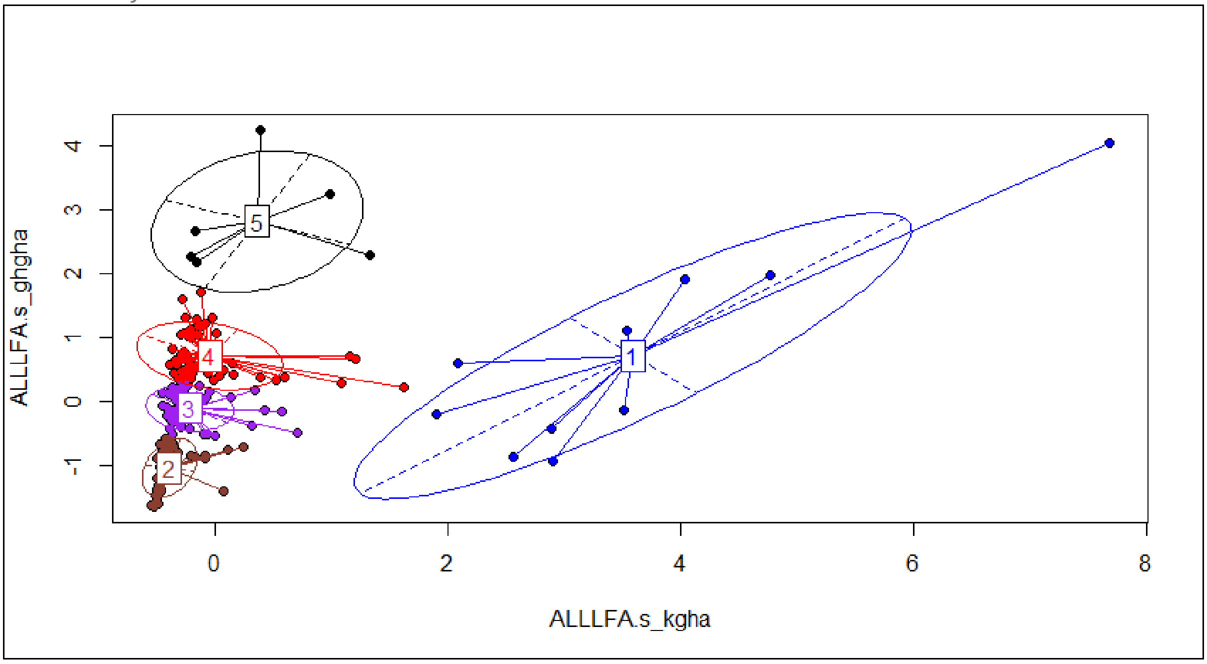
The figures that follow show the standardised values for production in kg/ha on the x-axis and the GHG emissions per ha on the y-axis. The farms can be seen as points within a cluster, with the minimum relative mean distance drawn from the centre of each cluster.

A1 Dairy farming

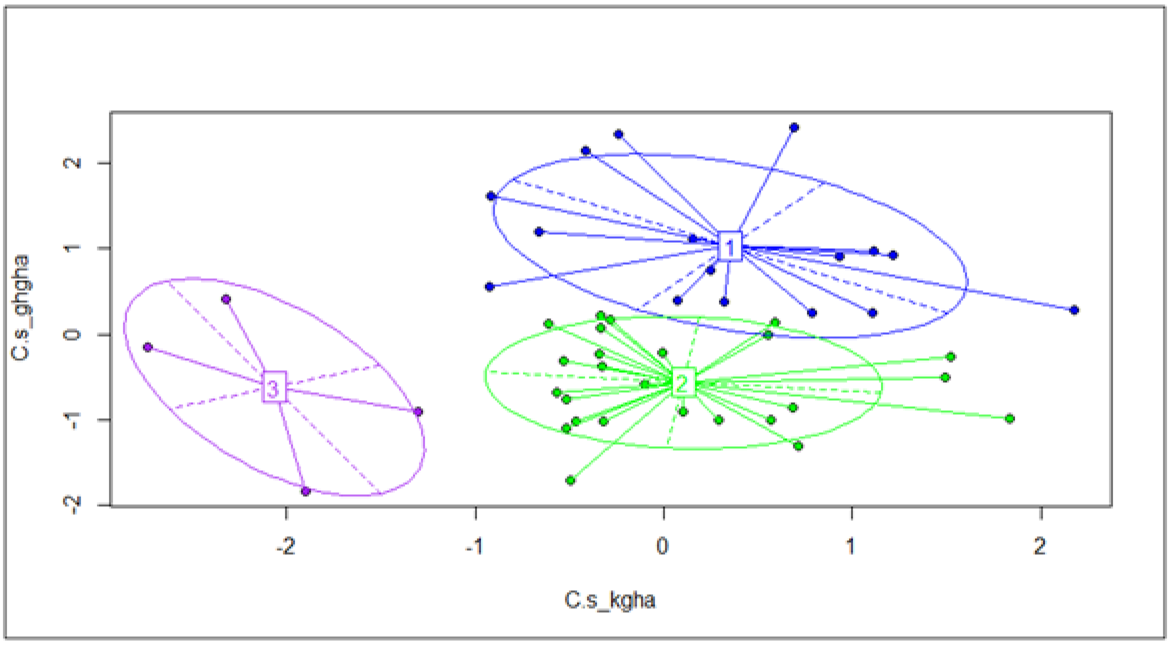


45 https://cran.r-project.org/web/packages/ade4/ade4.pdf

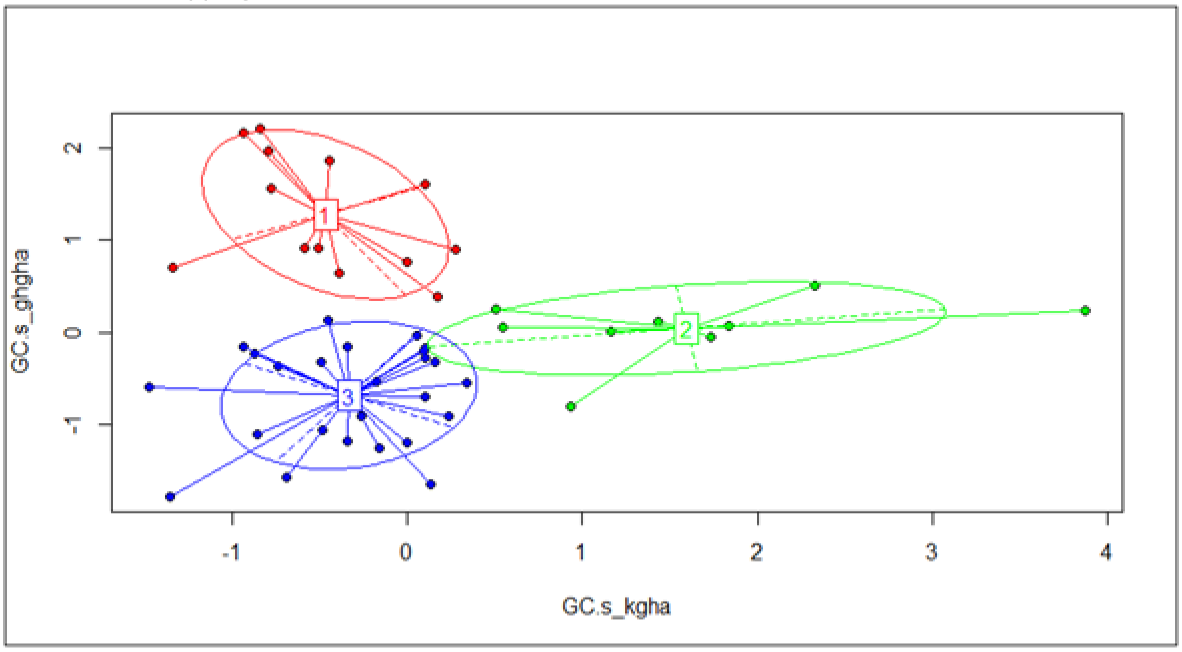
A2. LFA Drystock farms



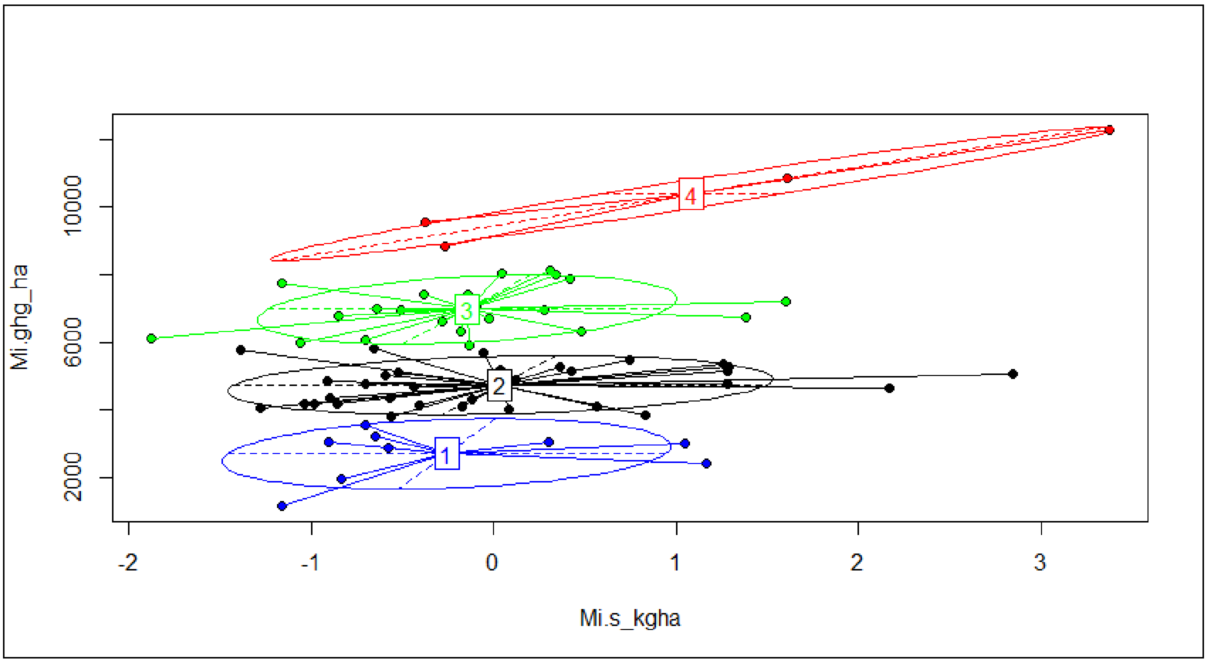
A3. Cereal farms



A4. General Cropping farms



A5. Mixed farms



Drystock (LFA and Lowland) Farming analysis

Whereas we focus on LFA farming only a small number of observations cover lowland cattle and sheep farms. This restricts application of the clustering methodology. The analysis below includes both LFA and Lowland farms as a whole. Overall, the clustering solutions did not change with the addition of lowland farms, but characteristics changed.

Figure A6(a,b) shows the relationship between production – which will be mostly sheep or beef meat - by kg/ha and GHG emissions at kg CO_2e /ha.

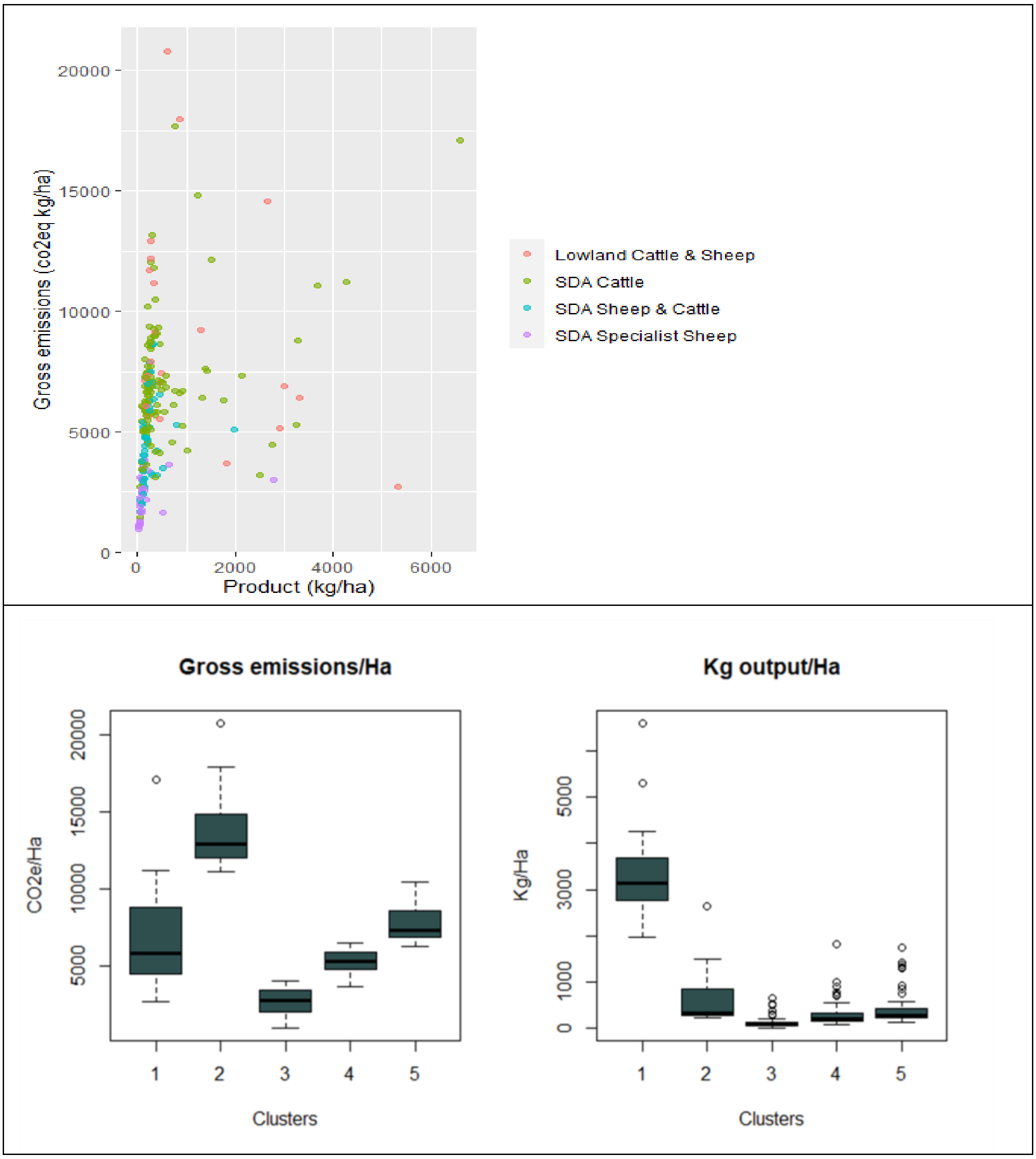


Table 3a. Greenhouse gas emissions for the SFBS drystock farms

	C 1(n=14)		C2(n=13)		C3(n=57)		C4(n=60)		C5(n=63)		
	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*	sig.
Product (kg/ha)	3,410	*1,257*	736	*706*	130	*127*	294	*281*	412	*343*	***
Gross emissions (kg/ha)	6,984	*3,967*	14,078	*2,982*	2,704	*880*	5,345	*702*	7,695	*1,002*	***
Direct emissions (kg/ha)	414	*167*	578	*114*	150	*90*	269	*107*	385	*132*	***
Indirect emissions (kg/ha)	1,722	*1,233*	3,401	*1,711*	368	*227*	930	*304*	1,313	*497*	***
CH_4 emissions (kg/ha)	3,269	*1,921*	6,485	*1,171*	1,593	*497*	2,859	*507*	4,121	*640*	***
N_{ox} emissions (kg/ha)	1,579	*840*	3,614	*1,168*	593	*210*	1,286	*250*	1,877	*380*	***
Net emissions (kg/ha)	6,716	*3,788*	13,939	*3,000*	1,228	*5,684*	5,230	*732*	7,517	*1,104*	***

Table 3b. Economic indicators of the drystock farms clusters

	C 1(n=14)		C2(n=13)		C3(n=57)		C4(n=60)		C5(n=63)		
	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*	sig.
Operating profit (£/ha)	(52)	*336*	(324)	*696*	(77)	*233*	(108)	*256*	(153)	*368*	
Variable cost (£/ha)	616	*369*	1,165	*641*	207	*96*	387	*109*	559	*181*	***
Gross margin (£/ha)	832	*359*	1,081	*571*	428	*170*	632	*219*	819	*300*	***
Net margin (£/ha)	(220)	*288*	(362)	*625*	(127)	*240*	(185)	*225*	(218)	*364*	
FBI (£/ha)	155	*219*	119	*465*	88	*180*	87	*156*	139	*232*	
Output/Input^	0.94	*0.20*	0.85	*0.20*	0.63	*0.24*	0.76	*0.15*	0.81	*0.17*	***

Table 3c. Farm structural indicators for the drystock farm clusters

	C 1(n=14)		C2(n=13)		C3(n=57)		C4(n=60)		C5(n=63)		
	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*	sig.
Adj. Ag. Area	162	*144*	104	*77*	257	*172*	211	*155*	153	*90*	***
Stocking density	1.05	*0.52*	1.96	*0.46*	0.63	*0.21*	0.92	*0.15*	1.29	*0.21*	***
Livestock Specialisation	0.89	*0.13*	0.99	*0.02*	0.97	*0.07*	0.97	*0.08*	0.98	*0.04*	**
Feed (£/livestock unit)	287	*107*	325	*202*	146	*80*	178	*82*	198	*82*	***
Homefeed used (%)	25%	*29%*	20%	*27%*	3%	*12%*	18%	*24%*	18%	*24%*	***
Nitrogen Use Efficiency	45%	*42%*	16%	*13%*	14%	*12%*	17%	*14%*	17%	*13%*	**

Farm characteristics including outlier value for general cropping farm type

	C 1(n=13)		C2(n=9)		C3(n=25)		
	Mean	*SD*	Mean	*SD*	Mean	*SD*	sig.
Product (kg/ha)	4,982	*2,416*	15,198	*5,184*	5,645	*2,463*	***
Gross emissions (kg/ha)	5,170	*873*	3,475	*491*	2,477	*747*	***
Direct emissions (kg/ha)	547	*176*	857	*351*	431	*132*	**
Indirect emissions (kg/ha)	1,649	*330*	1,561	*329*	997	*406*	***
CH_4 emissions (kg/ha)	1,418	*921*	15	*44*	265	*461*	***
N_{ox} emissions (kg/ha)	1,557	*275*	1,042	*185*	783	*268*	***
Net emissions (kg/ha)	5,109	*854*	3,357	*484*	2,358	*894*	***

	C 1(n=16)		C2(n=25)		C3(n=4)		
	Mean	*SD*	Mean	*SD*	Mean	*SD*	sig.
Operating profit (£/ha)	9	*332*	745	*466*	164	*398*	**
Variable cost (£/ha)	609	*198*	938	*354*	347	*101*	***
Gross margin (£/ha)	1,006	*223*	1,989	*769*	1,168	*660*	**
Net margin (£/ha)	(183)	*272*	422	*313*	39	*355*	**
FBI (£/ha)	177	*210*	633	*354*	343	*285*	**
Output/Input^	0.97	*0.13*	1.20	*0.16*	1.08	*0.24*	*

	C 1(n=16)		C2(n=25)		C3(n=4)		
	Mean	*SD*	Mean	*SD*	Mean	*SD*	sig.
Adj. Ag. Area	216	*87*	236	*120*	163	*76*	
Crop specialisation	0.71	*0.19*	0.99	*0.02*	0.88	*0.23*	**
Fertiliser (£/ha)	199	*39*	271	*123*	126	*49*	***
Nitrogen Use Efficiency	0.59	*0.12*	0.94	*0.27*	0.95	*0.34*	***

© Published by Scotland's Rural College 2022 on behalf of ClimateXChange. All rights reserved.

While every effort is made to ensure the information in this report is accurate, no legal responsibility is accepted for any errors, omissions, or misleading statements. The views expressed represent those of the author(s), and do not necessarily represent those of the host institutions or funders.

Scotland's centre of expertise connecting climate change research and policy

info@climatexchange.org.uk
+44(0)131 651 4783
@climatexchange_
www.climatexchange.org.uk

ClimateXChange, Edinburgh Climate Change Institute, High School Yard, Edinburgh EH1 1LZ