Report by the SEFARI Gateway Scientific Advisory Group

Estimating Green House Gas Emissions for the Scottish Food and Drink Industry

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Introduction

In March 2024 SEFARI Gateway and Scotland Food and Drink Partnership Net Zero Programme formed a Scientific Advisory Group (SAG) for "estimating greenhouse gas emissions for the Scottish Food and Drink Industry." This was formed of SEFARI scientists with the option to co-opt external expertise as and when needed. The aims of the SAG were:

- To review the estimated Greenhouse Gas Emissions (GHGEs) for the food and drink industry and make recommendations to improve the accuracy of these estimations.
- To evaluate the progress different sub-sectors of the food and drink industry have made towards reducing GHGEs and the methodologies they use to estimate emissions since the baseline year (1990).
- Examine current strategic research outputs and those across the agriculture emissions landscape to assist recommendations on how changes in farming practice may impact GHGEs in Scotland.
- To examine interactive ways of displaying the data to convey key trends to the stakeholder community

GHGEs associated with Scottish food and drink production systems, including farming and land use, were estimated in a manner that is compliant with the current Scottish greenhouse gas inventory and hence would be comparable to international estimates from other countries[1]. In our approach, emissions from the Scottish food and drink industry were attributed to the categories of Agriculture and Land Use, Land Use Change and Forestry (LULUCF) (but excluded emissions associated with settlements), and include a proportion of

[1] https://www.gov.scot/publications/scottish-greenhouse-gas-statistics-2021

the emissions from: business plus industrial processes, energy supply, transport and waste management. The proportions were estimated from the literature based on GHGEs in Scotland or using values derived for the whole of the UK, where values were not available for Scotland. We provide a discussion on these estimates and how to refine this model further to improve these estimates below.

Across the food sector, there was no single methodology that all sub-sectors are using to estimate GHGEs, and in many cases estimates are lacking. The SAG considered the best methods for estimating GHGEs for individual sub-sectors. To provide estimates for sub-sectors, we have identified a method based on our original approach and estimates using the national GHGE inventory. For scope 1 and 2 emissions, previous estimates were made by dividing the Food and Drink sector into sub-sectors based on Office of National Statistics classifications (Kelsall et al. 2020). This provided a means to estimate the GHGEs for the processing of food and drink. To estimate scope 3 emissions, we recommend a method based on agrifood utilisation within sub-sectors. This requires an estimate of the input of commodities and the use of GHGEs associated with each food and drink component.

GHGEs associated with agriculture have stayed relatively constant since the 1990 baseline, despite significant decarbonisation in other industries, e.g. energy production[2]. To address this, we suggest a range of abatements including:

i. increasing the efficiency of livestock production via improvements in nutrition, health, reducing parasite load and genetic improvements

ii. the increased use of legumes in grasslands to reduce the reliance on fertilisers,

iii. improved manure management strategies

iv. feed additives to reduce enteric fermentation and

v. measures designed to sequester carbon above and below ground.

In addition, further reductions could be achieved via measures that address the market failures that are a major contributor to climate change. For example, adopting a range of strategies to support consumers reduce their demand for foods associated with larger environmental footprints (and thereby production) that could range from light-touch campaigns to more restrictive measures such as carbon pricing.

[2] https://www.gov.scot/publications/scottish-greenhouse-gas-statistics-2021

1. Estimating GHGEs for Scotland's food and drink Industry

The method used in this report is based on a report produced by SRUC and SEFARI scientists **M. MacLeod**, **C J Newbold** and **M Fischer-Moller** in April 2021 to estimate GHGEs by the food and drink sector using data from the Scottish greenhouse gas inventory2. Scottish GHGEs are reported against 10 main sectors: **i. energy supply, ii. business, iii. industrial processes, iv. transport, v. international aviation and shipping, vi. public, vii. residential, viii. agriculture, ix. land use, land use change and forestry and x. waste management**. We have briefly summarised the sectors that form the bulk of the contributions to the food and drink industry below.

Energy supply - Emissions from fuel combustion for electricity and other energy production sources, and fugitive emissions from fuels (such as from mining or onshore oil and gas extraction activities). North Sea oil & gas extraction emissions are not allocated to Scotland.

Business – Emissions from fuel combustion and product use in industrial and commercial sectors, and fluorine gas emissions from refrigeration and air conditioning in all sectors. This includes industrial off-road machinery.

Industrial processes - Emissions resulting from industrial processes, except for those associated with fuel combustion, which are included in the Business sector.

Transport (excluding international aviation and shipping) - Emissions from domestic aviation, road transport, railways, domestic navigation, fishing and aircraft support vehicles.

Agriculture - Emissions from livestock, agricultural soils (excluding carbon stock changes which are included in the LULUCF sector), stationary combustion sources and off-road machinery.

Land Use, Land Use Change And Forestry (LULUCF) – Emissions/removals of CO_2 from changes in the carbon stock in forestland, cropland, grassland, wetlands, settlements and harvested wood products, and of other greenhouse gases from drainage (excl. croplands and intensive grasslands) and rewetting of soils, nitrogen mineralisation associated with loss and gain of soil organic matter, and fires. Because the impact of biomass harvest on carbon stocks in ecosystems is included in this sector, any emissions of CO_2 from burning biomass (regardless of the country of origin) are excluded from other sectors to avoid double-counting them.

Waste management - Emissions from waste disposed of to landfill sites, waste incineration, and the treatment of wastewater.

When emissions are reported by source, emissions are attributed to the sector that emits them directly. These high-level sectors are made up of a number of more detailed sub-sectors, which follow the definitions set out by the Intergovernmental Panel on Climate Change[1], and which are used in international reporting tables which are submitted to the United Nations Framework Convention on Climate Change (UNFCCC) every year.

For estimating GHGEs for the Food and Drink Industry in Scotland, assumptions were made based on previous literature reports as to how the proportions should be calculated to reflect activity within the food and drink sector. These are listed below under assumptions, along with any updates we have performed here for our calculation where we could find further information.

One challenge is how much of the rural component of **LULUCF** should be included under food and drink production, particularly what proportion of emissions associated with grassland, wetland and forestry should be proportioned. To complicate matters this number may shift with time if farmers opt to trade carbon credits in private voluntary markets – such movements in land use or mixed land use will not be always captured at the macroscopic level as used in the national inventory.

For this report we have included three values where:

i. **the two sub-categories of cropland and grassland are included and**

ii. **all of LULUCF is included excluding emissions associated with settlements.**

iii. **the two sub-categories of cropland and grassland are included but a proportion of woodland associated with farming is also included.**

GHGEs had also been updated for all categories in the latest release of the national inventory to reflect current consensus on how to measure these, which has increased and decreased some estimates compared with previous releases. We were also able to use GHGEs for heavy goods vehicles (HGVs) and light goods vehicles (LGVs) transport in Scotland to estimate transport GHGEs, rather than a composite figure for all transport.

While there will be some debate about the calculation assumptions, the broad changes in GHGEs associated with each category will remain the same and we suggest these should be the immediate focus on how the sector should reduce GHGEs in the future.

[1] IPCC; www.ipcc-data.org

Calculation assumptions:

Based on an initial literature search our analysis is based on attributing emissions in these sectors as follows:

- The Scottish food and drink industry was estimated to account for 30% of total Scottish manufacturing GHGEs[1].
- Based on the Scottish Energy Study: Volume 1: Energy in Scotland: Supply and Demand[2] we have assumed that circa 20% of the total energy usage in Scotland can be attributed to the food and drink sector (note this does not include energy usage by consumers). This estimate is derived from the total non-domestic energy usage reported in the Scottish Energy Study and the estimated proportion that the food and drink industry make up of the total non-domestic usage.
- Based on the Scottish Transport Statistics[3] we have assumed that transport associated with agricultural and food products accounts for circa 33% of goods lifted / moved by UK HGVs, for journeys within the UK with a Scottish origin or destination (note this does not include transport by consumers; based on "Table 3.4 Goods lifted / moved by UK HGVs, for journeys within the UK with a Scottish origin or destination, by commodity, 2017"). We have continued to use this estimate but taken figures directly for GHGEs for HGVs and combined it with a third of total LGVs emissions. WRAP estimate that 19% of the emissions allocated to waste management could be attributed to the food and drink sector[4].

Results:

Figure 1 displays the trends in total GHGE for Scotland (**Fig 1A**) and the categories that used in the calculation for the Scottish Food and Drink Sector (**Fig 1B**). These are unweighted and represent the total emissions for each category. There are some immediate major trends in the data. Decarbonisation of the energy sector has been a major success since 1990, with reductions year on year (representing reductions of 75% and 78% of baseline in 2020 and 2021, respectively). The LULUCF sector has also shown a large reduction, in part because of offsets by forestry – and more recently peatland restoration, negating GHGEs from other sub-categories (reductions of 95% and 94% in 2020 and 2021, respectively). For agriculture, which makes up the largest contribution to the estimates for the food and drink industry in Scotland, there has been more modest declines with agriculture reducing by 12% and 11% in 2020 and 2021, respectively, compared with the baseline year of 1990 (it should be noted that this is against a background of increased production of food to keep pace with population growth). Looking at the other categories that contribute GHGEs to the food and drink industry, waste management has seen a major reduction of 77% and 76% in 2020 and 2021, respectively, as has industrial processes (77% and 76% for 2020 and 2021, respectively) and business (34% and 36% for 2020 and 2021, respectively). Transport, as a sector, represents an intermediate reduction of 27% and 19% by 2020 and 2021.

1 https://www.fdfscotland.org.uk/fdf/business-insights-and-economics/facts-and-stats/

2 https://www.gov.scot/collections/energy-statistics

3 https://www.transport.gov.scot/media/44025/scottish-transport-statistics-no-37-2018-edition.pdf

4 https://www.wrap.ngo/content/all-sectors

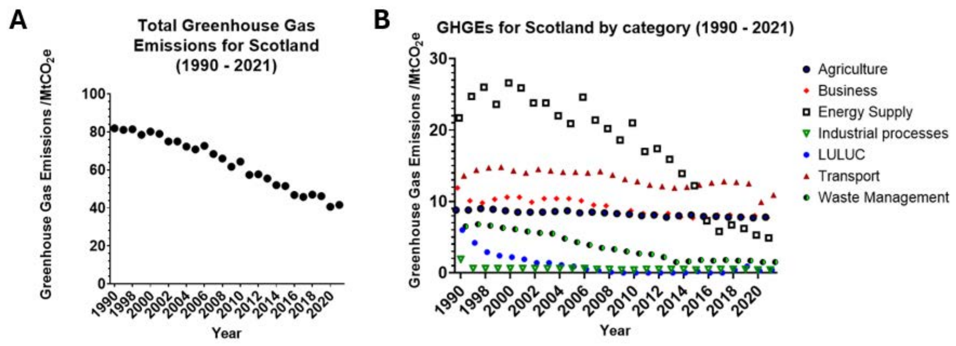


Figure 1: Greenhouse gas emissions (GHGEs) for Scotland from 1990-2021 for the total and major reporting categories relevant for the food and drink industry.

A shows the total GHGEs for Scotland against reporting year, while **B** shows the main categories used in the estimate for the food and drink industry (note this is prior to any scaling of the categories to reflect the proportional activity for the food and drink industry). Figures are from the Greenhouse Gas Statistics for Scotland: (https://www.gov.scot/publications/scottish-greenhouse-gas-statistics-2021/).

An important caveat when viewing these figures is that, because of the COVID-19 pandemic both 2020 and 2021 were not normal activity years (e.g., evident in the reduced transport emissions), but many of the reductions highlighted represent longer term trends which give us some confidence in interpreting them.

Figure 2 displays our first estimate of GHGEs for the Food and Drink Industry in Scotland for 1990 (baseline year), 2020 and 2021 based on the National Inventory as a bar graph and using the assumptions outlined above and including the sub-categories of grassland and cropland from LULUCF in the calculation. We estimate that GHGEs for the Scottish food and drink Industry were 29.03 $MtCO_2e$ in 1990, 19.26 $MtCO_2e$ in 2020 and 19.08 $MtCO_2e$ in 2021. This is equivalent to 66.3% and 65.7% for 2020 and 2021 of the baseline value (1990) and reductions of 33.7% and 34.3%, respectively.

While an number of assumptions were made regarding the relative proportions of categories and sub-categories to allocate to the food and drink sector, this does demonstrate a consistent reduction in GHGEs for the sector as well as a major change in the reporting categories that contribute to the estimate. **If these assumptions are accurate the Food and Drink industry for Scotland would have accounted for up 47% and 45% of total GHGEs for 2020 and 2021 (compared with 35% in 1990 (figures include grassland and cropland but no other category from LULUCF)).** Perhaps a better way of representing these figures is to measure them in terms of all GHG producing processes, rather than the net figure that includes Forestry and Sinks for GHGEs under **LULUCF**. These sinks of CO_2 accounted for 21.0 and 20.9 $MtCO_2$ absorption. **Using only GHG producing processes, our estimate of the GHGEs for the food and drink industry are 38.4% and 38.2% for 2020 and 2021, respectively.**

It can be argued that farming is associated with the major sink of GHGs in the form of on-farm woods and forestry. If we decide to include all of LULUCF apart from GHGEs associated with settlements, this dramatically reduces the total emission values for the food and drink industry, largely because of the successes in carbon capture by re-foresting. Based on this approach we estimate total emissions from the Scottish food and drink sector to be 14.3 $MtCO_2$ equivalents based on 2021 data. This is 35 % of total Scottish GHG emissions, a figure that is comparable to the recent WRAP report[5] that suggested that the food we consume is responsible for around 35% of UK territorial GHG emissions.

[5] https://wrap.org.uk/sites/default/files/2021-10/WRAP-UK-Food-System-GHG-Emissions-Technical-Report_0.pdf

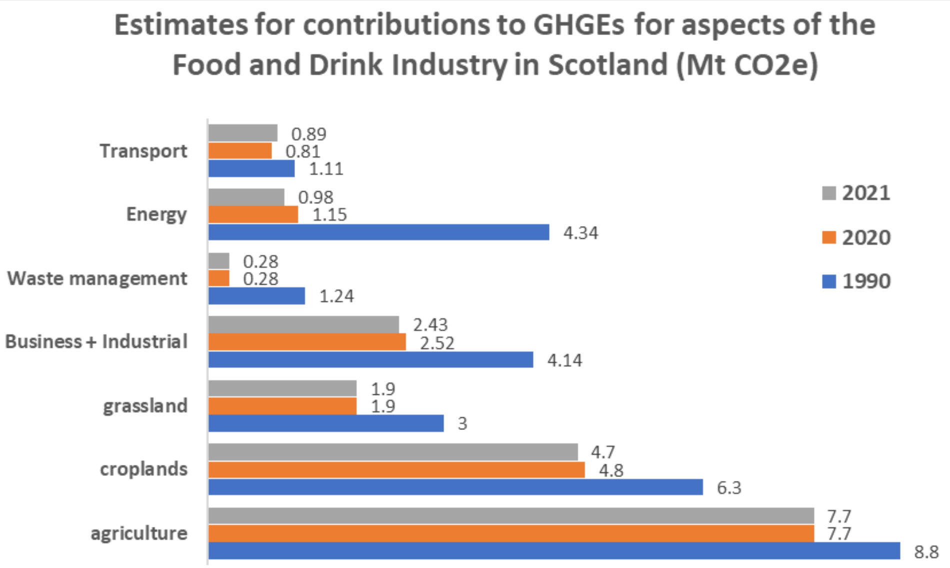


Figure 2: Estimates for the contributions of the various categories that contribute to GHGEs to the food and drink industry in Scotland. Values are in $MtCO_2e$. Note that transport, waste management, business and industry and agriculture are national communication categories while grassland and cropland are sub-categories of land use and land use change (LULUC).

It is possible to estimate the amount of woodland associated with farmland across Scotland, with 36% of woodland in Scotland being classified as farm woodland (sources: For; est Research (2019), Forest Research (2020b);[6]). Using this value to proportion how much of forestry should be included in our calculation this reduces the baseline year to 27.26 $MtCO_2$ equivalents, and 2020 and 2021 years to 16.6 $MtCO_2$ and 16.45 $MtCO_2$, respectively. This represents 61.1% (2020) and 60.5% (2021) of the baseline year, respectively.

[6] https://www.soilassociation.org/media/24209/trees-and-woodland-in-the-farmed-landscape-scotland-rev-1.pdf

However, most forestry is not integrated into food production. Some is (e.g. hedges and shelter belts) but a lot is not. The same could be said about wind and solar farms – even if located on farmland they would be reported in a different category of the national inventory and not accounted for as part of the food and drink industry. All on farm renewable energy is accounted for in the energy sector - despite some being used on farm - to include these changes in land use would require a major change in how we proportion GHGEs to specific sectors.

Presented as the proportion of emissions that can be explained by source (**Fig. 3**) then energy represents a falling source in line with the move for Scotland towards more renewable sources of power. Similarly, whilst transport is shown as a growing source of emissions, one might assume that as Scotland moves towards an increased reliance on electrically powered transport, particularly for LGVs, with that electricity produced from renewable sources that this source will also decline. Clearly that leaves waste, business and industrial processes and primary agricultural production as major sources. Waste management is consistently a small source of emissions, falling from 8 to 3% of emissions over the period. Whilst it would be logical to explore emissions from waste management and business and industrial processes and the possibility of reducing the emissions from these sources, primary production from agriculture remains the major source of greenhouse gases. GHGEs are further mitigated by a proportion of biomass from agriculture being used for energy production (e.g. anaerobic digestors).

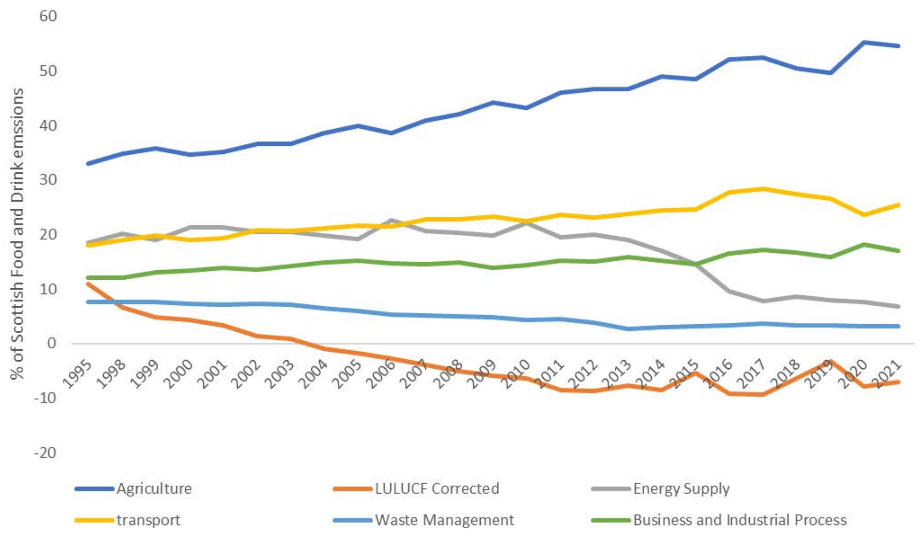


Figure 3. Greenhouse gas emissions from the Scottish food and drink sector by source of emissions

Refinements of the Model:

i. **Better apportioning LULUCF**: This is a key assumption in the calculations which has a major impact on both the overall amount of GHGEs for the food and drink industry and its direction of change, especially with forestry increasing as a major sink for CO_2. Approximately 35% of woodland and forestry are associated with farms[7] and similar estimates could be made for wetlands and grasslands. The recommendation is to consult with wider SEFARI initiatives focused on land use and land use change to refine these estimates and understand the assumptions used in the estimates to get a more reliable estimate, and how it changes year on year.

ii. **Method discussion around expert elicitation:** There are two or three estimates in the model that the SAG felt could be refined further through a stakeholder elicitation. One area suggested was that better estimates could be made around road haulage. This would work by bringing together expertise from the sector (e.g. the Scottish Wholesalers Association, individual truck haulier companies) to understand what data is available and what areas need to be estimated. Areas of uncertainty could then be mathematically modelled. One warning though is that this area, as well as GHGEs associated with waste, are minor contributors to the overall figure.

iii. **Estimating trends and significant changes in the data**: The data in the national inventory is used in this report without any error bars in the measurements or variance associated with the certainty of the measurements. This brings into question about whether differences between one year and another are real or represent these errors in measurement. The National Inventory report discusses uncertainty and estimates of error in each category using two methods which could be used.

[7] https://www.soilassociation.org/media/24209/trees-and-woodland-in-the-farmed-landscape-scotland-rev-1.pdf

Alternatively, the trends in the data can be modelled across a series to better define this variance. Using the variance of residuals of fits of the different data sources we can estimate whether trends are true reductions or within the variance of the measurements. We have performed such an analysis for the different components that make up GHGEs for agriculture and this analysis could be extended to other sectors (see supplementary report by Nick Schurch from BioSS).

There needs to be a discussion on how Scottish agriculture is being accounted for in the Scottish Food and Drink Emissions. The majority of sheep meat is not processed in Scotland, or consumed here, with beef also largely being consumed in England rather than in Scotland (although much more is killed and processed here then transported). Most whisky is consumed out of Scotland. As scope 3 emissions become important one could ask how do exports impact the direct growing / production emissions being accounted for as others are reporting them e.g. in English Scottish beef sales.

The estimates we provide here are dominated by land-based food production, with aquaculture only accounted for in terms of energy use and transport. Calculations for GHGEs is further complicated that the UK imports significant amounts of white fish, tuna and prawns, while exporting oily fish and seafood.

2. Estimating GHGEs for Sub-sectors of Scotland's Food and drink Industry

While it was beyond the scope and funding of the SAG to calculate estimates for all the sub-sectors that make up the food and drink industry, we did discuss a methodology to address this question. The Air and Energy Accounts for Scotland Report [2020] provided scope 1 and 2 GHGEs for a range of industries, including the food and drink industry for the years 1998 to 2018. These calculations were made according to the Standard Industrial Classification 2007 (SIC07) by the Office of National Statistics. For the food and drink industry the classification is:

i. preserved meat and meat products;
ii. processed and preserved fish, crustaceans, molluscs, fruit and vegetables,
iii. dairy products, vegetable and animal oils and fats,
iv. grain mill products, starches and starch products,
v. bakery and farinaceous products,
vi. other food products,
vii. prepared animal feed,
viii. alcoholic beverages – spirits, wines, ciders,
ix. alcoholic beverages – beer and malt,
x. soft drinks.

From conversations with the Scottish Government Statisticians these data could be generated on a yearly basis for the Food and Drink Partnership.

For scope 3 emissions, we suggest this could be based on carbon footprints of Scottish food commodities coupled with production and consumption data (e.g. Kantar World Panel). This latter approach has been used to consider the UK food system and detailed data based around emissions per food type are available (Clark et al., 2022; Stewart et al., 2023;[1]). However, such an approach is complicated by imports and exports to the home nations – these are not currently tracked but could be estimated.

This analysis would require some work to ensure no double accounting of GHGEs dependent on the source of data, but this could be tackled through a fellowship in consultation with members of the food and drink sub-sector.

The major trends that contribute to GHGEs for the agricultural sector have also been examined and in turn contribute to the individual sub-sectors. The trends in the data from the agriculture sector can be modelled across a series to better define the variance in these measurements. Using the variance of residuals of fits of the different data sources, estimates can be made of whether trends are true reductions or within the variance of the measurements. This report is provided as an annex.

[1] https://www.nesta.org.uk/report/exploring-the-potential-for-reformulation-across-popular-food-in-scotland/

3. Examining current strategic research outputs on how changes in farming practice may impact GHGEs in Scotland:

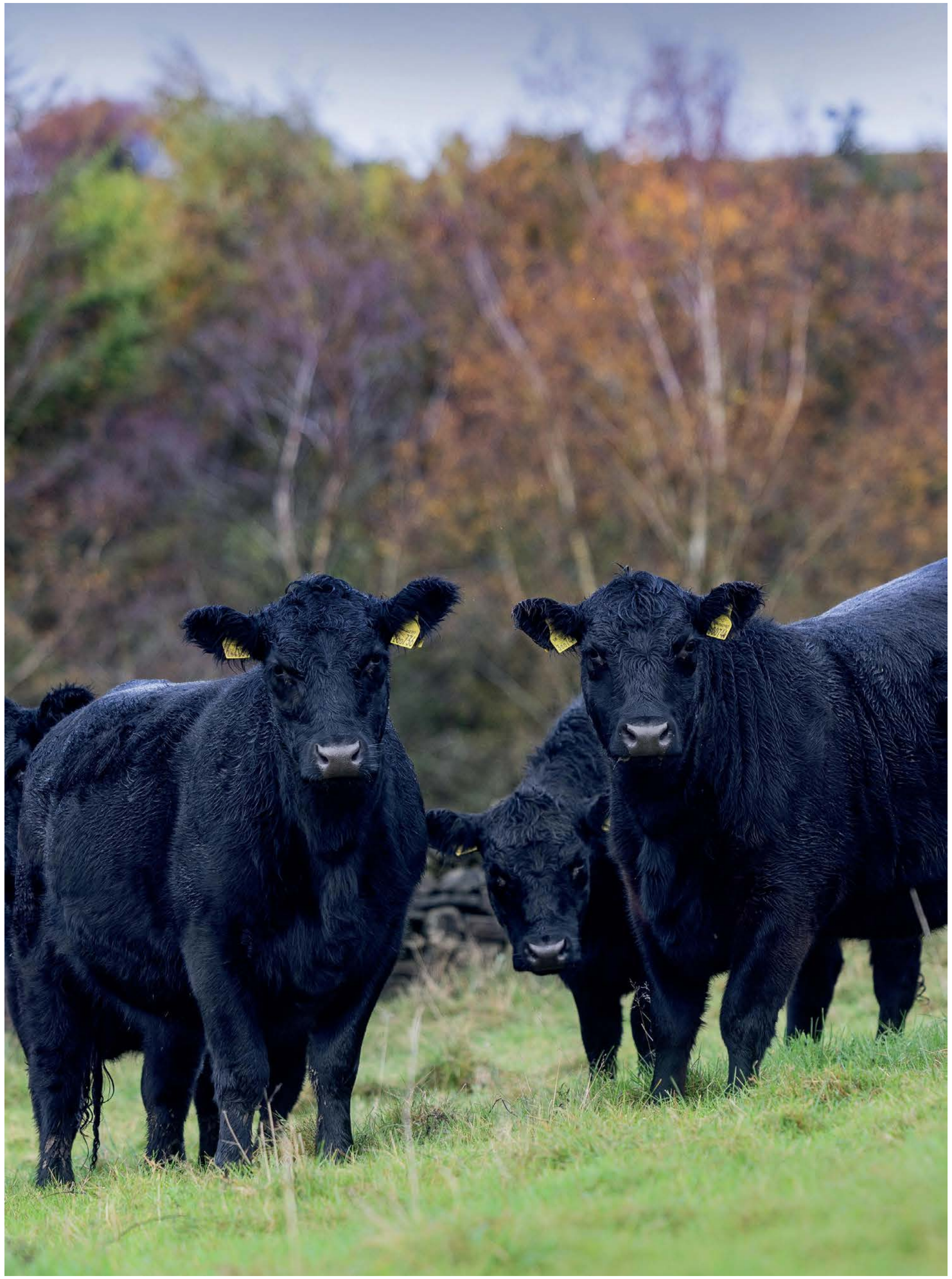
This subject has been the focus of a number of reports produced recently both at UK and Scotland levels. The SAG considered the Sectorial MACC report produced by Macleod, et al. (2024) which detailed several interventions to reduce GHGE. This details how to abate GHGEs for dairy, beef, sheep, arable, pigs and poultry (Tables 6-9 in the report). Consistent across the models reported moving to grass-legume mixes, whereby clover is introduced to grass swards to reduce the need for synthetic fertilisers, would have the biggest impact on beef, dairy and sheep production. This is already common practice for reseeded Temporary Grass (TGRS) but could be further expanded. For beef production the next biggest impact would be by increasing cattle liveweight gain. In general, improving livestock health would further reduce GHGEs for beef, sheep and pigs. Feed additives (3NOP and nitrate) can directly target enteric methane production and reduce GHGEs for beef and dairy. Costs for this intervention are likely to reduce with wider adoption. Furthermore, better manure management would also have a significant impact on GHGEs for agriculture, particularly for beef, dairy and pigs. From the sectorial MACC report if implemented this might reduce GHGEs by as much as 40% dependent on what happens around demand, population growth and abatement strategies (assuming a take-up of 50-75% of the mitigation strategies). In the medium to long-term, further significant reductions in enteric methane may be achieved by the genetic selection of ruminants for improved productivity and/or for reduced rates of methane excretion.

Even with all these mitigations, GHGEs for agriculture are unlikely to decrease further unless there is also a change in consumer demand and thereby production. Beef, lamb and dairy will continue to be major sources of GHGEs even after the above mitigations without substantially reducing the ruminant population (CCC 7th Carbon Budget). While per capita consumption of meat is generally reducing (beef and sheep meat) or static (pork, poultry meat and milk plus cheese), increases in demand are likely to be driven by UK population growth, which is forecast to increase by 10% between 2024 and 2046 (Population Estimates, Office for National Statistics 2024). Hence, there is also a need to move to more plant-based foods if we are to reduce GHGEs below the 60% level compared with 2020 values. This change in dietary behaviours has to be balanced against the high micronutrient content of meats and dairy products, with a significant proportion of the population deriving major components of their regular nutrition from these foods. These foods are also popular with a significant proportion of the population. Such dietary changes need to be considered along with the fact the UK still imports ~20% of its beef requirements and a proportion of Scottish beef is exported to other home nations or globally (10% for beef and 35% for sheep[1]). The SAG noted recent successes in food reformulation to reduce fat, salt, sugar and calories in certain foods as part of the response to The Scottish Government's 'A Healthier Future' plan [Reformulation for Health, 2024] and such approaches could be used to reduce GHGEs associated with meals by decreasing meat-based protein in favour of plant-based protein. In addition, schemes to discount fruit and vegetables for parts of the population [e.g. The Healthy Start scheme for women more than 10 week pregnant and families with children under 4] have been successful in promoting fruit and vegetable consumption for health and could be extended to encourage plant-based protein consumption. The impact on farming and rural communities, particularly for the livestock and dairy industries much of which is on less favourable agricultural land,

[1] https://qmscotland.co.uk/news/scotlands-red-meat-exports-climb-to-a-record-164-million-as-qms-heads-to-anuga-2025

also need to be considered. Thus, any attempt to change agricultural output needs to be carefully managed.

To have an impact on the national inventory all the changes described above need to be implemented at scale and be measurable in the inventory in terms of those changes (e.g. capturing changes in farming practise in the inventory). This would require mass adoption of abatement strategies by farming and consumers changing their dietary habits on mass (albeit then by a modest amount). The SAG was unsure how Scotland Food and Drink Partnership will mobilise both farming and the public to make these major changes. This will require major legislative changes, investment in new technology and a re-think about our food supply network, along with an appreciation of the true cost of non-sustainable food to drive these processes. These are massive challenges. In terms of promoting abatement strategies for farming, one possible win would be that if Scotland opted to change their farming practises as a whole, this might bring financial gains in their products having a higher perceived worth stemming from their sustainability credentials.



4. Estimates for 2022

Since drafting the report figures were released for 2022. We estimate the GHGEs associated with the food and drink industry in Scotland for 2022 was 18.80 MtCO2e. The further reductions were driven by reductions in GHGEs from agriculture (associated with a reduction in the national herd size) and slight rises from transport, waste and power generation.

Using the SRUC sectorial marginal abatement cost curve and a reasonable implementation of these farming practises could have reduced GHGEs by 0.94 MtCO2e emissions which is equivalent to the decrease in emissions associated with agriculture between the baseline year of 1990 and 2022, and would have made a major contribution to achieving current targets for reductions in GHGEs.

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