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Understanding the climate impact of food consumed in Scotland

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1 Executive summary

The foods we eat in Scotland contribute to greenhouse gas (GHG) emissions. Different foods have different GHG emissions, and therefore dietary transitions can play a role in meeting net zero emission targets. The Climate Change Committee's Scottish progress review in December 2022 included a call to change Scottish diets.

This report examines current evidence on dietary patterns and their associated emissions to establish a baseline understanding of the climate impact of food consumed in Scotland.

1.1 What are food systems?

The draft National Good Food Nation Plan defines foods systems in line with the United Nations' definition as "all the elements (environment, people, inputs, processes, infrastructures, institutions, etc.) and activities involved in the production, processing, distribution, preparation and consumption" of food.

Some of the food produced or processed in Scotland is exported to the rest of the UK or overseas. While this is important for Scotland's territorial emissions, exported food is not within the remit of this report.

1.2 How does the food we eat contribute to greenhouse gas emissions?

Activities at each stage of the food system contribute to GHG emissions. Examples include from the production of synthetic fertilisers; from energy use during processing, packaging, and cold storage; and from the disposal of food and food packaging waste, though globally 70% of food system-related emissions arise from food production.

The most comprehensive analysis of GHG emissions associated with food consumed in the UK, by WRAP, found the following breakdown:

- 29% from UK agriculture and fishing
- 26% from imported food
- 10% from land use change from imported food and animal feed
- 6% from household energy use to prepare food
- 5% from energy use to manufacture food in the UK
- 4% from energy use by hospitality and food service
- 4% from food packaging
- 4% from transport within the UK

Thus, improvements in the efficiency of food production are especially critical for climate change mitigation.

1.3 Food consumption in Scotland

Current consumption patterns, particularly of meat and dairy, are important for understanding the GHG emissions associated with food consumption in Scotland and identifying strategies to improve the sustainability of Scottish diets. Our analysis and review of food consumption in Scotland revealed that:

- The four most important food groups contributing to nutrient intake in Scotland are:
    - Cereal products
    - Milk products
    - Meat
    - Vegetables and potatoes
- Meat is frequently consumed in Scotland by most people. Meat eaten is primarily poultry (37% of total grams of meat consumed by adults 16+ years), pork (34%) and beef (25%). Lamb (3%) makes only a small contribution.
- Milk products are consumed even more frequently than meat in Scotland and by nearly all people (86% of adults consume some meat and 99% consume some dairy).
- Milk products are especially important for children aged 1.5-3 years, constituting nearly one-quarter of energy intake.
- One-third of adults and one-fifth of children consume oily fish at least once a week.
- Only about one-fifth of adults and children consume 5 or more portions of fruits and vegetables per day. Tomatoes and potatoes are the most frequently reported vegetables, whereas bananas are the most frequently reported fruits.
- In recent years, fewer adults and children report consuming sugar-containing soft drinks and biscuits on a daily basis.
- Generally, those living in the most deprived areas of Scotland have less healthy diets than those living in the least deprived areas. Specifically, they have lower intakes of fruits and vegetables, brown/wholemeal bread and fish; and higher intakes of sugar-containing soft drinks, processed potatoes and takeaway foods.

1.4 Greenhouse gas emissions from food consumed in Scotland

- We found very limited evidence for the GHG emissions associated with food consumption in Scotland. Given that food consumption patterns are broadly similar in Scotland and the UK, we relied on the wider evidence base on emissions associated with food consumption in the UK, assuming emissions are proportional to population.

- There is substantial uncertainty in the magnitude of emissions associated with food consumption in Scotland, with estimates ranging 4.9 to 17.1 $MtCO_2e$.
- Several factors likely contribute to this variability:
    - Some models include land use and land use change whereas others do not.
    - Only one model included emissions from packaging, hospitality and food service, household energy use, consumer transport and deliveries and food waste management, which together accounted for approximately 18% of GHG emissions associated with food consumed in the UK.
    - Two of the models relied on self-reported dietary intake, which is known to be under-reported.
    - Each model handled emissions from imported food differently, and all models had significant uncertainty in country-of-origin data for imported foods.
- There is consistency in several results:
    - Red and processed meat (including processed pork and other processed meat) is consistently the largest food group contributing to emissions.
    - GHG emissions associated with food consumption have declined over the past 30 years due to several factors, including reductions in consumption of red meat and decarbonisation of electricity.

1.5 Conclusions

While cereals, vegetables and potatoes are important contributors to nutrient intake, meat and dairy are important contributors to **both** nutrient intake and GHG emissions in Scottish diets.

There is significant uncertainty around the magnitude of emissions associated with food consumed in Scotland. Data gaps contribute to uncertainty of estimates for children and of regional variability in food consumption and associated emissions.

While recent data on adult food consumption and food life cycle assessment (LCA) databases are available, and together could help fill these gaps, further research into the following would improve the accuracy of such estimates:

- Information on where foods consumed in Scotland are produced and processed
- The nature of under-reporting in food consumption data in Scotland, particularly for specific foods (e.g., meat and dairy)

Taking a ‘bottom up’ approach (starting with consumption data) is recommended to enable estimation of emissions from specific food groups, e.g., meat versus fruits and vegetables, and by specific population subgroups, e.g., men versus women, adults versus children, and by neighbourhood deprivation.

At the same time, a ‘top down’ approach (adding up the emissions from sectors involved in the food system) has the benefit of being more comprehensive. However, it is challenging to estimate emissions associated with specific foods or for population subgroups using this approach.

A ‘top down’ approach can include emissions often missing in ‘bottom up’ studies such as emissions from household and hospitality energy use, consumer transport and food waste disposal. Together, both approaches would provide a more complete picture of GHG emissions associated with food consumed in Scotland, and provide cross-validation.

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4 Glossary / Abbreviations table

Centre for Research into Energy Demand Solutions (CREDS)	CREDS (https://www.creds.ac.uk/) is a UKRI-funded project involving researchers, businesses and policy makers, to support the transition to a zero-carbon society.
Discretionary food and drink	Food and drink products that are high in fat, sugar or salt, including confectionery, biscuits, crisps, savoury snacks, cakes, pastries, sugary drinks, puddings, ice cream and dairy desserts.
Greenhouse gas (GHG)	A GHG "is a gas which absorbs infrared radiation emitted from the surface of the Earth, helping to retain a portion of that energy in the atmosphere as heat" (Scottish Government, 2023).
Kantar Worldpanel (KWP)	KWP is a consumer panel of food and drink run by a market research company.
Living Costs and Food Survey (LCFS)	LCFS[1] is a representative survey of food consumption in the UK[2] that began in 1940 as the National Food Survey, and was merged with the Family Expenditure Survey to form the Expenditure and Food Survey in 2001. In 2008, the Expenditure and Food Survey was renamed LCFS. This is the most comprehensive source of information on trends in food consumption in the UK. Reliable estimates of out of home food and drink are available from 2001. The sample includes about 5,000 households in the UK each year. The response rate in 2022 (latest available) was 27%. LCFS is representative of the Scottish population, and has been analysed in 3-year intervals from 2001/03 to 2016/18 (Barton, 2021).
Life cycle assessment (LCA)	A tool for calculating the environmental impacts, including GHG emissions, of a product.
National Diet and Nutrition Survey (NDNS)	The NDNS Rolling Programme[3], launched in 2008, is a continuous cross-sectional survey designed to assess food consumption of people aged 1.5+ years in the UK. The latest published tables are for Year 11 (2018/19) of the Rolling Programme. Year 12 (2019/20) tables are expected to be released in spring 2024. A follow-up survey of prior NDNS participants was conducted in August and October 2020 but this was not a representative sample.
Rapid evidence assessment (REA)	An REA is "a type of evidence review that aims to provide an informed conclusion on the volume and characteristics of an evidence base, a synthesis of what that evidence indicates and a critical appraisal of that evidence" (Collins *et al.*, 2015).

[1] UK Data Archive link: https://beta.ukdataservice.ac.uk/datacatalogue/series/series?id=2000028

[2] Extended to include Northern Ireland in 1996.

[3] UK Data Archive link: https://beta.ukdataservice.ac.uk/datacatalogue/studies/study?id=6533

Scientific Advisory Committee on Nutrition (SACN)	SACN advises the Office for Health Improvement and Disparities and other UK government organisations on nutrition and related health matters.
Scottish Dietary Goals (SDGs)	The SDGs "describe, in nutritional terms, the diet that will improve and support the health of the Scottish population" (Scottish Government, 2016).
Scottish Health Survey (SHeS)	The SHeS[4] provides detailed information about the health of people living in Scotland. It was established in 1995 and repeated in 1998, 2003 and annually since 2008.
Scottish Index of Multiple Deprivation (SIMD)	The SIMD "is the Scottish Government's official measure of area based multiple deprivation. It is based on 37 indicators across 7 individual domains of current income, employment, housing, health, education, skills and training and geographic access to services and telecommunications. SIMD is calculated at data zone level, enabling small pockets of deprivation to be identified. The data zones are ranked from most deprived (1) to least deprived (6505) on the overall SIMD index. The result is a comprehensive picture of relative area deprivation across Scotland" (Scottish Government, 2018).
Waste and Resources Action Programme (WRAP)	"WRAP is a climate action NGO working around the globe to tackle the causes of the climate crisis and give the planet a sustainable future" (Forbes, 2022).

[4] UK Data Archive link: https://beta.ukdataservice.ac.uk/datacatalogue/studies/study?id=9048

5 Background

5.1 What are food systems?

The draft National Good Food Nation Plan[5] defines foodsystems in line with the United Nations' definition as "all the elements (environment, people, inputs, processes, infrastructures, institutions, etc.) and activities involved in the production, processing, distribution, preparation and consumption" of food (Westhoek *et al.*, 2016) (Figure 1).

Figure 1: Stages of the food system.

Because some of the food we eat in Scotland is produced and processed in the rest of the UK or overseas, our food system encompasses not only farms, fisheries, aquaculture, processors and distributors in Scotland, but also in many other parts of the world.

Some of the food produced or processed in Scotland is exported to the rest of the UK or overseas. While this is important for Scotland's territorial emissions, exported food are not considered for consumption metrics such as the carbon footprint of Scottish diets, which is the focus of this report.

5.2 How does the food we eat contribute to greenhouse gas emissions?

Activities at each stage of the food system (Figure 1) contribute to greenhouse gas (GHG) emissions. For example, GHG emissions arise from:

- deforestation to expand agricultural area to produce food or animal feed,
- the production of synthetic fertilisers,
- greenhouse gas emissions from production, such as methane emissions from ruminants and nitrous oxide emissions from fertiliser use,
- diesel used by fishing vessels,

[5] https://www.gov.scot/publications/national-good-food-nation-plan/pages/1/

- energy use for processing and packaging commodities like wheat, sugarcane, and oilseeds into processed foods,
- diesel used to distribute food to retailers,
- energy use for cold storage during transport and in retail settings,
- energy use of appliances for preparing food at home,
- and disposing of food and food packaging waste.

The use of land for food production contributes to GHG emissions (Intergovernmental Panel on Climate Change, 2019). The quantity of carbon stored in soils and vegetation varies dramatically with land use change. Forests and peatlands are excellent at storing carbon, so when they are converted to pasture for livestock or cropland, the carbon stored is released to the atmosphere. If burning is used to convert the forests or peatlands, these emissions can occur rapidly. However, even when the land use change occurs through other means, e.g., draining of peatlands, the carbon is emitted as the vegetation and organic matter in the soil decays, either as carbon dioxide or methane – both GHGs. Additionally, when fertiliser is applied to pastures or crops, microbes in the soil break it down in a process that produces nitrous oxide, another GHG.

The most comprehensive analysis of GHG emissions associated with food consumed in the UK (Forbes, 2022) found that

- 29% of emissions were from UK agriculture and fishing,
- 26% from imported food,
- 10% from land use change from imported food and animal feed,
- 6% from household energy use to prepare food,
- 5% from energy use to manufacture food in the UK, and
- 4% each from
    - energy use by hospitality and food service,
    - food packaging, and
    - transport within the UK.

Other stages of the food system contributed <4% each to GHG emissions, including energy use by food retailers, consumer transport, consumer deliveries of groceries and takeaway, refrigerants, imported animal feed, fertiliser manufacture and disposal of food waste.

Though improvements in the efficiency of food production are critical for climate change mitigation, their ability to reduce GHG emissions has limits (Stewart *et al.*, 2023). This is because some foods have higher impacts regardless of how they are produced. The emissions from even the lowest-impact beef exceed the average emissions from milk, which in turn exceeds the average emissions from eggs and plant-based proteins (e.g., tofu, groundnuts, pulses, peas and nuts) (Poore and Nemecek, 2018).

There are two major reasons beef production results in more emissions than other foods. First, cows emit methane, a potent GHG, over the course of their lifetime. This methane production contributes to the emissions associated with beef consumption. Although options exist to reduce methane emissions from cows, all ruminants – including cows and sheep – produce methane as part of their digestion. Second, it takes about 9.5kg of feed to produce

1kg of beef.[6] The emissions associated with beef consumption include the emissions from producing feed, whether that be fertilised pasture, soya or some other feed.

The wide range of emissions from different foods means that dietary transitions can play a major role in achieving net zero by reducing consumption of high-emissions foods in favour of low-emissions ones.

6 Aims

The foods we eat in Scotland contribute to GHG emissions. Different foods have different GHG emissions, therefore dietary transitions can play a role in achieving net zero. Recognising this, the Climate Change Committee recommended in their December 2022 report a target of a 20% reduction in all meat and dairy by 2030, increasing to a 35% reduction in all meat by 2050. In the Scottish Government's response (June 2023), the Climate Change Committee's recommendation was partially accepted. Several recent policies will support equitable, sustainable dietary transitions. Foremost among these is the Good Food Nation (Scotland) Act (2022). The Act requires that Scottish Ministers and relevant authorities, in preparing Good Food Nation plans, have regard to the role of sustainable food systems in contributing to climate change mitigation.

The objectives of this report were to describe current and historical food consumption patterns in Scotland, and the implications of these consumption patterns for GHG emissions. To meet these objectives, we conducted a rapid evidence assessment and secondary analyses of publicly available data from the UK Data Archive (see Appendix A for methodology). We then held a workshop with the authors of four UK models that estimated the GHG emissions associated with food consumption to better understand why their models resulted in different estimates of emissions (see Appendix B for a summary of that workshop).

The three aims were to:

1. Describe food consumption patterns of people living in Scotland.
    a. Compare patterns of consumption by sex, age group, Scottish Index of Multiple Deprivation (SIMD) and health board.
    b. Quantify the contribution of food groups to intake of essential nutrients, overall and by population subgroup.
    c. Determine where the food consumed in Scotland is produced.
2. Summarise how a typical 'Scottish diet' has changed over the past 50 years.
3. Describe the GHG emissions associated with food consumed in Scotland.
    a. Qualitatively estimate how changes in food consumption patterns over the past 50 years have affected GHG emissions.
    b. Compare GHG emissions associated with food consumption by population subgroups.

[6] Estimates derived from data from the Agriculture and Horticulture Development Board available from https://ahdb.org.uk/beef-feed-efficiency-programme and https://ahdb.org.uk/beef-carcase-yield

7 Evidence

7.1 Major sources of food consumption information in Scotland

Before describing current and historical food consumption patterns in Scotland, it is important to understand where the underlying data come from (Table 1). The focus of diet monitoring in Scotland over the past two decades has been the Scottish Dietary Goals (SDGs, see Appendix B

7.2 Summary of workshop on four published models to estimate greenhouse gas emissions associated with food consumed in the UK

The University of Edinburgh convened a one-hour online workshop to discuss the different approaches to modelling emissions associated with food consumed in the UK. The lead authors of the four published models identified in our review attended the workshop. The discussion was in two parts: (1) the lead authors presented an overview of their modelling approach (Table 7), and then (2) the group discussed potential drivers of differences across models in estimated greenhouse gas emissions associated with food consumed in the UK (Table 8).

Model	Summary of approach
WRAP	Builds the estimates using sector-specific information from published UK inventories of emissions, rather than LCAs of specific foods consumed. Current area of focus is improving the estimates of imported food emissions, with future intentions to look at the potential impact of on-farm mitigation in the UK. Several strengths of this approach, including: • Ability to capture hospitality, cooking at home, and food waste management [which are typically not reflected in cradle-to-retail gate LCAs] • Ability to update estimates every year to account for shorter-term changes, e.g., in the electricity grid, whereas LCAs are often ‘static’ to a particular year LCAs are used for imported food and are, in some cases, specific to country of import – where there is reason to believe there would be a substantial impact, such as beef and lamb. Further work for this model will focus on improving estimates for traded food and the associated emissions, looking at creating more specificity for products coming from certain locations, and integrating international transport.

Model	Summary of approach
	However, it is not without limitations: • Cannot look at population subgroups • Harder to look at food groups; could be done using other datasets not currently included in their model but this is outside their current scope of work • Land use change is currently focused on specific commodities such as palm oil and soya; this could be improved Data sources: • Governmental datasets such as UK inventories for agriculture and energy consumption by sector (manufacturing, food, retail, etc.) • Other data filled in, e.g., for household deliveries, hospitality, and refrigerant specific emissions • UK trade data linked to LCAs for imported foods
Stewart	This model matches food consumption data to LCAs to estimate emissions. FAO data on food supply, production, imports, exports, seed and feed, were combined with Poore and Nemechek (2018) LCA data. Several strengths of this approach, including: • LCAs were disaggregated by continent and updated over time to reflect variability between continents and over time in emission intensities for commodities • Able to look at food group level data • Able to quantify changes in emissions from changes in consumption versus production efficiency versus trade However, a limitation is that it does not include emissions from hospitality, cooking at home, consumer transport and deliveries, etc. Data sources: • FAO Food Balance Sheets • FAO emission intensities • Poore and Nemechek (2018) LCA data
Bates	This model uses a database of emissions linked to NDNS food consumption data, originally developed for the University of Newcastle's Intake24 dietary recall tool in order to provide feedback to survey participants on the environmental impact of their diets. The model strengths are:

Model	Summary of approach
	• GHGs were mapped from the largest number of unique foods and beverages than any previous UK study at the time • GHGs (CO2e as g/100g) were matched to the majority of individual foods in the NDNS database • Able to look at consumption by food groups and by population subgroups. Data sources: • Published studies and company websites for LCA data • NDNS for food consumption data
CREDS	Primarily purpose was to explore the potential of demand-side mitigation. The model explores three consumer-facing strategies: shifting to plant-based diets, following UK dietary recommendations, and reducing food waste. NDNS data were used for consumption levels by product, whilst the Family Food Survey was used for the calorific intake estimates. The correction for under-reporting was applied on a calorific basis. The representation of diets was based on 17 dietary profiles outlined in the academic literature. There are 69 food product categories covered by the model, using the Classification of Individual Consumption by Purpose (COICOP) classification system. UK MRIO model captures all process-based emissions and factors per food category expressed as emissions per £ spent. Whilst there are uncertainties in most input-output based modelling approaches, the UKMRIO model does incorporate import data from 15 world regions (based on data from 50 countries). This also reflects differences in agricultural production techniques (and consequently emissions factors) from each region. This model does not capture emissions associated with cooking or waste management, land use, or agricultural efficiencies, but subsequent iterations of UK MRIO do take into account land use change. Data sources: • NDNS, Family Food survey and literature reviews to describe example diets • UK MRIO model

Table 7: Summary of modelling approaches used to estimate the greenhouse gas emissions associated with food consumed in the UK.

Aspect of model	Summary of differences
Land use change emissions	WRAP and Stewart are the only models that include emissions from land use change
Packaging, hospitality sector, and post-retail emissions	WRAP is the only model that includes emissions from packaging, hospitality sector, and post-retail (e.g., home food preparation, consumer transport and deliveries, food waste management)
Under-reporting of self-reported food consumption	• Tendency to under-report in food diaries used in Bates and CREDS • CREDS did make a simple adjustment for under-reporting in their model
Handling of imported foods	• Concerns regarding the accuracy of the FAO trade database used in Stewart model • Uncertainty on country of origin data and farming systems (thus associated emissions) for imported foods – applies to all models • WRAP did some analysis around tracing country of origin and found that even when tracing a food product, if it does not come from our first trade partner, the second and third are often the same. For example, The Netherlands is our fourth-largest trade partner for palm oil, but they mostly import from the same top two trade partners as the UK (Indonesia and Malaysia). There were some anomalies, but for most, the import chain did not appear to make much of a difference • Stewart did a sensitivity analysis accounting for continent and found it varied by food group. For example, with beef, accounting for continent increased emissions by 25% (i.e., imported meat has higher emissions on average than UK produced beef), but with mutton, it decreased by 28% (i.e., imported mutton has lower emissions on average than UK produced mutton)

Table 8: Summary of potential sources of variability between models used to estimate the greenhouse gas emissions associated with food consumed in the UK.

Appendix C for a list of the SDGs), which were first set in 1996 (formerly known as Scottish Dietary Targets).

As such, the Scottish Health Survey (SHeS) has collected data in adults and children on the frequency of consuming some foods such as fruits and vegetables since 1995, and on most foods relevant to the SDGs every 2 years since 2008. However, in order to estimate the GHG emissions associated with food consumption, you must know not only *what* foods are consumed but *how much* of each food is consumed. In 2018 and 2021, comprehensive food consumption data – i.e., what and how much – were also collected from adults 16+ years old in SHeS using a method known as a 24-hour dietary recall. This method involves asking the respondent to list all the foods and drinks they had on the previous day, and the amount they had.

Self-reported food consumption is under-reported in the UK. A comparison study among adults in the UK of the 24-hour dietary recall method used in SHeS to a direct physiological measure of energy intake that is considered the 'gold standard' found that the recalls under-estimated energy intake by 25% (Foster *et al.*, 2019). We do not know to what extent specific foods (e.g., meat and dairy) are under-reported. It is therefore difficult to estimate the impact of this under-reporting on GHG emissions.

The second major source of food consumption information in Scotland is the Living Costs and Food Survey (LCFS). LCFS collects information on household food purchases and methods have been developed to estimate individual consumption from these data in Scotland (Wrieden *et al.*, 2013; Barton, 2021). We did not identify any validation of LCFS data against measures of dietary intake, and therefore cannot comment on the extent of misreporting in LCFS estimates.

Data source	Years available	Population represented	Strengths	Limitations
SHeS	1995, 1998, 2003, from 2008 every 2 years (partial) 2018, 2021 (full)	Adults 16+ years	Free, publicly available Can look at differences by sex, age and other individual level characteristics	Intake is under-reported Intake in earlier years only for select foods
LCFS	1940-2000 (partial) 2001-2022 (full)	Households	Free, publicly available	Estimates average consumption for the household so cannot look at differences by sex or age

Table 1: Major sources of food consumption information in Scotland.

It is not possible to directly compare published estimates from SHeS and LCFS due to differences in the classification of foods. For example, SHeS groups vegetables and potatoes together and fruits separately, whereas LCFS groups fruits and vegetables together and potatoes separately.

Moreover, neither SHeS nor LCFS have sufficient samples in a given year to estimate food consumption patterns at the level of the local authority. Even at the level of health boards, NHS Borders, NHS Dumfries and Galloway, NHS Orkney, NHS Shetland and NHS Western Isles have samples of under 100 adults in SHeS 2021.

In the following section, all results for adults are from SHeS 2021, the latest representative data, unless otherwise specified. The latest representative data for children living in Scotland are from 2010 (Masson, 2012). A representative survey of diets in children and young people living in Scotland was launched in January 2024 and results should become available in the spring 2024.[7] As dietary patterns are broadly similar between Scotland and the wider UK (Figure 2), for children we rely on UK-wide data collected as part of the National Diet and Nutrition Survey (NDNS). The latest published estimates for children from NDNS are combined estimates for 2016/17, 2017/18 and 2018/19 (herein 2016/19). By combining three cycles, a sample size of 306 children 1.5-3 years, 725 children 4-10 years and 683 children 11-18 years is achieved. NDNS does not publish how many of the children in each age category are from Scotland versus elsewhere in the UK, although the overall survey is broadly representative of the UK, with around 10% of the sample from Scotland each year.

7.3 Current patterns of food consumption in Scotland

To explore current patterns of food consumption, we explored which food groups contribute the most to energy intake (Figure 2).[8]

[7] Press release available from: https://www.foodstandards.gov.scot/news-and-alerts/fss-invites-families-to-complete-an-online-survey-to-understand-the-eating-habits-of-children-and-young-people-in-scotland

[8] Qualitatively, the results from SHeS 2021 are consistent with results from the latest analysis of LCFS for Scotland (2016/18), which found that the top contributors to energy intake were cereal products, meat, and milk and cheese (Barton, 2021).

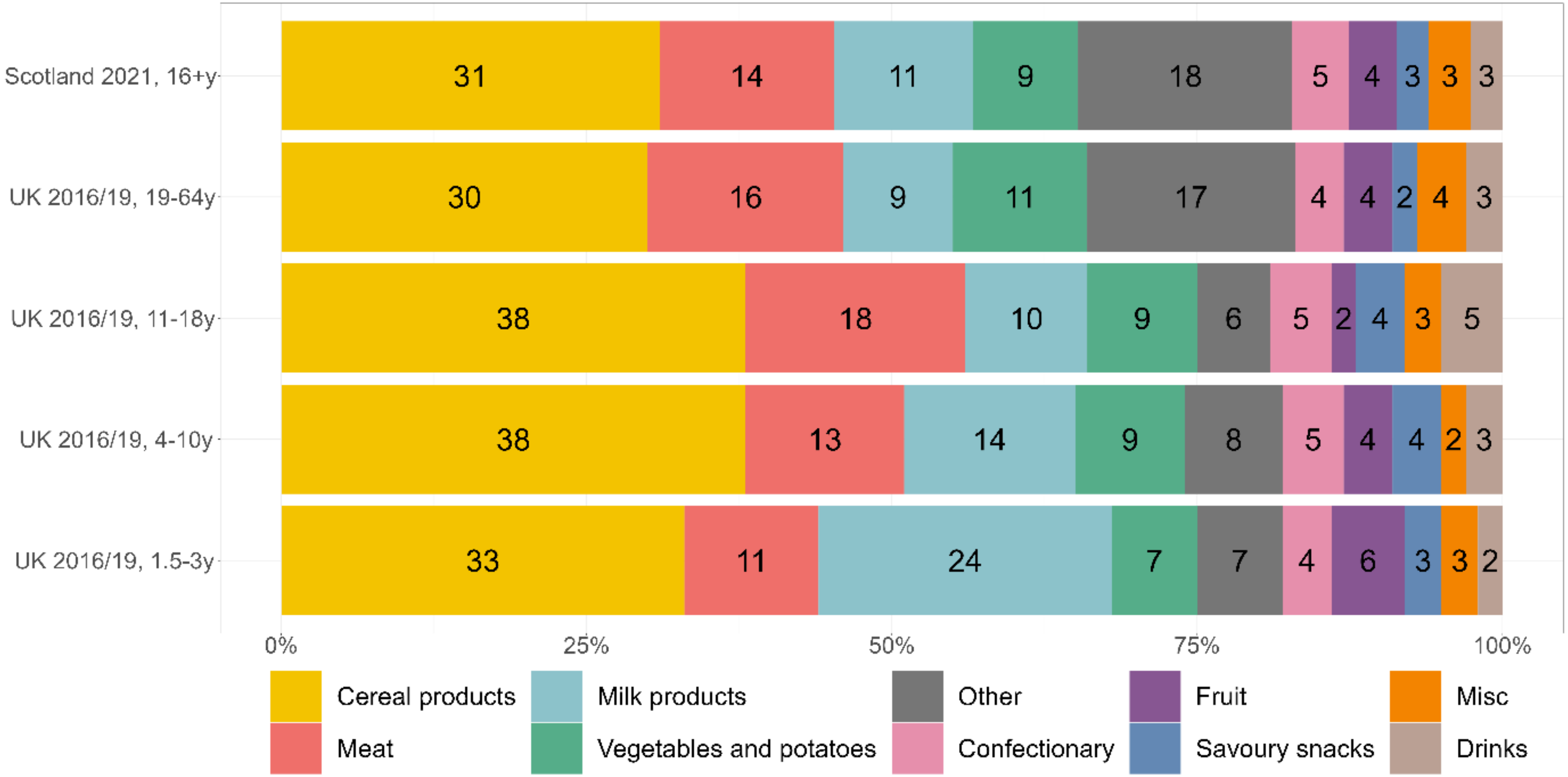

Figure 2: Food groups contributing to energy intake in Scotland (SHeS 2021, 16+ years) and the UK (NDNS 2016/19, 1.5-64 years)

'Cereal products' includes pasta, rice, pizza, bread, breakfast cereals, biscuits, buns, cakes, pastries, fruit pies, and cereal based and sponge puddings. 'Meat' includes bacon and ham; beef, veal and dishes; lamb and dishes; pork and dishes; coated chicken and turkey; chicken and turkey dishes; liver, products and dishes; burgers and kebabs; sausages; meat pies and pastries; and other meat and meat products. 'Confectionary' includes sugars and preserves. 'Drinks' are non-alcoholic. 'Other' is food groups contributing <4% of energy for all population subgroups, including eggs and egg dishes, nuts and seeds, and fish and fish dishes. For details, see: https://assets.publishing.service.gov.uk/media/5a7c7da5ed915d6969f453de/dh_128551.pdf

7.3.1. Meat and meat products

Meat and meat products contributed 14% of energy intake in adults; 18% in young people 11-18 years old; and 11-13% in children 1.5-10 years old.

Meat is frequently consumed in Scotland. In 2021, 86% of adults consumed meat on at least one of up to two days of dietary recalls, with 69% consuming meat on both days (Stewart *et al.*, 2023). Men consumed more meat than women. This difference begins early in life; SHeS 2018 for children 2-15 years found that boys were more likely than girls to eat meat products (such as sausages, meat pies, bridies, corned beef or burgers) at least twice a week (41% of boys versus 36% of girls) (Scottish Government, 2018). Processed meat intake was highest among young adults 16-24 years old and white meat intake was highest among adults aged 25-34 years. There was no difference in total meat intake by SIMD. However, adults in the least deprived SIMD were less likely to be a high consumer of red and red processed meat (31%) than those in the most deprived SIMD (44%).

Most meat eaten was poultry (37% of total grams of meat consumed by adults 16+ years), pork (34%) and beef (25%), with very small contributions from lamb (3%) and game (1%). These contributions did not differ with sex or SIMD, except for game which had a higher contribution among those in the least deprived SIMD. The contribution of lamb to meat intake was higher among older age groups. The most frequently reported ways in which adults in Scotland eat meat are chicken breast (fried, roasted or grilled), ham sandwiches, spaghetti Bolognese, chili con carne, beef lasagne, chicken curry, chicken casserole/stew and roast beef.

With regards to the SDG for red and red processed meat, nearly three quarters of adults (72%) consumed no more than 70 grams of red and red processed meat per day (Scottish Government, 2022). Women were much more likely to meet this Goal than men (79% versus 64%, respectively). Adults 65+ years old were most likely to meet this Goal (76-77%) and those aged 35-44 years were least likely (66%).

7.3.2. Milk products

Milk products contributed 11% of energy intake in adults; 24% in children 1.5-3 years; and 10-14% in children and young people 4-18 years.

Nearly all adults (95%) in Scotland consumed milk products on at least one of up to two days of dietary recalls, 88% consumed milk products on both days (Stewart *et al.*, 2023). Among consumers, mean daily consumption of milk products was 241g, comprised of 180g milk, 27g yoghurt, 23g cheese and smaller quantities of cream and dairy desserts (7g) and butter (4g). There was no difference in milk product consumption by sex or age group among adults. Adults living in the least deprived areas of Scotland were the highest consumers of cheese, while adults in SIMD 4 (second-least deprived areas) were the highest yoghurt consumers.

Most milk products came from milk (62%), followed by cheese (19%) and yoghurt (10%) with smaller contributions from cream and dairy desserts and butter (both 4%). Half of consumers only consumed low fat varieties of milk and yoghurt, while 23% consumed only full fat varieties.

7.3.3. Fruits and vegetables

Vegetables and potatoes contributed 9% of energy intake in adults and children and young people 4-18 years and 7% in children 1.5-3 years. The most frequently consumed vegetables[9] were fresh tomatoes, side salad (including lettuce, tomato and cucumber) and oven chips (4% of adults report consuming each of them); cherry tomatoes, carrots, new potatoes, frozen peas, boiled broccoli and baked beans (each 3% of adults); and mashed potato, cucumber, potatoes, chips, lettuce and baked potato (each 2% of adults). The most frequently reported fruits consumed were bananas (25% of adults report consuming them), apples (13% of adults), blueberries and tangerines/ mandarins/ clementines/ satsumas (both 6% of adults), strawberries, oranges and red grapes (each 5% of adults), raspberries (3% of adults), and pears, avocados, olives, fresh fruit salad and white grapes (each 2% of adults).

With regards to the SDG for fruits and vegetables, only one-fifth of adults and children in Scotland consumed 5 or more portions of fruits and vegetables per day (Scottish Government, 2022). Adults 65-74 years old were most likely to consume their five-a-day (28% of men and 29% of women), whereas young adults 16-24 years old were least likely (9% of men and 17% of women). There were no significant variations in fruits and vegetable intake by age or sex among children.

7.3.4. Discretionary foods

Together, all **discretionary foods and drinks account for 15% of energy intake in adults 16+ years** with sweet biscuits being the largest contributor within the category (Food Standards Scotland, 2023). Additional foods that may also be high in fat, sugar or salt such as breakfast cereals; roast potatoes, chips and similar roasted potato products; pizza; yoghurts, fromage frais and dairy desserts; and ready meals together account for an additional 13% of energy intake.

- Young adults aged 16-34 years and adults living in the most deprived communities drank the most sugar-containing soft drinks.
- Young adults aged 16-24 years ate the most roast potatoes, chips and similar roasted potato products; whereas adults aged 75+ years ate the most sweet biscuits, cakes, sweet pastries and puddings, ice cream and ice lollies, yoghurts, fromage frais and dairy desserts and breakfast cereals.
- 16% of children 2-15 years (18% of boys and 15% of girls) consumed sugar-containing soft drinks at least once a day (falling from 35% in both boys and girls in 2016) (Scottish Government, 2018).
- Consumption of biscuits at least once a day also fell, from 32% in 2016 to 28% (30% of boys and 27% of girls) in 2018 (Scottish Government, 2018).

7.3.5. Other food groups

Cereal products contribute to nearly one-third of energy intake in adults and children 1.5-3 years and 38% in children and young people 4-18 years. The most frequently consumed cereal products are toasted white bread (6% of adults report consuming it), toasted brown bread (5% of adults), white bread rolls and white basmati rice (both 3% of adults), digestive

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[9] This does not include vegetables consumed as part of composite dishes such as tomatoes in a Bolognese sauce.

biscuits, toasted multiseed wholemeal bread, Weetabix/wheat biscuits, brown bread (not toasted), chocolate digestive biscuits, white bread (not toasted), porridge made with water, and pasta shapes (white/ tricolore) (each 2% of adults).

Sandwiches contribute 7% of energy intake in adults. The most frequently consumed sandwiches are ham sandwiches (25% of adults report consuming them), cheese sandwiches (14%), cheese and ham sandwiches (8%), bacon sandwiches (4%), egg mayo sandwiches (4%), and tuna mayo sandwiches (3%).

Fish only contributes 3% of energy intake in adults and 2% in children and young people 1.5-18 years. About one-third of adults (33% of women and 29% of men) and 19% of children eat oily fish, such as salmon, at least once a week (Scottish Government, 2018).

7.4 Food groups contributing to nutrient intake in Scotland

There are four major food groups that contribute to nutrient intake in Scotland:

- Cereal products
- Milk products
- Meat products
- Vegetables and potatoes

There are some additional food groups contributing at least 10% to select other nutrients (Table 2). Non-alcoholic drinks including tea, coffee, juice and sugary drinks.

While there are some differences in the relative magnitude of these contributors between men and women, adults and children, and by deprivation, for all population subgroups, these are the top contributors.[10]

[10] Results by population group are available on GitHub: https://github.com/Cristina-Stewart/SHeS_ClimateXChange

	Cereal products	Meat	Milk products	Vegetables and potatoes	Non-alcoholic drinks	Other
Protein	24%	27%	14%			
Fat	22%	19%	18%			
Carbohydrates	43%			10%		
Free sugars	29%				17%	Sugar, preserves & confectionery (24%)
Fibre	38%	10%		22%		
Calcium	26%		34%			
Chloride	26%	18%	11%			Sandwiches (10%)
Copper	31%	12%		13%		
Iodine	12%		38%			
Iron	39%	16%		12%		
Magnesium	26%	12%	11%	12%	11%	
Manganese	44%			11%	12%	
Phosphorus	24%	17%	20%			
Potassium	15%	13%	13%	18%	13%	
Selenium	27%	26%				Fish (11%)
Zinc	27%	25%	16%			
Thiamine (B1)	31%	15%		15%		
Riboflavin (B2)	20%	13%	30%			
Niacin (B3)	26%	29%			10%	
Vitamin B6	18%	21%	12%	12%		
Vitamin B12	11%	19%	36%			Fish (10%)
Folate	28%			21%		
Vitamin A	12%	10%	25%	22%		Miscellaneous (11%)
Vitamin C				28%	25%	Fruit (19%)
Vitamin E	23%	11%		17%		

Table 2: Food groups contributing at least 10% to specified nutrients, analysed for adults 16+ years living in Scotland.

Data are from the Scottish Health Survey (2021). ‘Miscellaneous’ includes dry weight beverages, soup, nutrition powders, savoury sauces pickles, gravies and condiments.

7.5 Where food we eat comes from

Where food is produced is important for GHG emissions associated with food consumption not only because of transport's contribution to emissions, but because the efficiency of production varies substantially between countries (Crippa *et al.*, 2021). For example, the emissions associated with producing a litre of milk in the UK are, on average, 1.2 kg CO_2e (AHDB, 2021) whereas the global aggregate estimate in the frequently used Poore and Nemecek database for a litre of liquid milk is 3.2 kg CO_2e (Poore and Nemecek, 2018). Given that most liquid milk consumed in Scotland is likely produced in the UK, and that 44% of total dairy intake among adults in Scotland is liquid milk (Jaacks *et al.*, 2024), use of the global aggregate estimates will over-estimate GHG emissions from liquid milk.

A contrasting example is lamb. The carbon footprint of lamb produced in New Zealand and consumed in the UK is 19 kgCO_2e per kg of lamb meat (Ledgard *et al.*, 2011), compared with 25 kgCO_2e per kg of lamb meat in the UK (AHDB, 2021). For the lamb produced in New Zealand and consumed in the UK, 80% of GHG emissions are from the farm, 3% from processing, 5% from all transportation stages (including domestic transport in New Zealand and the UK *and* ocean shipping) and 12% from retailer/consumer/waste stages (dominated by retail storage and home cooking[11]) (Ledgard *et al.*, 2011). The reason for lower emissions from lamb produced in New Zealand could relate to the fact that New Zealand sheep farming systems are based on year-round grazing of permanent perennial grass and white clover pastures, and low application rates of fertiliser to pastures (Ledgard *et al.*, 2011). Importantly, brought-in feeds are not used in these systems (Ledgard *et al.*, 2011).

Of relevance to Scotland, where the food and drink sector is dominated by small- and medium-sized enterprises (SMEs), a recent review found that there is a large amount of variation in techniques, ingredients and production scale, which influence the GHG emissions associated with the products produced. They concluded: "For this reason, widescale generalisations are likely to not lead to accurate conclusions on climate related impacts for this sector" (Sandison and Yeluripati, 2023).

We identified only one study that explicitly discussed the origin of food in Scotland (Copus, Hopkins and Creaney, 2016). This was a survey completed by 97 SMEs in the food and drink sector. Given that there are more than 40,000 food businesses in Scotland, and the low response rate for this survey,[12] results should be interpreted with caution as they are unlikely to be generalisable to the entire food and drink sector. While there was substantial variability between SMEs, on average, they found that SMEs were relatively localised: 37% of all inputs came from within 1 hour's travel time of the production site and 29% from elsewhere in Scotland. In terms of sales, 47% of outputs were sold within 1 hour's travel time and 25% to customers elsewhere in Scotland; less than 10% was sold outside the UK. However, there was substantial variability by product type. While no more than 5% of sales of bakery products, dairy/cheese, fruits/vegetables, and meat products were sold ? outside Scotland, 26% of grains/cereals, 40% of alcoholic drinks and 44% of fish/seafood were sold

[11] The method of cooking can influence this estimate. A sensitivity analysis showed that cooking-related emissions were 20% greater by roasting the lamb compared with frying it.

[12] Out of 862 SMEs contacted in September-October 2015, 11% completed the survey.

outside Scotland. Data from a larger, more representative sample is needed to understand the wider food and drink sector in Scotland.

An unpublished report, entitled, ‘Estimation and evaluation of the origins of food consumed in Scotland,’ was recently commissioned by Scottish Government (SAC Consulting, 2024). This report was the first exercise to estimate the origins of food in Scotland so comprehensively. Consumption surveys (Table 1) do not collect information on the country of origin of reported foods. Key findings were as follows:

- There is an increasing trend towards processing of Scottish produce in England and, in some cases, in Northern Ireland
    - As a result, the export and reimport of products is commonplace
    - This complicates the attribution of products consumed in Scotland. For example, if milk was produced in Scotland and transported to England for the production of cheese, which was then sold and consumed in Scotland
    - This is true across food groups, including meat, dairy, seafood and cereals
- Based on production statistics, we produce enough milk, beef and lamb to meet current consumption levels in Scotland
- Chicken production is ‘virtually non-existent in Scotland’ and pork production is ‘very small relative to demand’
    - Thus, most chicken and pork consumed in Scotland comes from the rest of the UK or is imported
- There is very limited capacity to meet demand for white fish and for fruits and vegetables out of season
    - Most fish consumed in Scotland is imported
- Bread wheat is imported from the rest of the UK, Germany and Canada (among other countries)

Based on the recent Scottish Government report (SAC Consulting, 2024), 2022 horticulture statistics from Defra for the whole UK (Defra, 2023)[13] and a report from the UKRI-funded BeanMeals project (Nicholson and Jones, 2023), we summarised where a majority of top-consumed foods in Scotland are likely produced (Table 3). Fruits and vegetables have the greatest uncertainty.

[13] For apples, while UK home production is 205.5 thousand tonnes, a further 321.9 thousand tonnes are imported. For pears, 113.7 thousand tonnes are imported versus just 17.9 thousand tonnes home production. For raspberries, UK home production in 16.3 thousand tonnes and 27.3 thousand tonnes are imported. For tomatoes, UK home production is 71.9 thousand tonnes versus 385.3 thousand tonnes imported. For lettuce and broccoli (reported together with cauliflowers), quantities for UK home production and imports are similar (103 and 132.8 thousand tonnes, respectively for lettuce and 14.8 and 129.5 thousand tonnes, respectively for broccoli and cauliflowers).

Food Group	Food Items	Scotland	Rest of UK	Rest of world
Cereal products	Bread[1]			
	Digestive biscuits[1]			
	Basmati rice[1]			
	Oatcakes[1]			
	Weetabix[1]			
	Porridge[1]			
Meat	Ham for sandwiches[1]			
	Bacon for sandwiches[1]			
	Chicken breast[1]			
	Mince beef[1]			
	Roast beef[1]			
Milk products	Milk[1]			
	Yoghurt[1]			
	Cheese[1]			
Vegetables and potatoes	Tomatoes[2]			
	Potatoes[2]			
	Carrots[2]			
	Peas[2]			
	Lettuce[2]			
	Cucumber[2]			
	Broccoli[2]			
	Baked beans[3]			
	Green beans[2]			
Fruits	Bananas[2]			
	Apples[2]			
	Blueberries[2]			
	Strawberries[2]			
	Citrus[2]			
	Red grapes[2]			
	Raspberries[2]			
	Pears[2]			
	Avocados[2]			

Table 3: Summary of likely main sources of top-consumed foods in Scotland.

Given limitations of published data, we could not estimate what proportion of food items is from Scotland versus the rest of the UK versus the rest of the world.

[1]Estimate from SAC Consulting, 2024.

[2]Estimate from Defra, 2023.

[3]Estimate from Nicholson and Jones, 2023.

7.6 How food consumption patterns have changed in Scotland in the past 50 years

The oldest dietary intake data identified in the rapid evidence assessment with national coverage was from the Scottish Heart Health Study, which recruited a random sample of 10,359 women and men aged 40-59 years across 22 districts of Scotland in 1984-86. At the time, dietary intake monitoring was more focused on nutrients and a few select food groups rather than overall diet. Only 8% of women in the highest social-class group met the World Health Organisation target for fruits and vegetables, while men and those in the lowest social-class group were even less likely to meet the targets (Bolton-Smith, 1991). Additional differences in consumption by socio-economic group were evident at that time – those in the lowest social-class group had higher total energy intakes and a higher proportion of diet from bread and potatoes, but a lower proportion from red meat and puddings (Bolton-Smith, 1991). These disparities were reflected in nutrient intakes: those in the lowest social-class group had 20-25% lower nutrient density values for fibre, vitamins C and E, and beta-carotene compared to those in the highest social-class group (Bolton-Smith *et al.*, 1991a).

The Scottish Heart Health Study also assessed 'special diets' and found 0.4% of the sample self-reported following a 'vegetarian' diet and 1 participant self-reported being a 'vegan' (Bolton-Smith *et al.*, 1991). More than two decades later, in the NDNS (2008/09 to 2018/19 combined), 2.1% of participants reported being 'vegetarian' and 0.2% 'vegan' (Stewart *et al.*, 2021).

To understand trends prior to 1984-86, one must rely on UK-wide trends reported as part of LCFS. Key trends covering the period of 1970 to 2000, shown as figures in Appendix , include (Defra, 2011):

- Milk and milk products
    - Total liquid milk decreased, and full fat milk was largely replaced with skimmed milks (including semi-skimmed and fully skimmed milks)
    - Yoghurt[14] increased
    - Cheese remained relatively unchanged
- Meat
    - Beef, lamb, bacon and ham, and sausages decreased
    - Poultry increased
    - Pork remained relatively unchanged
- Fish and eggs
    - White fish, cooked fish (e.g., canned fish) and eggs decreased
    - Oily fish and shellfish increased slightly
- Fruits and vegetables
    - Potatoes and, to a lesser extent, fresh green vegetables decreased
    - Other fresh vegetables, frozen vegetables, bananas and fruit juice increased
    - Apples and pears, citrus and canned vegetables remained relatively unchanged
- Grains
    - Flour, and, to a lesser extent, bread and biscuits decreased

[14] Includes fromage frais.

- Cakes and pastries decreased in the 1970s and have remained relatively constant since then
- Breakfast cereal increased

Scotland-specific trend analyses of LCFS data from 2001/03 to 2015/18 are available and provide information about more recent trends, namely:

- Disparities in food consumption by SIMD did not improve from 2001/03 to 2007/09 (Barton *et al.*, 2015)
    - Those living in the most deprived quintile have lower intakes of fruits and vegetables, brown/wholemeal bread, breakfast cereals, oily fish and white fish than those in the least deprived quintile
    - Those living in the most deprived quintile have higher intakes of sugar-containing soft drinks, other red meat products (includes the meat portion of meat pies, sausages, corned beef, burgers and pate), whole milk, processed potatoes and takeaway foods than those in the least deprived quintile
- Some trends observed in earlier years have continued whereas others have not, namely, from 2001/03 to 2015/18 (Wrieden *et al.*, 2013; Barton, 2021),
    - Fruits and vegetables and oily fish did not change
    - Red and processed meat decreased; the decrease has been much larger for women than men
    - Total bread decreased, driven by a decrease in white bread
    - Total milk decreased, driven by a decrease in full fat milk
    - Sugar-containing soft drinks decreased and sugar-free soft drinks increased
    - White fish and fresh potatoes decreased
    - Nuts increased
    - Cakes, biscuits, confectionery, processed potatoes and savoury snacks remained relatively constant

One previous analysis used Kantar World Panel data to evaluate food energy purchases in 2007 as compared to 2012, hypothesising that these would be lower as a result of inflation-adjusted food prices being 12% higher in 2012 than in 2007[15] whilst median equivalised disposable income had decreased over the same time period (Whybrow, Horgan and Macdiarmid, 2017). They found that food energy *purchases* did indeed decrease, from 8.6 to 8.2 MJ per adult equivalent per day. At the same time, however, food waste decreased, and so the net food energy *consumed* did not change significantly: 7.3 vs. 7.2 MJ per adult equivalent per day (Whybrow, Horgan and Macdiarmid, 2017). Changes in food groups over this time period were not reported.

[15] Average food inflation in Jan-Oct 2023 was 16%: https://www.ons.gov.uk/economy/inflationandpriceindices/articles/costoflivinginsights/food#:~:text=Prices%20of%20food%20and%20non,seen%20for%20over%2045%20years.

7.7 GHG emissions associated with food consumption in Scotland

7.7.1. The literature

We identified only two abstracts[16] that estimated the GHG emissions associated with food consumption in Scotland. Both abstracts used purchase data from 2,844 households in the Kantar Worldpanel linked to emissions data from the Barilla Center for Food & Nutrition.

The first abstract found that GHG emissions associated with food consumed in Scotland decreased from 2007 to 2012 by approximately 10%, with no differences by SIMD: for example, in SIMD 1 (most deprived), from 3.4 to 3.0 $kgCO_2e$ per adult equivalent per day (Whybrow and Macdiarmid, 2018). This was in part due to a reduction in purchases of red and processed meat. For comparison, an analysis of NDNS data (2008/9-2013/14) found that the diets of adult men and women, respectively, had average GHG emissions of 4.27 and 3.36 $kgCO_2e$ per day (Bates, Chambers and Craig, 2019) (see Appendix E for details regarding the LCA database used). Children had significantly lower diet-associated GHG emissions: 3.15 and 2.77 $kgCO_2e$ per day for boys and girls, respectively (Bates, Chambers and Craig, 2019). Applying these NDNS food consumption emission intensities to the 2022 Scottish Census data,[17] the GHG emissions associated with food consumption in Scotland would be estimated at 7.2 $MtCO_2e$ per year.

The second abstract examined the relative quality of diet – as defined by adherence to the Scotland Dietary Goals – and compared it to dietary GHG emissions. When looking at how the interaction of diet quality and dietary GHG emissions was associated with cost, they found that the highest quality diets[18] with the lowest GHG emissions were 50% more expensive than the lowest quality diets with the highest GHG emissions (61 versus 40 p/MJ respectively) (Whybrow, Horgan and Macdiarmid, 2018). They also found that the highest quality diets were not necessarily lower in GHG emissions.

[16] We have confirmed with the authors that these two abstracts were not written up as full papers.

[17] Adult females, 2,243,000; adult males, 2,062,200; girls, 551,600; boys, 579,700. Available from: https://www.scotlandscensus.gov.uk/2022-results/scotland-s-census-2022-rounded-population-estimates/

[18] In this abstract, 'healthiest' was defined as the highest tertile in terms of meeting the Scottish Dietary Goals.

7.7.2. Modelling sources

Given this major gap in the literature of recent Scotland-specific studies on GHG emissions associated with food consumption, and given evidence that the foods consumed in Scotland are largely similar to those in the UK, we pivoted to three models of GHG emissions associated with food consumed in the UK and one global model that published UK-specific estimates (see Appendix B and Appendix E for details of each model). To convert UK-wide estimates to Scotland, we made the assumption that emissions are proportional to population (e.g., that Scotland is responsible for 8.2% of UK emissions).

Two broad approaches have been used to estimate emissions associated with food consumed in the UK (Table 4). 'Bottom up' approaches link food consumption data to life cycle assessment data to calculate emissions. 'Top down' approaches sum emissions from the food and drink sector, subtracting emissions associated with exports and adding emissions associated with imports.

Approach	Method	Limitations	Models
'Bottom up'	Linking consumption data (food availability, food purchases or dietary intake) to food life cycle assessments (LCAs) and calculating per capita GHG emissions	• Consumption may be misreported • Uncertainty in origin of food reported and lack of specificity of LCAs limits accuracy • Issues over system boundaries, for example, LCAs typically end at retail and therefore do not include emissions from household and hospitality energy use, consumer transport or waste disposal • LCAs can become out-dated and may not accurately reflect improvements in production efficiency	Stewart model CREDS[1] model Bates model
'Top-down'	Summing GHG emissions from sectors involved in food supply chain, subtracting exports and adding imports	• Significant uncertainty and variability in emissions associated with imported food • Issues over system boundaries, for example, whether or not land use emissions (e.g., from agricultural soils) or land use change emissions are in scope	WRAP[2] model

Table 4: Summary of the two broad approaches used to estimate greenhouse gas emissions from food consumed in the UK: (1) 'bottom up' and (2) 'top down'.

[1]Centre for Research into Energy Demand Solutions. The CREDS model referred to in this report is from Garvey et al. 2021.

[2]Waste and Resources Action Programme.

7.7.3. Variations in the modelling

The GHG emissions associated with food consumed in Scotland vary widely (Figure 3), with estimates ranging from 4.9 to 17.1 $MtCO_2e$.

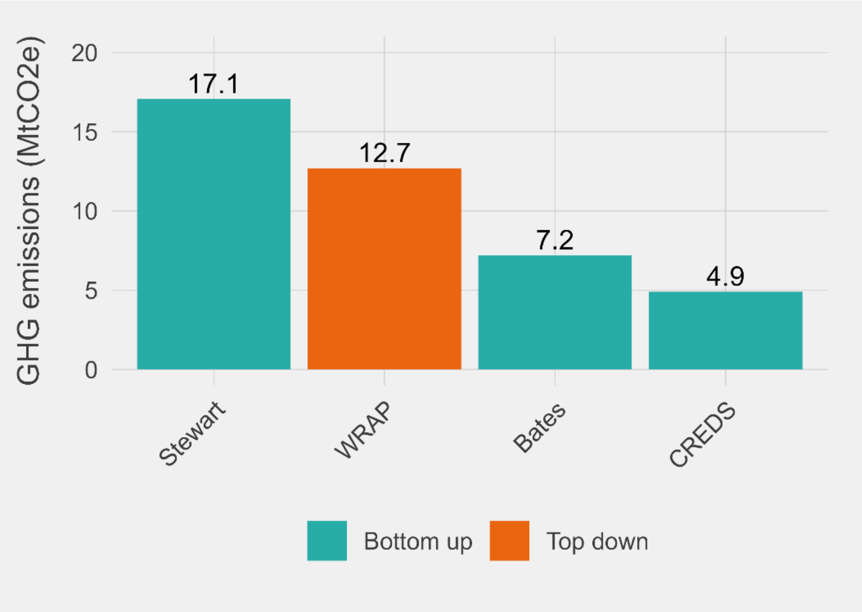

Figure 3: Greenhouse gas emissions associated with food consumed in Scotland.

Values are from UK-wide models, extrapolated to Scotland by assuming emissions are proportional to population (e.g., Scotland is responsible for 8.2% of UK emissions).

Several factors likely contribute to this variability:

- Some models include land use and land use change[19] (Stewart and WRAP) whereas others do not (Bates and CREDS)
    - The WRAP model estimated that 10% of GHG emissions associated with food consumed in the UK come from land use change for imported food and animal feed; thus, this could partly explain why the Stewart and WRAP models resulted in higher GHG emissions than the Bates and CREDS models
- Only the WRAP model included emissions from packaging, hospitality and food service, household energy use, consumer transport and deliveries and food waste management, which together accounted for ~18% of GHG emissions associated with food consumed in the UK
- Two of the models relied on self-reported dietary intake (Bates and CREDS) which is known to be under-reported (see Section 7.1)

[19] Forests and peatlands store carbon, and so when they are destroyed for livestock grazing or agriculture, they release carbon into the atmosphere. If, in the process of destroying forests and peatlands, they are burned, the burning results in additional emissions. In addition to GHG emissions from these land use changes, microbes in soils can produce GHG emissions. For example, when fertiliser is applied to pastures or crops, microbes in the soil break it down in a process that produces a GHG called nitrous oxide.

  - This may partly explain why the Bates and CREDS models had lower estimates of GHG emissions than the Stewart and WRAP models
  - Of note, the Stewart model used FAO Food Balance Sheets and the WRAP model used a top-down approach that did not rely directly on estimates of food consumption
- Each model handled emissions from imported food differently
  - Some models matched specific LCA data to food groups based on trade information, either from FAO (Stewart) or UK Government (WRAP and CREDS)
  - All models had significant uncertainty in country-of-origin data and farming systems (thus associated emissions) for imported foods

The results of each model are discussed in greater detail below.

7.7.4. Results of the WRAP model

Sourced from Forbes, Fisher and Parry, 2021; Forbes, 2022)

- Food consumed in the UK contributed 154.8 MtCO_2e in 2020
  - Applying the assumption that emissions are proportional to population, food consumed in Scotland would contribute 12.7 MtCO_2e per year
- The estimates were calculated by summing GHG emissions from 15 stages of the food supply chain, subtracting exports and adding imports
  - The 15 food supply chain stages were: (1) UK Agriculture and Fishing; (2) Fertiliser Manufacture; (3) Imported Animal Feed; (4) Imported Food; (5) Land Use Change from Imported Food and Feed; (6) UK Food Manufacture; (7) Refrigerants; (8) Packaging; (9) Transport (UK Supply Chain); (10) Transport (Consumer); (11) Transport (Consumer Delivery); (12) Food Retail Energy Use; (13) Hospitality and Food Service Energy Use; (14) Household Energy Use; and (15) Waste Disposal
- Of the 15 supply chain stages, UK Agriculture and Fishing (which includes GHG emissions from livestock, agricultural soils, stationary combustion sources, off-road machinery, and fishing) and Imported Food (which uses life cycle assessments and trade data to estimate the emissions for net imports) were the largest contributors to GHG emissions, together accounting for more than half of GHG emissions associated with food consumption in the UK in 2020 (Figure 4)
- The greatest uncertainty is in the GHG emissions associated with Imported Food
  - This is due to uncertainty in land use change estimates for many Imported Food products

  The WRAP model does not currently provide estimates for specific food groups, e.g., what proportion of GHG emissions are from meat versus other food groups

- Between 2015 and 2020, there was a 12% reduction in GHG emissions associated with food consumption in the UK
  - GHG emissions from Food Manufacturing, Food Retail and Household Energy Use have gone down due to decarbonisation of electricity and reduced electricity demands (e.g., from more energy-efficient appliances)
  - GHG emissions from Refrigerants have gone down slightly due to use of lower-impact refrigerants, particularly in commercial settings

- GHG emissions from Food Waste have gone down slightly due to food waste reductions and diversion from landfill
- GHG emissions from UK Agriculture and Fishing and Fertiliser Manufacture have been largely static
- GHG emissions from Packaging have gone up, notably increases in plastics and glass
- Changes in GHG emissions from Hospitality and Food Service Energy Use, Transport (Supply Chain) and Transport (Consumer) were likely to be impacted by lockdowns in 2020 and so conclusions cannot be drawn on trends until subsequent years of data are integrated

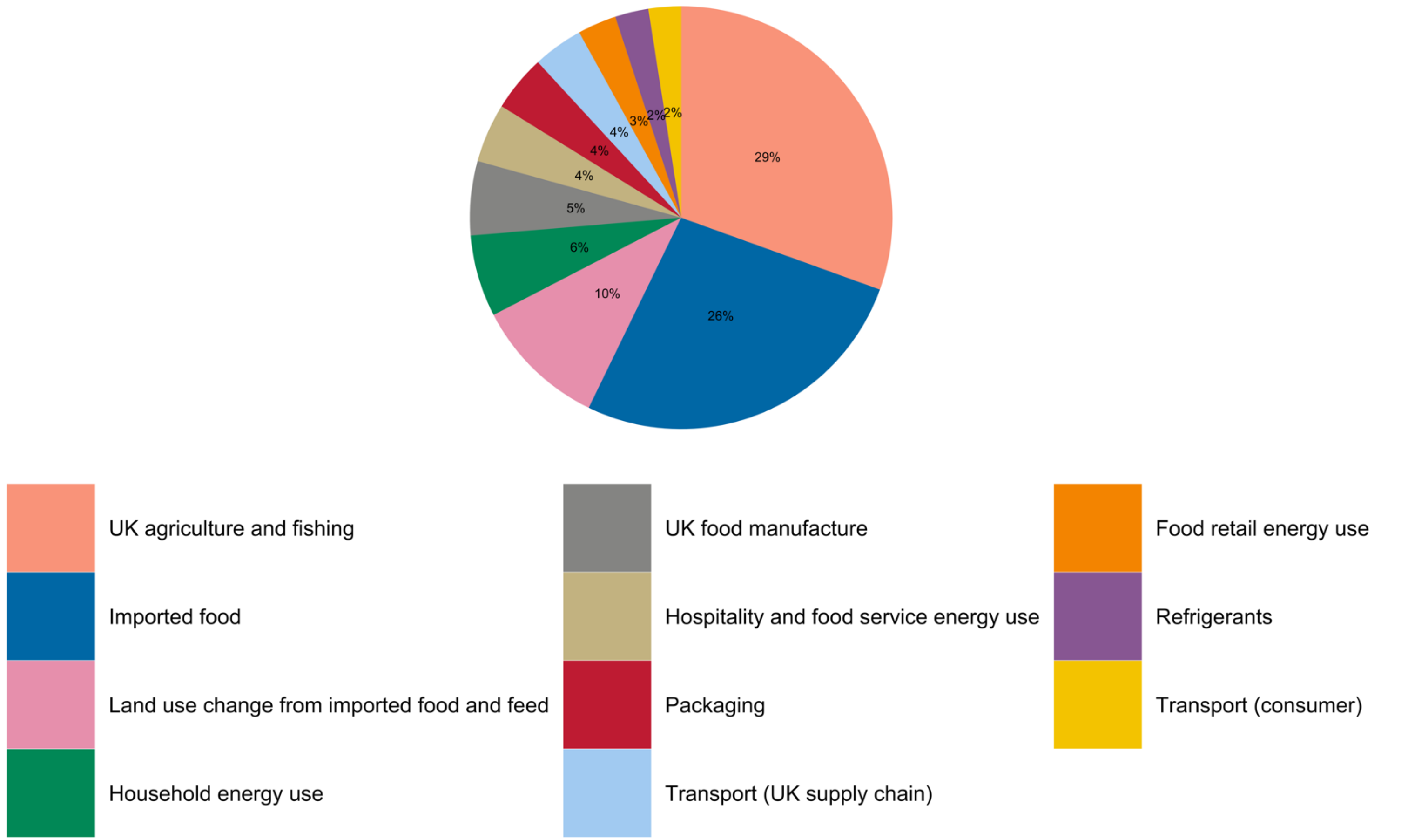

Figure 4: Greenhouse gas emissions associated with food consumed in the UK, by stage in the food system (2020).

Data are from Forbes 2022. Sectors contributing <2% not shown including, Imported Animal Feed, Fertiliser Manufacture, Transport (Consumer Delivery) and Waste Disposal.

7.7.5. Results of the Stewart et al. (2023) model:

- Food consumed in the UK contributed 208 $MtCO_2e$ in 2017
    - Applying the assumption that emissions are proportional to population, the food consumed in Scotland would have contributed 17.1 $MtCO_2e$ per year
- The Stewart model combined data on food availability from FAO Food Balance Sheets with GHG emissions from life cycle assessments to estimate overall and per-capita GHG emissions for food available in the UK
- The model does not examine different stages of the food system (production, transport, etc.) but rather the emissions attributable to the following categories:
    - Production side: changes in emissions intensity, defined as the FAO measure of emissions associated with producing a kilogram of a given product up to the farm gate
    - Consumer side: changes in consumer behaviours including dietary intake and waste at the retail and household level
    - Trade patterns: accounts for differences in continent of origin for food imports and differences in production efficiency by continent of origin, but excludes emissions from transport
- Between 1986 and 2017, there was a 20% reduction in *overall* emissions associated with food consumed in the UK
- Between 1986 and 2017, there was a 32% reduction in *per capita* GHG emissions
    - Changes in the production side resulted in a 21% reduction in per capita GHG emissions
    - Changes in the consumer side resulted in a 10% reduction in per capita emissions
    - Changes in trade patterns resulted in a 2% reduction in per capita emissions
        - Food produced closer to the UK did not always have lower emissions
        - Trade emissions for ruminant meat were slightly lower as it was increasingly sourced from Europe rather than from Latin America
        - Trade emissions for dairy were slightly higher
            - The UK was a net exporter of dairy in 1986 but a net importer in 2017
            - Additionally, a higher share of dairy imports were from Europe versus Oceania in 2017; and European dairy has higher production emissions than dairy produced in Oceania
        - Trade emissions for nuts and pulses were higher in 2017 versus 1986
- The authors also examined changes in per capita GHG emissions by food group
    - Per capita GHG emissions from ruminant meat decreased by 35% from 1986 to 2017
        - Reduced consumer-side GHG emissions made the greatest contribution to this reduction, accounting for 46% of the change
    - Per capita GHG emissions from dairy decreased by 50% from 1986 to 2017
        - Improvements in production accounted for 70% of the change
    - Per capita GHG emissions from fruits and vegetables decreased by 50% from 1986 to 2017
        - Changes in the production side, consumer side and trade patterns contributed approximately equally to this change
    - Per capita GHG emissions for nuts and pulses increased from 1986 to 2017

        - This was largely due to increased consumer demand for and trade of these products

7.7.6. Results of the CREDS model (Garvey *et al.*, 2021):

- Food consumed in the UK contributed 59.8 MtCO2e in 2017
    - Applying the assumption that emissions are proportional to population, food consumed in Scotland would have contributed 4.9 MtCO2e per year
- Meat products, particularly processed meats, account for the largest proportion of UK agriculture emissions in order to meet UK demand for these products

8 Conclusions

This report has examined current and historical food consumption patterns in Scotland, and the implications of these consumption patterns for GHG emissions.

Though improvements in the efficiency of food production are critical for climate change mitigation, their ability to reduce GHG emissions has limits (Stewart *et al.*, 2023). This is because some foods have higher impacts regardless of how they are produced. The emissions from even the lowest-impact beef exceed the average emissions from milk, which in turn exceeds the average emissions from eggs and plant-based proteins (Poore and Nemecek, 2018). The Climate Change Committee therefore recommended a 20% reduction in meat and dairy consumption by 2030, increasing to a 35% reduction in meat by 2050.

Meat and dairy are frequently consumed in Scotland by most people. However, the type of meat consumed has changed over time, and this, among other factors, has contributed to a decline in GHG emissions associated with food consumption. Specifically, since 1970, the consumption of red and processed meat, particularly beef, lamb, bacon, ham and sausages has declined. Nevertheless, red and processed meat continue to be the largest food group contributing to food system-related GHG emissions.

With regards to total GHG emissions from food consumed in Scotland, which we extrapolated from UK models because no Scotland-specific estimates are available, there is considerable uncertainty, with estimates ranging from 4.9 to 17.1 MtCO_2e. On-farm emissions account for a majority of food system-related emissions whereas transport – even when consumer transport and deliveries are included – accounts for less than 10% of emissions. As such, eating local to lower emissions may be an oversimplification of the relationship between where food comes from and environmental impact.

For a more comprehensive and specific understanding of GHG emissions associated with food consumed in Scotland, further work is needed. In particular, to determine the nature of under-reporting in food consumption data and access to better data on where food consumed in Scotland is produced and processed. The latter would facilitate the matching of country- and product-specific LCA data (where available) to food consumption data. This is important because the efficiency of production varies substantially between countries (Crippa *et al.*, 2021).

Finally, future models should take into account emissions beyond those reflected in most LCA data, including packaging, hospitality and food service, household energy use, consumer transport and deliveries, and food waste management for a more holistic picture of GHG emissions associated with food consumed in Scotland.

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10 Appendix A

10.1 Rapid evidence assessment protocol

We searched Web of Science Core Collection, MEDLINE, ProQuest Dissertations & Theses Citation Index, Preprint Citation Index and SciEL Citation Index for articles published in English between 1 January 1970 and 31 October 2023. All non-human organisms were excluded and the following major concepts were excluded: ‘Wildlife Management’, ‘Animal Husbandry’ and ‘Veterinary Medicine.’

The title/abstract/indexing was searched using the following search string:

(TS=(scotland) or TS=(scottish)) AND (TS=(diet*) or TS=(food*) or TS=(consum*) or TS=(eat*) or TS=(culinary) or TS=(nutrition*) or TS=(meal*) or TS=(intake) or TS=(dish*)) NOT (TI=(whisky) or TI=(alcohol*) or TI=(drug) or TI=(smok*) or TI=(substance use) or TI=(eating disorder) or TI=(intervention) or TI=(trial) or TI=(dolphin*) or TI=(porpoise*) or TI=(whale*) or TI=(deer) or TI=(cat*) or TI=(fox*) or TI=(grouse*) or TI=(crossbill*) or TI=(bird*) or TI=(seabird*) or TI=(gull*) or TI=(ducks) or TI=(skua) or TI=(sandpiper*) or TI=(kite) or TI=(owl) or TI=(sheep) or TI=(otter*) or TI=(weasel*) or TI=(hare*) or TI=(seal*) or TI=(bee*) or TI=(species) or TI=(loch) or TI=(pine) or TI=(DNA) or TI=(infection) or TI=(outbreak) or TI=(poisoning))

Search results were imported into Covidence where duplicates were removed. Titles/abstracts were screened for eligibility based on the following criteria:

- Inclusion criteria:
    - Published in English
    - Published after 1970
    - Scotland-specific estimates provided
    - Assessed food expenditures and/or food consumption
    - Full text available to the research team by 30 November 2023
- Exclusion criteria:
    - Focused on a time period before 1970
    - Only UK-wide estimates provided
    - Reviews, clinical trials and programme evaluations
    - Diets of livestock and wildlife
    - Only assessed alcohol or drug consumption
    - Only assessed dietary supplement use
    - Studies focused on eating disorders or foodborne illness
    - Studies on the association between diet and disease outcomes
    - Method development studies (e.g., validating a questionnaire)
    - Qualitative studies

Articles were tagged during screening as being relevant for RQ1, RQ2 and/or RQ3 to facilitate extraction.

Each study was assigned a +, ++ or +++ for recency, representativeness and presentation of results by population subgroup based on the following rubric (Table 5):

	+	++	+++
Recency	>10 years old	Past 10 years	Past 5 years
Representativeness	Small sample of a single population subgroup	Large sample of general population but not representative	Representative sample of general population
Presentation of results by population subgroup	Results not presented by any of the following: sex, age group or SIMD	Results presented by only 1 or 2 of the following: sex, age group and SIMD	Results presented by all 3 of the following: sex, age group and SIMD

Table 5: Rubric used for assessing studies included in the rapid evidence assessment for recency, representativeness and presentation of results by population subgroup.

The following data were extracted from all eligible articles:

- Last name of first author
- Affiliation of first author
- Year of publication
- Year(s) of data collection
- Study design (e.g., cross-sectional, cohort)
- Sampling method (e.g., convenience, population-based)
- Inclusion/ exclusion criteria
- Sample size
- Diet assessment method (e.g., recalls, records, FFQ, expenditures)
- Results
  - Dietary intake patterns (overall)
  - Dietary intake patterns (by SIMD)
  - Dietary intake patterns (by health board)
  - Dietary intake patterns (by age group)
  - Dietary intake patterns (by sex)
  - Dietary intake patterns (by age group and sex)
  - Dietary intake patterns (by life stage, e.g., pregnancy, cohabitating, older adults)
- Robustness
  - Consumption or expenditures
  - Comprehensive or select foods
  - Method validated in UK
  - Number of days (recalls/ records only)
  - Adjustment for usual intake

- Seasonality
- Day of week
- Funding source(s)
- Takes into account selection bias/Non-response

A total of 16 studies were included (Figure 5).

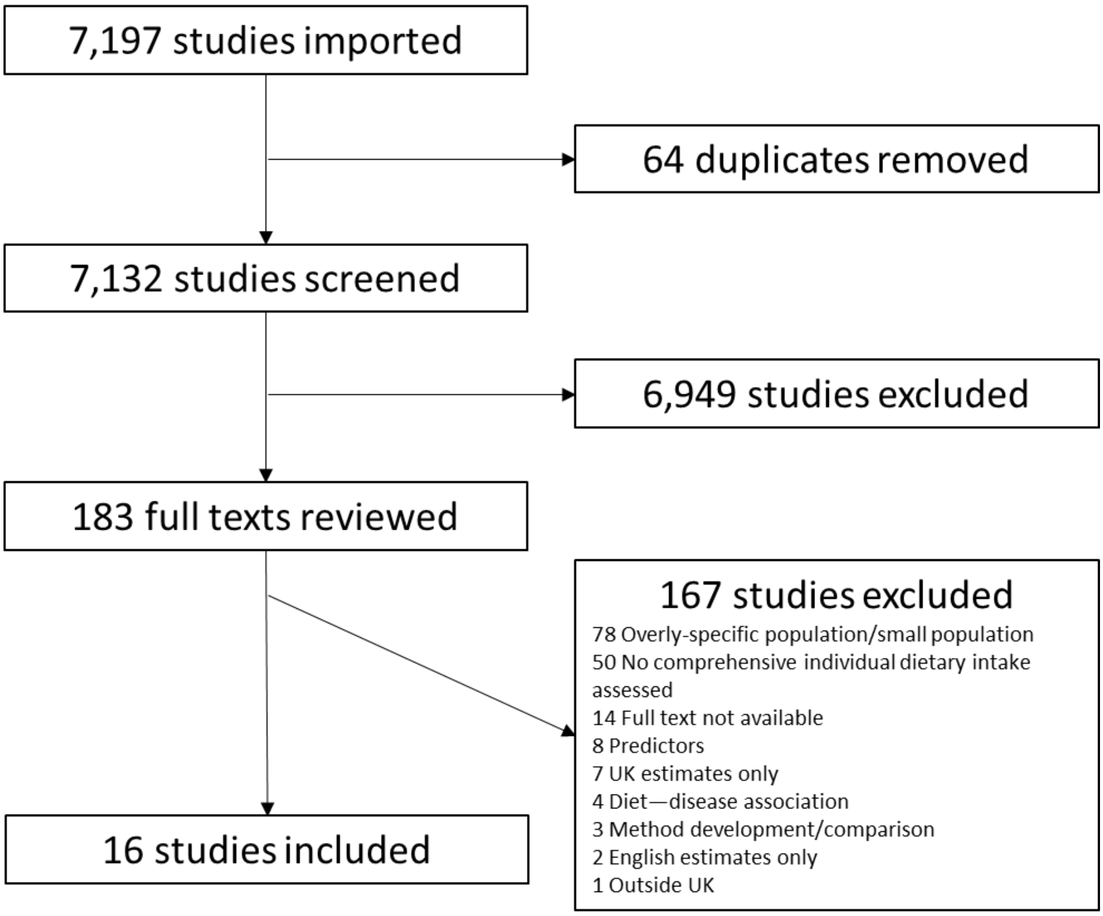


Figure 5: Rapid evidence assessment flow diagram.

We summarised studies excluded because they were conducted in population subgroups to understand the scope of the literature. Most were in specific age groups, such as children, adolescents and older adults (Figure 6).

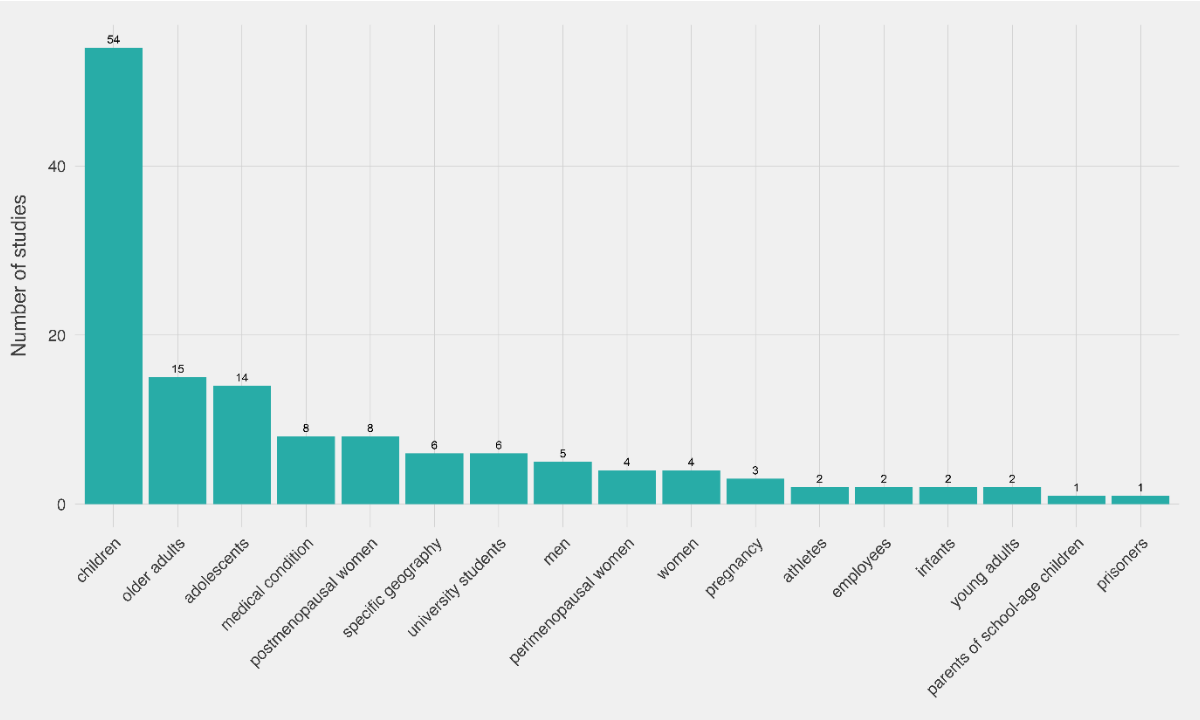


Figure 6: Summary of population subgroups in literature of food consumption in Scotland 1970-2023.

10.2 Secondary analysis of Scottish Health Survey (2021)

The latest nationally representative, comprehensive data on food consumption in Scottish adults is from the 2021 Scottish Health Survey (SHeS). SHeS 2021 also included questions on the frequency of consuming fruits and vegetables among children 2-15 years old. Two publications report on food consumption patterns using these data:

1. The Scottish Health Survey Main Report, which presents information on achieving the Scottish Dietary Goals except oily fish (Scottish Government, 2022). The latest information on oily fish, which is a weekly Goal, is from the 2016 SHeS (Scottish Government, 2017).
2. A report by Food Standards Scotland on consumption of discretionary foods and drinks (Food Standards Scotland, 2023).

The contribution of all food groups to nutrient intake has not been conducted for the 2021 SHeS. We therefore conducted a secondary analysis of these data to assess mean daily intakes and nutritional contributions of the following food groups: cereal and cereal products; meat and meat products; milk and milk products; eggs and egg dishes; fat spreads; fish and fish dishes; vegetables and potatoes; savoury snacks; nuts and seeds; fruits; sugar, preserves and confectionery; non-alcoholic beverages; tea, coffee and water; alcoholic beverages; and miscellaneous. We explored this overall and among population subgroups (based on sex, age group and SIMD and health board). Given the small sample for some health boards (Table 6).

NHS Health Board	SHeS 2021 sample size
Ayrshire and Arran	180
Borders	79
Dumfries and Galloway	83
Fife	172
Forth Valley	223
Grampian	327
Greater Glasgow and Clyde	798
Highland	207
Lanarkshire	338
Lothian	556
Orkney	74
Shetland	58
Tayside	285
Western Isles	67
Total	3447

Table 6: Sample size by health board for adults 16+ years living in Scotland who participated in the Scottish Health Survey (SHeS), 2021.

11 Appendix B

11.1 Summary of workshop on four published models to estimate greenhouse gas emissions associated with food consumed in the UK

The University of Edinburgh convened a one-hour online workshop to discuss the different approaches to modelling emissions associated with food consumed in the UK. The lead authors of the four published models identified in our review attended the workshop. The discussion was in two parts: (1) the lead authors presented an overview of their modelling approach (Table 7), and then (2) the group discussed potential drivers of differences across models in estimated greenhouse gas emissions associated with food consumed in the UK (Table 8).

Model	Summary of approach
WRAP	Builds the estimates using sector-specific information from published UK inventories of emissions, rather than LCAs of specific foods consumed. Current area of focus is improving the estimates of imported food emissions, with future intentions to look at the potential impact of on-farm mitigation in the UK. Several strengths of this approach, including: • Ability to capture hospitality, cooking at home, and food waste management [which are typically not reflected in cradle-to-retail gate LCAs] • Ability to update estimates every year to account for shorter-term changes, e.g., in the electricity grid, whereas LCAs are often 'static' to a particular year LCAs are used for imported food and are, in some cases, specific to country of import – where there is reason to believe there would be a substantial impact, such as beef and lamb. Further work for this model will focus on improving estimates for traded food and the associated emissions, looking at creating more specificity for products coming from certain locations, and integrating international transport. However, it is not without limitations: • Cannot look at population subgroups • Harder to look at food groups; could be done using other datasets not currently included in their model but this is outside their current scope of work

<table>
<tr><th>Model</th><th>Summary of approach</th></tr>
<tr><td></td><td>Land use change is currently focused on specific commodities such as palm oil and soya; this could be improved
Data sources:
Governmental datasets such as UK inventories for agriculture and energy consumption by sector (manufacturing, food, retail, etc.)
Other data filled in, e.g., for household deliveries, hospitality, and refrigerant specific emissions
UK trade data linked to LCAs for imported foods</td></tr>
<tr><td>Stewart</td><td>This model matches food consumption data to LCAs to estimate emissions. FAO data on food supply, production, imports, exports, seed and feed, were combined with Poore and Nemechek (2018) LCA data.

Several strengths of this approach, including:
LCAs were disaggregated by continent and updated over time to reflect variability between continents and over time in emission intensities for commodities
Able to look at food group level data
Able to quantify changes in emissions from changes in consumption versus production efficiency versus trade
However, a limitation is that it does not include emissions from hospitality, cooking at home, consumer transport and deliveries, etc.

Data sources:
FAO Food Balance Sheets
FAO emission intensities
Poore and Nemechek (2018) LCA data</td></tr>
<tr><td>Bates</td><td>This model uses a database of emissions linked to NDNS food consumption data, originally developed for the University of Newcastle’s Intake24 dietary recall tool in order to provide feedback to survey participants on the environmental impact of their diets.

The model strengths are:
GHGs were mapped from the largest number of unique foods and beverages than any previous UK study at the time
GHGs (CO_2e as g/100g) were matched to the majority of individual foods in the NDNS database</td></tr>
</table>

Model	Summary of approach
	• Able to look at consumption by food groups and by population subgroups. Data sources: • Published studies and company websites for LCA data • NDNS for food consumption data
CREDS	Primarily purpose was to explore the potential of demand-side mitigation. The model explores three consumer-facing strategies: shifting to plant-based diets, following UK dietary recommendations, and reducing food waste. NDNS data were used for consumption levels by product, whilst the Family Food Survey was used for the calorific intake estimates. The correction for under-reporting was applied on a calorific basis. The representation of diets was based on 17 dietary profiles outlined in the academic literature. There are 69 food product categories covered by the model, using the Classification of Individual Consumption by Purpose (COICOP) classification system. UK MRIO model captures all process-based emissions and factors per food category expressed as emissions per £ spent. Whilst there are uncertainties in most input-output based modelling approaches, the UKMRIO model does incorporate import data from 15 world regions (based on data from 50 countries). This also reflects differences in agricultural production techniques (and consequently emissions factors) from each region. This model does not capture emissions associated with cooking or waste management, land use, or agricultural efficiencies, but subsequent iterations of UK MRIO do take into account land use change. Data sources: • NDNS, Family Food survey and literature reviews to describe example diets • UK MRIO model

Table 7: Summary of modelling approaches used to estimate the greenhouse gas emissions associated with food consumed in the UK.

Aspect of model	Summary of differences
Land use change emissions	WRAP and Stewart are the only models that include emissions from land use change
Packaging, hospitality sector, and post-retail emissions	WRAP is the only model that includes emissions from packaging, hospitality sector, and post-retail (e.g., home food preparation, consumer transport and deliveries, food waste management)
Under-reporting of self-reported food consumption	• Tendency to under-report in food diaries used in Bates and CREDS • CREDS did make a simple adjustment for under-reporting in their model
Handling of imported foods	• Concerns regarding the accuracy of the FAO trade database used in Stewart model • Uncertainty on country of origin data and farming systems (thus associated emissions) for imported foods – applies to all models • WRAP did some analysis around tracing country of origin and found that even when tracing a food product, if it does not come from our first trade partner, the second and third are often the same. For example, The Netherlands is our fourth-largest trade partner for palm oil, but they mostly import from the same top two trade partners as the UK (Indonesia and Malaysia). There were some anomalies, but for most, the import chain did not appear to make much of a difference • Stewart did a sensitivity analysis accounting for continent and found it varied by food group. For example, with beef, accounting for continent increased emissions by 25% (i.e., imported meat has higher emissions on average than UK produced beef), but with mutton, it decreased by 28% (i.e., imported mutton has lower emissions on average than UK produced mutton)

Table 8: Summary of potential sources of variability between models used to estimate the greenhouse gas emissions associated with food consumed in the UK.

12 Appendix C

12.1 Scottish Dietary Goals

The thirteen Scottish Dietary Goals (Table 9) "describe, in nutritional terms, the diet that will improve and support the health of the Scottish population" (Scottish Government, 2016).

Nutrient or food group	Goal
Calories	1. A reduction in calorie intake by 120 kcal/person/day. 2. Average energy density of the diet to be lowered to 125 kcal/100g by reducing intake of high fat and/or sugary products and by replacing with starchy carbohydrates (e.g., bread, pasta, rice and potatoes), fruits and vegetables.
Fruits and vegetables	3. Average intake of a variety of fruits and vegetables to reach at least 5 portions per person per day (> 400g per day).
Oily fish	4. Oil rich fish consumption to increase to one portion per person (140g) per week.
Red meat	5. Average intake of red and processed meat to be pegged at around 70g per person per day. 6. Average intake of the highest consumers of red and processed meat (90g per person per day) not to increase.
Fats	7. Average intake of total fat to reduce to no more than 35% food energy. 8. Average intake in saturated fat to reduce to no more than 11% food energy. 9. Average intake of trans fatty acids to remain below 1% food energy.
Free sugars	10. Average intake of free sugars, not to exceed 5% of total energy in adults and children over 2 years.
Salt	11. Average intake of salt to reduce to 6g per day.
Fibre	12. An increase in average consumption of fibre for adults (16+) to 30g/day. Dietary fibre intakes for children to increase in line with SACN recommendations.
Total carbohydrate	13. Total carbohydrate to be maintained at an average population intake of approximately 50% of total dietary energy with no more than 5% total energy from free sugars.

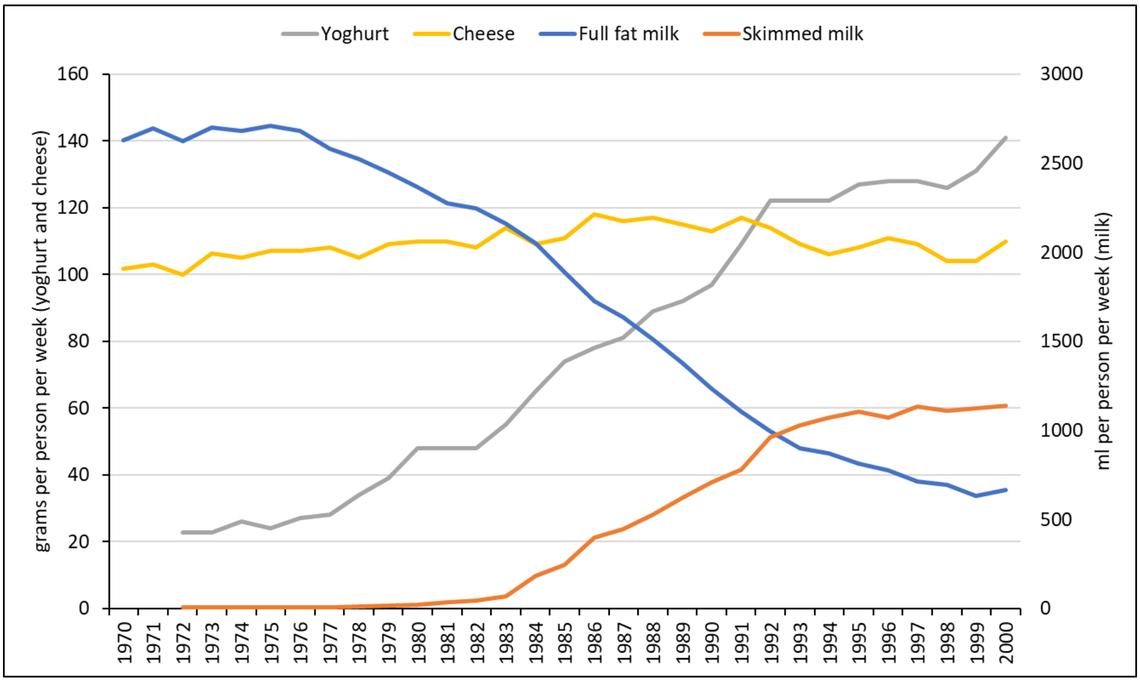
Table 9: Scottish Dietary Goals.

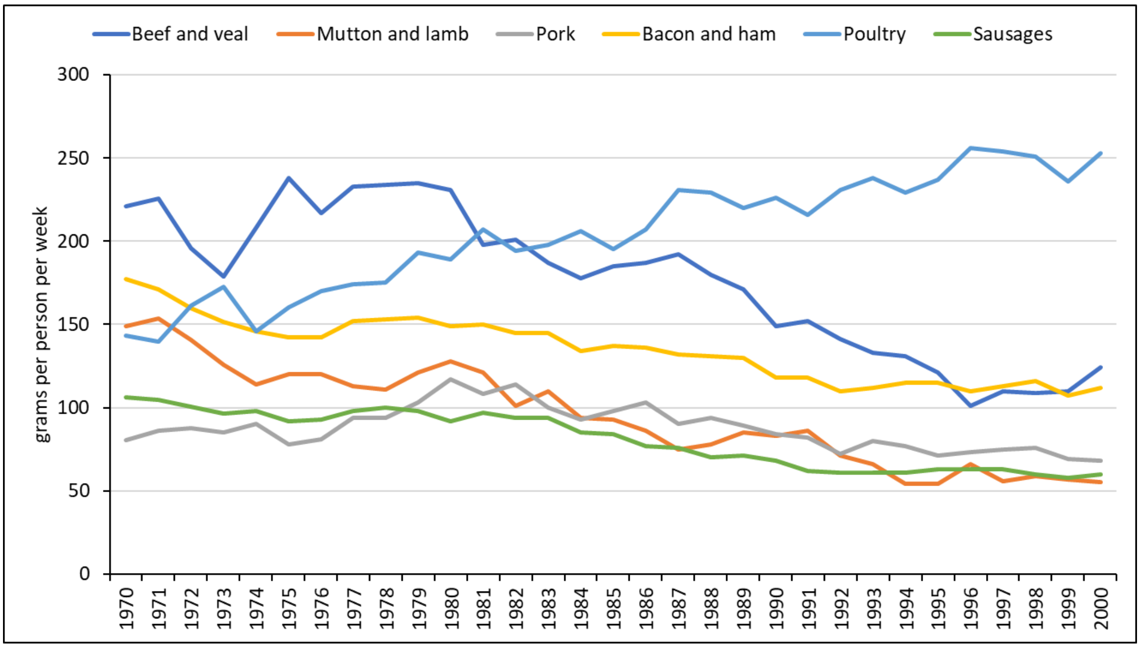
13 Appendix D

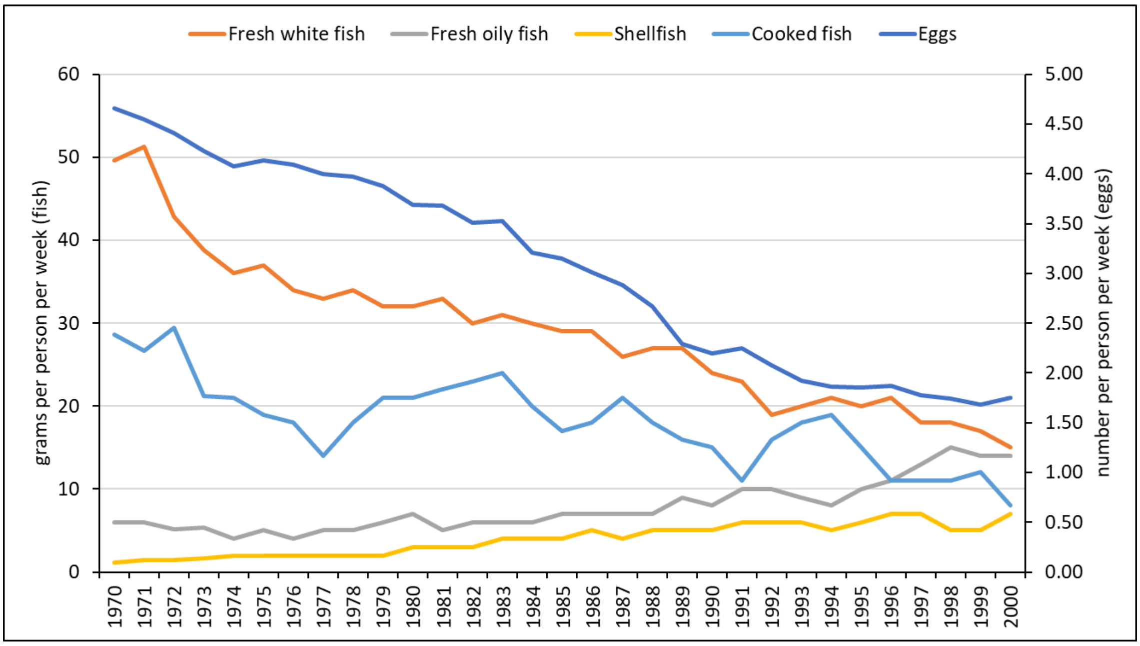
13.1 Trends in foods consumed in the UK 1970-2000

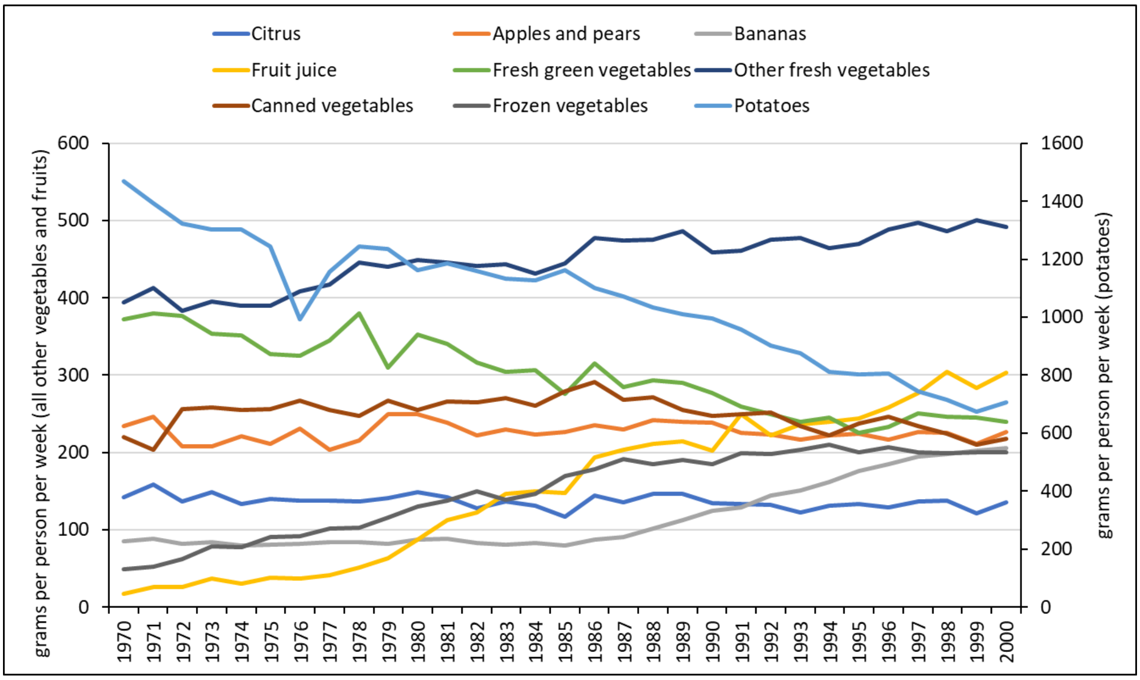
These figures were generated using data downloaded from:

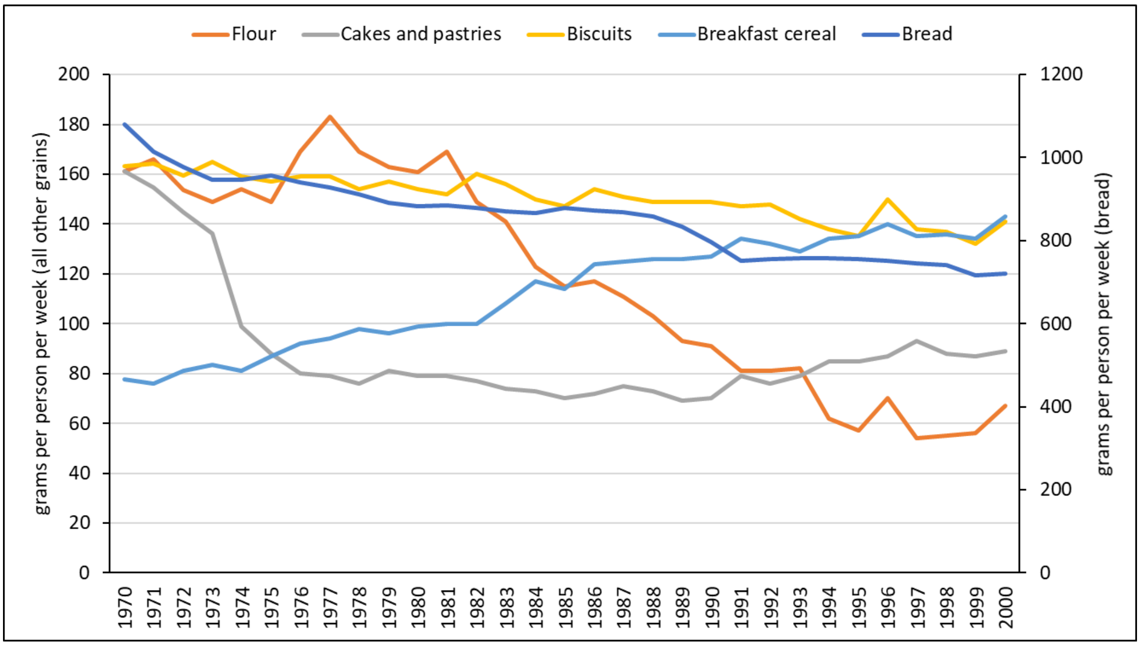
https://webarchive.nationalarchives.gov.uk/ukgwa/20130103024837/http://www.defra.gov.uk/statistics/foodfarm/food/familyfood/nationalfoodsurvey/






Fresh white fish
Fresh oily fish
Shellfish
Cooked fish
Eggs
grams per person per week (fish)
number per person per week (eggs)
0
10
20
30
40
50
60
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000


Citrus
Apples and pears
Bananas
Fruit juice
Fresh green vegetables
Other fresh vegetables
Canned vegetables
Frozen vegetables
Potatoes
grams per person per week (all other vegetables and fruits)
grams per person per week (potatoes)
0
100
200
300
400
500
600
0
200
400
600
800
1000
1200
1400
1600
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000


Flour
Cakes and pastries
Biscuits
Breakfast cereal
Bread
grams per person per week (all other grains)
grams per person per week (bread)
0
20
40
60
80
100
120
140
160
180
200
0
200
400
600
800
1000
1200
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000

14 Appendix E

14.1 Data Sources for food-associated GHG emissions in the UK

14.1.1. Poore and Nemecek (2018)

Because the Poore and Nemecek (2018) LCA database is used in several models, we have included a summary of what is included and excluded in this database. Table modified from Fig. S1. In supplemental material of Poore and Nemecek (2018).

Sector	Included	Not Included
Land use change	• Above ground carbon stock change • Below ground carbon stock change • Forest burning • Organic soil burning	• Leaching • Runoff • Induced non-CO_2 emissions
Crop production	• Seed and nursery • Inputs production • Machinery • Greenhouse and trellis infrastructure • Electricity and fuel • Fertiliser and retained crop residue • Urea and lime • Flooded rice • Residue burning • Cultivation of drained organic soils • Drying and grading • Irrigation water consumption • Land use: seed, fallow, arable, permanent crops	• Soil emissions • Organic fertliser application • Nitrogen fixation emissions • Carbon sequestration in crop residue • Runoff • Residue burning indirect emissions Human labour

Sector	Included	Not Included
Livestock and aquaculture	• Pasture management • Feed processing • Housing energy use • Enteric fermentation • Manure management • Aquaculture ponds • Drinking and service water • Land use: permanent pasture, temporary pasture, aquaculture ponds	• Infrastructure • Pasture residue (emissions or burning) • Pasture nitrogen fixation emissions • Pasture runoff • Manure management • Human labour
Processing	• Energy • Wood burning • Wastewater • Incineration • Processing water consumption	• Miscellaneous inputs • Human labour • Infrastructure • Land use
Packaging	• Materials • Materials transport • End of life disposal	• Human labour • Infrastructure • Land and water use
Retail	• Energy use	• Human labour • Infrastructure • Land and water use

14.1.2. Bates model

As this work pre-dated the Poore & Nemecek (2018) database, a database was created using published LCAs available at the time; referenced below.

AMIENYO, D., CAMILLERI, C. and AZAPAGIC, A., 2014. Environmental impacts of consumption of Australian red wine in the UK. Journal of Cleaner Production, 72, pp. 110-119.

BERNERS-LEE, M., 2011. How bad are bananas?: the carbon footprint of everything. Greystone Books.

BSI, 2008-last update, Guide to PAS 2050 How to assess the carbon footprint of goods and services. Available: http://webarchive.nationalarchives.gov.uk/20130123162956/http:/www.defra.gov.uk/environment/consumerprod/pdf/PAS2050-carbon-footprint.pdf [09/25, 2015].

LEDGARD, S.F., LIEFFERING, M., COUP, D. and O'BRIEN, B., 2011. Carbon footprinting of New Zealand lamb from the perspective of an exporting nation. Animal Frontiers, 1(1), pp. 40-45.

MITHRARATNE, N., BARBER, A. and MCLAREN, S.J., 2010-last update, Carbon Footprinting for the Kiwifruit Supply Chain – Report on Methodology and Scoping Study Final Report. Available: http://www.landcareresearch.co.nz/publications/researchpubs/Kiwifruit_Methodology_Report_2010.pdf [01/21, 2017].

PEPISCO, 2013-last update, Carbon Labelling. Available: http://www.pepsico.co.uk/news-and-comment/carbon-labelling [01/25, 2013].

POOVARODOM, N., PONNAK, C. and MANATPHROM, N., 2012. Comparative Carbon Footprint of Packaging Systems for Tuna Products. Packaging Technology and Science, 25(5), pp. 249-257.

QUORN, 2015-last update, Quorn Foods - Sustainability. Available: Quorn Foods - Sustainability [12/23, 2016].

SCOTTISH AQUACULTURE RESEARCH FORUM, 2010-last update, Carbon Footprint Of Scottish Suspended Mussels And Intertidal Oysters . Available: http://www.sarf.org.uk/cms-assets/documents/43896-326804.sarf078 [01/21, 2017].

SHEANE, R., LEWIS, K., HALL, P., HOLMES-LING, P., KERR, A., STEWART, K. and WEBB, D., 2011. Identifying opportunities to reduce the carbon footprint associated with the Scottish dairy supply chain - Main report. Edinburgh: Scottish Government.

SVANES, E. and ARONSSON, A.K., 2013. Carbon footprint of a Cavendish banana supply chain. The International Journal of Life Cycle Assessment, 18(8), pp. 1450-1464.

TATE & LYLE, 2009-last update, Tate & Lyle Reduces Its Footprint With The Carbon Trust. Available: http://mediacentre.tateandlyle.com/r/849/tate___lyle_reduces_its_footprint_with_the_carbon [12/10, 2016].

TERRAPASS, 2016-last update, Chips aren't for (carbon) free: carbon labeling hits the shelves in the UK. Available: https://www.terrapass.com/chips-arent-for-1 [12/10, 2016].

TESCO, 2012-last update, Tesco product carbon footprints. Available: http://www.tescoplc.com/.../Tesco_Product_Carbon_Footprints_Summary; [11/09, 2012].

THE ECONOMIST, 2011-last update, Following the footprints | The Economist. Available: http://www.economist.com/node/18750670 [11/10, 2012].

14.1.3. WRAP model

Sector	Data Source	Included	Not Included
UK agriculture and fishing	BEIS UK GHG national statistics https://www.gov.uk/government/statistics/final-uk-greenhouse-gas-emissions-national-statistics-1990-to-2020	Livestock, agricultural soils, stationary combustion sources, off-road machinery, fishing vessels	Aquaculture energy use and waste treatment
Fertliser manufacture	For UK and EU production: Fertilizers Europe https://www.fertilizerseurope.com/publications/the-carbon-footprint-of-fertilizer-production-regional-reference-values/ For non-EU production: The mean values for Russian, US and Chinese production from Brentrup et al. (2016) https://www.researchgate.net/publication/312553933_Carbon_footprint_analysis_of_mineral_fertilizer_production_in_Europe_and_other_world_regions	Year-to-year changes in share of imports from outside the EU	UK-specific estimates for manufacture emissions and share of imports from outside the EU (both assumed to be the same as the EU)
Imported animal feed	1. Volume (tonnes) of traded (import and export) food and feed multiplied by GHG emission factors (tonnes CO_2-equivalent / tonne production) 2. Total emissions from exported items subtracted from total emissions from imported items Trade data from HMRC's UK Trade Info:	Different emission factors for UK versus imports from EU versus non-EU sources	Year-to-year changes in production emissions

Sector	Data Source	Included	Not Included
Imported food	https://www.uktradeinfo.com/trade-data/ Emission factors from: Poore and Nemecek (2018): forest commodities, fish, fruits, vegetables and non-UK / non-EU meat CIEL: EU and UK meat Agribalyse database: drinks Clune et al. (2017): dairy, gaps in fish, fruits and vegetables GFLI database: animal feed, cereals, rice and sugar		
Land use change from imported food and feed	Poore and Nemecek (2018) and GFLI database	Non-EU beef All sources of poultry, pork and dairy Cocoa, coffee, tea, cane sugar and spices Oilseeds, vegetable oils and other oilseed products	All other imported products Positive land use change linked to the food system
UK food manufacture	2 BEIS datasets: Digest of UK Energy Statistics (DUKES): https://www.gov.uk/government/statistics/energy-chapter-1-digest-of-united-kingdom-energy-statistics-dukes Energy consumption in the UK (ECUK): https://www.gov.uk/government/collections/energy-consumption-in-the-uk	Food and drink sector	Tobacco industry

Sector	Data Source	Included	Not Included
Refrigerants	BEIS National Atmospheric Emissions Inventory (NAEI) data: https://naei.beis.gov.uk/data/	Commercial, domestic, industrial and transport (manufacturing, lifetime and disposal) Assumes food and drink sector accounts for 78% of total refrigerants	None noted
Packaging	WRAP Courtauld signatories (93% of market share based on Kantar Worldpanel) on volumes of food and drink packaging materials and WRAP emission factors for packaging types Estimate scaled based on market share of organisations from Kantar Worldpanel	Paper and board Glass Steel Aluminium Plastics Other	None noted
Transport (UK supply chain)	Department for Transport (DFT) statistics: https://www.gov.uk/government/statistics/transport-statistics-great-britain-2021	All road freight assumed to be transported in an average laden, average HGV Waterborne transport assumed to be average roll-on, roll-off ferries	None noted
Transport (consumer)	DFT National Travel Survey (NTS): https://www.gov.uk/government/collections/national-travel-survey-statistics	Transport for food shopping	English travel data assumed to be representative of the UK (likely underestimating distance)

Sector	Data Source	Included	Not Included
Transport (consumer delivery)	Takeaways: Estimated number of online deliveries and direct orders per household in the UK using data from the Family Food Survey, Statista and ONS statistics Assumed average distance of 4.18km for online deliveries and 6.12 for direct orders (over the phone or picking up on way home) Assumed 40% of online deliveries were by motorbike; 40% by bicycle; and 20% by car Assumed 50% of direct orders by motorbike and 50% by car Grocery delivery: Estimated distance travelled by grocery delivery vans based on the association between distance travelled and sales in 2016, assuming a static relationship and using annual online grocery sales data from Statista	Takeaways and grocery delivery	Grocery delivery: assumes distance travelled by vans per unit of sales has remained constant over time; and that the composition of grocery delivery fleets has remained constant over time
Food retail energy use	BEIS published ECUK statistics Assumed share of household expenditure on food shopping is representative of the share of total retail energy use by food retail	Food retail energy use	Energy use for catering purposes
Hospitality and food service energy use	BEIS published ECUK statistics	Energy use for catering purposes	None noted
Household energy use	BEIS published ECUK statistics	Energy use for food-related home appliances (electric ovens and hobs)	Freezers, fridges, microwaves, dishwashers and kettles

Sector	Data Source	Included	Not Included
Waste disposal	WRAP and Defra data from local authorities in England on waste volumes and management: https://wrap.org.uk/resources/guide/waste-prevention-activities/food-love-waste-data https://www.gov.uk/government/statistics/local-authority-collected-waste-management-annual-results	Food and associated inedible parts that is wasted and not recycled or redirected	'Food surplus' redirected to other uses such as animal feed and food waste recycled to create a new product (e.g., compost, heat, electricity, etc.) Volume of waste from 2018 and will not be updated until 2023; the only changes year-on-year are in how the waste is disposed Sewer disposal only known for households, not hospitality and food service

14.1.4. Stewart et al. model

The primary source of data is FAO Food Commodity Balances, which are the quantity of food *available* to buy rather than the quantity of food bought.

	Data Source for Consumption	Data Source for GHG Emissions	Limitations
Fish and seafood	FAO Food Commodity Balances	Gephart et al. (2021)	Does not take into account changes in emissions intensity over time
Imported food	FAO Food Commodity Balances for total imports and FAO Detailed Trade Matrix (Imports) aggregated by Kastner, Kastner and Nonhebel (2011) categories and grouped by continent to determine proportion of imports from each continent	Continent-specific values from Poore and Nemecek (2018) If not available in Poore and Nemecek (2018), then EU or rest of the world specific values from Audsley et al. (2009) Changes in GHG emissions intensities from FAO: https://www.fao.org/faostat/en/#data/EI	Continent of origin is last destination of food before import to UK, not necessarily country of production Changes in emission intensities only refer to changes in agriculture (i.e. on-farm) Does not include emissions from transport involved in importing foods

	Data Source for Consumption	Data Source for GHG Emissions	Limitations
All other food	FAO Food Commodity Balances	Europe values from Poore and Nemecek (2018) If not available in Poore and Nemecek (2018), then UK-specific values from Audsley et al. (2009) Changes in GHG emissions intensities from FAO: https://www.fao.org/faostat/en/#data/EI	Assumes exports were produced within Europe (so if foods were imported into the UK, processed and then exported as a new product, the emissions assumed values for Europe even if the initial product was produced elsewhere in the world) Changes in emission intensities only refer to changes in agriculture (i.e. on-farm)

14.1.5. CREDS model

Pasted verbatim from supplemental material:

"Data on 2017 expenditure by COICOP food groups was used to calculate emissions.

The ONS produces Supply and Use Tables (SUT) on an annual basis at a 106 sector disaggregation (ONS, 2018). The use tables are 'combined' tables, which means that the inter-industry transaction table is the sum of both domestic transactions and intermediate imports, and the final demand table shows the sum of both domestic and imported final products. Less frequently, the ONS produces a set of analytical tables containing both domestic use and domestic final demand tables. From these tables, we can extract the proportion of domestic spend and produce domestic use and domestic final demand tables from the annual SUT tables, which span a greater time period. Any Imports to intermediate industries are shown as a single row of data and the exports to intermediate and final demand as a single column of data.

Data is extracted from the EXIOBASEv3.6 MRIO database (Wood et al., 2015) to disaggregate the import and export data to further sectors from other world regions. EXIOBASE data can also be used to show how foreign sectors trade among themselves, but the data must first be converted to Great Britain Pounds (GBP). The first step is to map the EXIOBASE MRIO database onto the UK's 106 sector aggregation. Once this has been done, the data can be further aggregated by region. Since EXIOBASE contains data from nearly 50 countries and regions, we can select the most appropriate regional grouping for the trade data. For this MRIO study, we construct fifteen regions: UK, Brazil, Russia, India, China, South Africa, USA, Japan, Rest of the European Union, Rest of Europe, Rest of the OECD, Rest of Africa, Rest of Americas, Rest of Asia, Rest of the Middle East.

The UK is unusual because the SUTs constructed by the ONS include final demand by UK households that is split by both product sectors in the IO structure and 42 COICOP sectors which are also found in the Annual Living Costs and Food (LCFS) survey (see Figure S1). This means that we can be confident in linking these datasets. The UK is unusual in providing this bridge table between the two formats of recording spend by products. In other studies much work has gone into the construction and evaluation of these bridge tables (Steen-Olsen et al., 2016; Min and Rao, 2017) but because the LCFS is in input to the national accounts, the ONS can supply this mapping at an aggregate scale.

The UKMRIO database contains information on how all UK households spend for 306 COICOP categories. To do this we use data from the 2016 LCFS (UK Data Service, 2019) which shows weekly expenditure by the 5,041 households involved in the survey. The LCFS is used to provide information on retail price indices, National Account estimates of household expenditure, the effect of taxes and benefits, and trends in nutrition. The survey strives to produce a representative sample of the 27 million UK households in 2016. We use this data to portion total UK household expenditure by top level COICOP category in the UKMRIO database."

If you require the report in an alternative format such as a Word document, please contact info@climatexchange.org.uk or 0131 651 4783.

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