Agriculture & Food Security

RESEARCH

Open Access

Assessing Scotland's self-sufficiency of major food commodities

Shashika D. Rathnayaka[1*], Cesar Revoredo-Giha[2] and Baukje de Roos[1]

Abstract

Background Analysis of food self-sufficiency at the regional level helps to better understand its dependency on, and vulnerability to, the food system. Moreover, achieving food self-sufficiency has gained prominence in the present policy agenda to increase resilience to adverse events and lower food resource footprint. Using a novel method, we estimated the food balance sheets of Scotland, the second-largest region in the United Kingdom, and assessed the self-sufficiency of major food commodities for the first time.

Methods Data from 2003 to 2019 were obtained from Economic Reports on Scottish Agriculture and the Department for Environment, Food and Rural Affairs (DEFRA)'s family food statistics. Food import and export data are not readily available for Scotland. Therefore, we developed a consumption-based approach to estimate the net trade values of each commodity. We also assessed the contribution of domestic production toward nutrient security.

Results According to our estimates, Scotland is a net exporter of beef, exporting an average of 51.3 thousand tons per year. It is also a net exporter of cereal (wheat, barley, oats) and potatoes, although this was not always the case between 2003 and 2019. Scotland has a strong level of self-sufficiency in cereals, potatoes, lamb, beef, dairy, and eggs. However, there is room for improvement in achieving self-sufficiency in poultry and pork, where the self-sufficiency ratio is relatively low. Our analysis of nutrient security indicates that wheat and dairy sourced from Scotland play crucial roles in the food supply chain, markedly influencing total energy, dietary protein, and primary dietary fat sources.

Conclusions Our assessment can serve as a foundation for evidence-based decision-making in Scotland's agricultural and food policy. It offers insights into where investments and support may be needed to enhance domestic production and promote a resilient and sustainable food system. Estimated self-sufficiency ratios provide a more accurate assessment of the extent of food localization in Scotland. The method we developed in this study has the potential to be a valuable tool for future research studies, allowing for the estimation of regional-level food self-sufficiency even when trade data and food balance sheets are unavailable.

Keywords Food systems, Food balance sheets, Self-sufficiency, Sustainability

Introduction

The regional food system framework has received a lot of attention recently from food advocates, planners, supply chain participants, and legislators as a workable blueprint for how we might best feed ourselves [1–5]. A region can be defined by political or administrative boundaries such as a county, state, or environmental protection agency (EPA) region [1, 5].

*Correspondence:
Shashika D. Rathnayaka
shashika.rathnayaka@abdn.ac.uk
[1] The Rowett Institute, University of Aberdeen, Aberdeen AB25 2ZD, UK
[2] Food Marketing Research Team, Scotland's Rural College (SRUC), Edinburgh EH9 3JG, UK

A regionally focused food system is more than the sum of local food systems within its boundaries.[1] Food produced locally with short food supply chains often emits fewer greenhouse emissions than food produced and transported from elsewhere. It has gained popularity as a model for a sustainable agricultural and food system [6–9]. Although there are many "locals" in a regional food system, it is broader geographically and in terms of its various functions, including volume/supply, food demands, variety, supply chains, markets, land use, and policy [1, 5, 10–12]. Moreover, regional food systems may be a catalyst for important changes in the way food is produced, delivered, and consumed. This might have positive effects on the economy, the environment, and society, and could contribute to food system resilience.

However, the availability of natural resources (climate, soil, and water), the opportunity costs of other uses of these resources (export crops, residential activities, and other economic activities like tourism), subsidies to specific crops or animal production, and the relative competitiveness of domestic production when compared to imported food in terms of production costs, relative prices, quality, and branding can all have an impact on regional food system's ability to produce food. An ideal regional food system, according to Clancy and Ruhf [1], is one in which as much food as is necessary to satisfy the needs of the population is produced, processed, distributed, and purchased at various levels and scales within the region. This enhances food self-sufficiency, minimizes importation, maximizes resilience, and provides a significant economic and social return to all regional stakeholders. The term "food self-sufficiency" typically refers to a country's ability to meet its food needs through domestic production [13–15]. It is quite important because it has a direct impact on the country's ability to meet the nutritional needs of its population. National food self-sufficiency has emerged as a key indicator of food availability and a critical pillar of food security [7].

However, no country or region can sustain itself on exclusively locally produced food, and estimates indicate that only one-third of the world's population can be fed locally (Clapp 2015, [16] and [17],). This shows that foreign food imports from different continents, countries, and regions are essential for maintaining global food security. [18]. Furthermore, mainstream economists have questioned the goal of achieving food self-sufficiency because they believe the policies supporting food self-sufficiency are inefficient and market-distorting [19]: [13]). Because they hinder the efficiency gains typically associated with international trade, certain policies linked with food self-sufficiency, such as export bans, tariffs, and subsidies, are widely regarded by economists as threatening the long-term goal of food security [13].

However, the 2007–2008 global food price crisis, the COVID-19 pandemic's destruction of the worldwide food supply chain, and the war in Russia and Ukraine sparked policy discussions on volatile global food markets, the resilience of disconnected agri-food systems, and regional self-sufficiency in food [7, 20–22]. In addition, import dependency, may not be sustainable as the global population expands and climate change affects production and natural resource availability in source countries. In light of this, achieving food self-sufficiency has gained recognition as a means of boosting resilience to adverse events, and reducing the resource footprint of food is currently moving up the policy agenda in a number of countries. Therefore, analysis of regional-level food self-sufficiency helps to better understand a country's or region's dependency on, and vulnerability to, the food system. Because, regional food systems are associated with numerous valuable attributes such as closed nutrient flows, close relationships between consumer and producer, healthy diets due to the availability of fresh and nutritious food, and a small carbon footprint caused by short transport distances [8, 23, 24]. Moreover, examining the degree to which regions can meet their population's demand for food is imperative for policy making. Regional SSRs, crucial for policy, include providing financial aid to farmers via subsidies, grants, or low-interest loans; enforcing land use planning and zoning rules favoring agricultural land protection; supporting research and development; implementing local procurement policies to prioritize locally sourced food; and investing in rural infrastructure like transportation, storage, and processing facilities to enhance market access and minimize post-harvest losses [25–27].

However, up to this point, research has mostly looked at country/nation-level food supply and self-sufficiency. Only a very few studies have focused on local/regional food self-sufficiency (See [1, 5, 24, 28, 29]). Data availability for regional studies is less than on the national level since regions are part of a political and institutional framework that is both national and supra-national. This can have a negative impact on the regional examination of food self-sufficiency. Furthermore, to our knowledge, there are no studies in the literature that examine the self-sufficiency of food in Scotland. In the current study, we, therefore, investigate the degree to which Scotland can satisfy their own food needs.

[1] However, the local food concept is challenged by processed foods, as for these to be truly local all ingredients would need to be produced and processed locally.

Scotland is one of the four constituent countries comprising the United Kingdom (UK). It is the second-largest region in the UK, comprises around 8% of the population and occupies the northernmost third of the British mainland. Although Scotland's food supply is closely tied to UK, European, and even international agendas, historically, the UK still has a significant impact [30]. Agriculture is currently the most prominent land user in Scotland, accounting for approximately three-quarters of all land [31]. Scotland's weather is notoriously unpredictable, with degrees of unpredictability rising, and the EU has currently categorized 85% of its agricultural area as a "Less Favored Area" [32]. Despite these obstacles, the Scottish food and drink sector has expanded to become the country's largest manufacturing sector (NFU [33]).

With the vision that "by 2025 Scotland will be a Good Food Nation[2] where people from every walk of life take pride and pleasure in, and benefit from, the food they produce, buy, cook, serve, and eat every day," Good Food Nation Act was imposed in July 2022. Since then, efforts have been made to enhance accessibility to and promote the advantages of nutritious local foods, ensuring the sustainability of Scotland's food industry and enhancing Scotland's standing as a Good Food Nation [34].

Given the concerns outlined, the present study investigates the production, import, and export dynamics in Scotland, as well as their connection to dietary recommendations. Specifically, we aim to answer the fundamental question of how self-sufficient Scotland is in meeting its food needs and the implications for its food security and sustainability. Scotland does not currently have a set of established benchmark estimates on the availability of food for market consumption and its supply sources. This paper contributes to the literature in the following ways. First, it maps existing food supply sources and estimates Scotland's food balance sheets (FBS) for ten major food commodities; barley, oats, wheat,, potatoes, poultry, lamb, beef, pork, dairy, and eggs. Our selection of these commodities is based on their significant roles in production, dietary intake, and nutrition supply in Scotland [35, 36]. These commodities collectively represent key components of the Scottish diet and are vital for sustaining both the economy and the nutritional needs of the population. By focusing on these commodities, we aim to provide insights into their contribution to the agriculture sector, trade, and nutrition addressing important aspects of food security and resource management in Scotland.

As far as we are aware, this is the first study that estimates the FBS of Scotland. Second, the paper estimates the self-sufficiency ratios of major food commodities in Scotland to provide a more accurate assessment of the extent of food localization in Scotland. Third, this paper assesses the supply of energy and macronutrients with respect to major food commodities and the contribution of Scottish production to nutrition security in the last two decades. Moreover, before we can have a meaningful conversation about food security or self-sufficiency in Scotland, we need to have a fair evaluation of the levels of consumption of different food groups, the qualities of the food consumed, and the origins or sources of supply. While there are a couple of studies concerned with food and nutrition security in the UK [15, 37–41], no studies so far focused specifically on the Scottish food system. Thus, this paper will also contribute to the food security literature by providing an analysis of food availability and supply sources in Scotland.

The remainder of this paper is organized as follows. A description of the data used and the methodology employed are presented next. The results of the study are then presented and discussed in a subsequent section. The last section of the paper provides a summary of the results and discusses policy implications with regard to the findings. Limitations and directions of future research are also described.

Methodology

The procedure employed in this study consists of three steps. First, the food balance sheets for wheat, barley, oats, potatoes, dairy, poultry, beef, pork, lamb, dairy, and eggs were estimated using the United Nations' Food and Agriculture Organization (FAO)'s FBS approach (see Fig. 1), and per capita food availability of each commodity was derived. Second, the degree of self-sufficiency of the above food commodities was measured to accurately assess the extent of total food available that is satisfied by local production, and finally, the contribution of local production to nutrition security was assessed.

Estimating Scotland's FBS

FBS is an accounting framework specific to food and agricultural products. In fact, the FBS framework is similar to the System of National Accounts (SNA) supply-use framework. FBS is, thus, naturally complementary to national account estimation. The FBS has a substantial amount of data regarding food use and supply. These data provide snapshots of the movement of food products from the farm or border to the domestic market where they will be sold. FBS data can be used to observe trends

[2] A Good Food Nation is defined as a country where: Residents know what good food is and how to find it; People are committed to serving and selling good food; Everyone has access to an adequate amount of healthy, nutritious food; There is a reduction in diet-related diseases and the environmental consequences of food consumption; Food producers work toward providing food that is increasingly healthy and sustainable. (https://www.gov.scot/policies/food-and-drink/good-food-nation/).

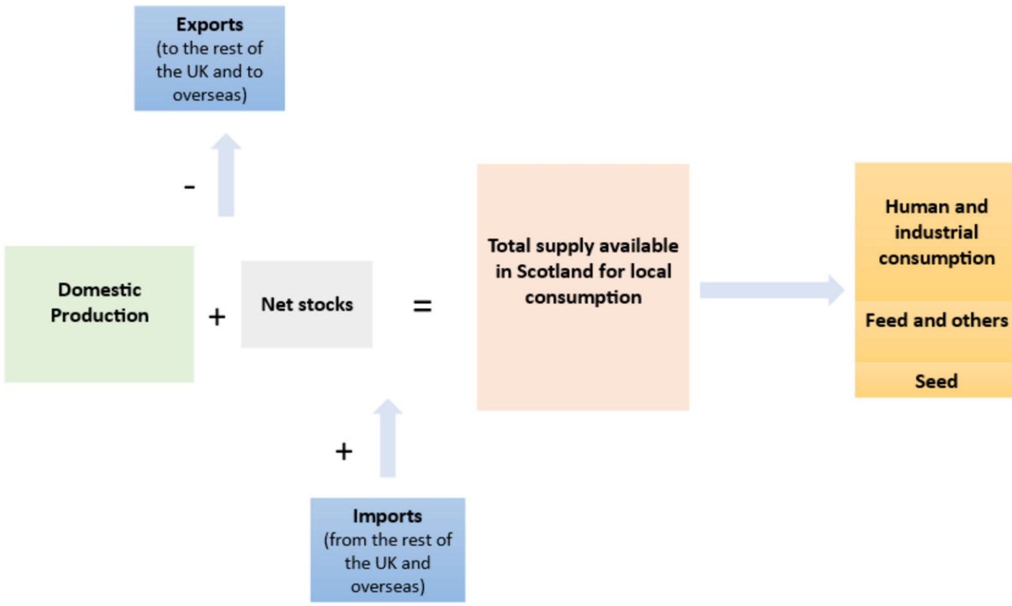


Fig. 1 FAO's FBS approach.

in a country's food supply, compare it to the nutritional needs of healthy diets, estimate supply/shortage measures, evaluate food and nutrition policies, analyze dietary changes, measure the degree of chronic undernutrition, assess self-sufficiency, and import dependence ratios, set trade and production targets, and project future food security.

Even though FBS are available for the UK, the FAO does not estimate the FBS for Scotland. Therefore, we first constructed the annual food balance sheets database for the years 2003 through 2019 for the above primary commodities. Domestic production, net stocks, Scottish food, seed, feed, and other data for each commodity were obtained from Economic Reports on Scottish Agriculture published by the Scotland government. Next, food purchase data for Scotland were collected from the Department for Environment, Food and Rural Affairs (DEFRA)'s family food survey, including 167 final food products. DEFRA's family food is a yearly publication offering detailed statistical information on amounts purchased, expenditures, and nutrient intakes from household food and drink use and eating out. This survey collects data using self-reported diaries supplemented by till receipts of all purchases, including food consumed out of home, during a two-week period. The survey encompasses a sample of 5000 households across the United Kingdom, covering various regions such as the Northeast, North West, Yorkshire and the Humber, East Midlands, West Midlands, East, London, South East, South West, England, Wales, Scotland, and Northern Ireland. For our analysis, we used data specific to Scotland. However, the amount of food consumed in Scotland that is sourced from imports and the amount of food produced in Scotland that is exported to the rest of the UK and the world are not readily available. This shortcoming is brought on by the challenges in integrating the numerous data sources on food imports and expenditures. This was the biggest challenge in estimating the FBS of Scotland. We, therefore, developed a consumption-based approach to estimate the net trade values of the above ten commodities. First, weekly consumption[3] which was obtained from the Department for Environment, Food and Rural Affairs (DEFRA)'s family food statistics (per person per week) of 167 food products was back-transformed into the corresponding annual consumption of primary commodity equivalents using the food conversion factors. For instance, wheat is processed into flour, then flour is used to produce various other derived food products such as bread, pastries, and cakes. In DEFRA's family food data, we only have purchasing amounts of these derived primary food products but not the consumption of primary commodities such as wheat. This conversion process involves mapping commodity trees which shows the relationship between primary commodities and derived products, some commodity trees are simple, and some are complex depending on the number of derived products, the number of processing levels, and the creation of co-products during processing. Moreover,

[3] We used the purchased data from DEFRA's family food survey as a proxy for actual consumption. Vepsäläinen et al., [81] examined the correlation between food purchase and consumption data utilizing automatically gathered purchase data. Their findings suggest that grocery purchase data can effectively reflect food consumption among adults. They propose that future studies should consider utilizing purchase data as a resource-saving and moderately valid measure in large samples.

the production of final food products involves more than one primary commodity, therefore some of the commodity trees are interconnected. After mapping the commodity trees linking final food products and primary food commodities, annual consumption of wheat, barley, oats, potatoes, poultry, lamb, pork, beef, eggs, and dairy in Scotland was estimated by multiplying the matrix of the weekly consumption of final products by the matrix of conversion factors as in Eq. 1. These all-conversion factors applied came from FAO [42, 43] and Arnoult et al. [44].

$$Q_{it}^{pc\,primary} = F\,Q_{it}^{pc\,final}\; i = 1,\ldots,n;\, t = 1,\ldots,T, \quad (1)$$

where F is the matrix of conversion factors, ${Q_{it}}^{pc\,final}$ is the matrix of weekly per capita consumption of final products and $Q_{it}^{pc\,primary}$ is the weekly purchase of primary commodity i in year t.

Next, $Q_{it}^{pc\,primary}$ was multiplied by the number of weeks per the year and the population in Scotland (N) to get the total consumption of primary commodity i (Q_{it}^{TF}) as in Eq. 2.

$$Q_{it}^{TF} = Q_{it}^{pc\,primary} \times 52 \times N. \quad (2)$$

As aforementioned, Scottish-origin food (Q_{it}^{SF}), feed (Q_{it}^{feed}), and seed (Q_{it}^{seed}) data were obtained from Economic reports on Agriculture. Therefore, non-Scottish food Q_{it}^{NSF} can be calculated as

$$Q_{it}^{NSF} = Q_{it}^{TF} - Q_{it}^{SF} \quad (3)$$

Total domestic utilization of each primary commodity (Q_{it}^{TDU}) was obtained using the following magnitudes:

$$Q_{it}^{TDU} = Q_{it}^{NSF} + Q_{it}^{SF} + Q_{it}^{feed} + Q_{it}^{seed} \quad (4)$$

According to the FBS's basic identity, total domestic supply (Q_{it}^{TDS}) should be equal to domestic utilization (Q_{it}^{TDU}).

$$Q_{it}^{TDU} = Q_{it}^{TDS} \quad (5)$$

Q_{it}^{TDS} can also be established as.

$$Q_{it}^{TDS} = Q_{it}^{PRD} + Q_{it}^{NS} + Q_{it}^{NT}, \quad (6)$$

where Q_{it}^{PRD} is the Scottish production of commodity i in year t, Q_{it}^{NS} is the net stock and Q_{it}^{NT} is the net trade as shown above. In the above equation, Q_{it}^{TDS} (derived above), Q_{it}^{PRD}, and Q_{it}^{NS} (obtained from Economic Reports on Scottish Agriculture) are known values; therefore, Q_{it}^{NT} of each primary commodity can be derived as.

$$Q_{it}^{NT} = Q_{it}^{TDS} - \left(Q_{it}^{PRD} + Q_{it}^{NS}\right) \quad (7)$$

To estimate per capita annual consumption of commodity i in year t, the total consumption of primary commodity i is divided by the population (N) in Scotland.

$$Q_{it}^{food\,per\,capita\,annual} = \frac{Q_{it}^{TF}}{N} \quad (8)$$

Estimating Scotland's food self-sufficiency ratio

According to FAO [14], the concept of food self-sufficiency is generally taken to mean the extent to which a country can satisfy its food needs from its own domestic production. Self-sufficiency ratio (SSR), which expresses food production as a percentage of available supply, is an important measure that conveys this more pragmatic meaning of the idea.

Several studies have used SSR to examine regional agriculture and food sector structural changes. Fitzpatrick [45], Luan et al. [46], Loke and Leung [47], Morrison et al. [48], Ostry and Morrison [49]; Puma et al. [50] and Kako [51] defined the SSR, on a calorie basis, as the ratio of calorie supply from domestically produced food to the total calorie supply from all food in a country. Alternatively, Holm et al. [52] and DEFRA [53] compute the SSR on a value basis as the fraction of consumer demand met by local production in terms of household food expenditures and farm-gate value. DEFRA [54] calculated the SSR for the United Kingdom by market value. Godenau et al. [28] measured the degree of food self-sufficiency on a regional scale considering the Canary Islands as a case study. Their measurement was undertaken using three dimensions—volume, value, and energy content—and for several hundreds of items.

As shown in FAO [55], Luan et al. [46], and Clapp [13, 56], the key indicator that captures a more practical comprehension of the self-sufficiency ratio (SSR) is one that express food production as a ratio of available supply. The SSR can be further refined by including fluctuations in the level of domestic food stocks as suggested by Puma et al., [50]. Following FAO [55] and Puma et al. [50], we estimated SSR as below,

$$SSR = \frac{Q_{it}^{PRD}}{Q_{it}^{PRD} + Q_{it}^{NT} + Q_{it}^{NS}} \times 100 \quad (9)$$

Assessing the nutrition supply

The dietary energy supply ($Q_{it}^{ES\,per\,capita\,annual}$), protein supply $\left(Q_{it}^{PRS\,per\,capita\,annual}\right)$ and fat supply ($Q_{it}^{FAT\,per\,capita\,annual}$) per capita per annum were estimated as follows. The conversion factors used here (f_E; calories by unit of edible weight, f_P; proteins by unit of

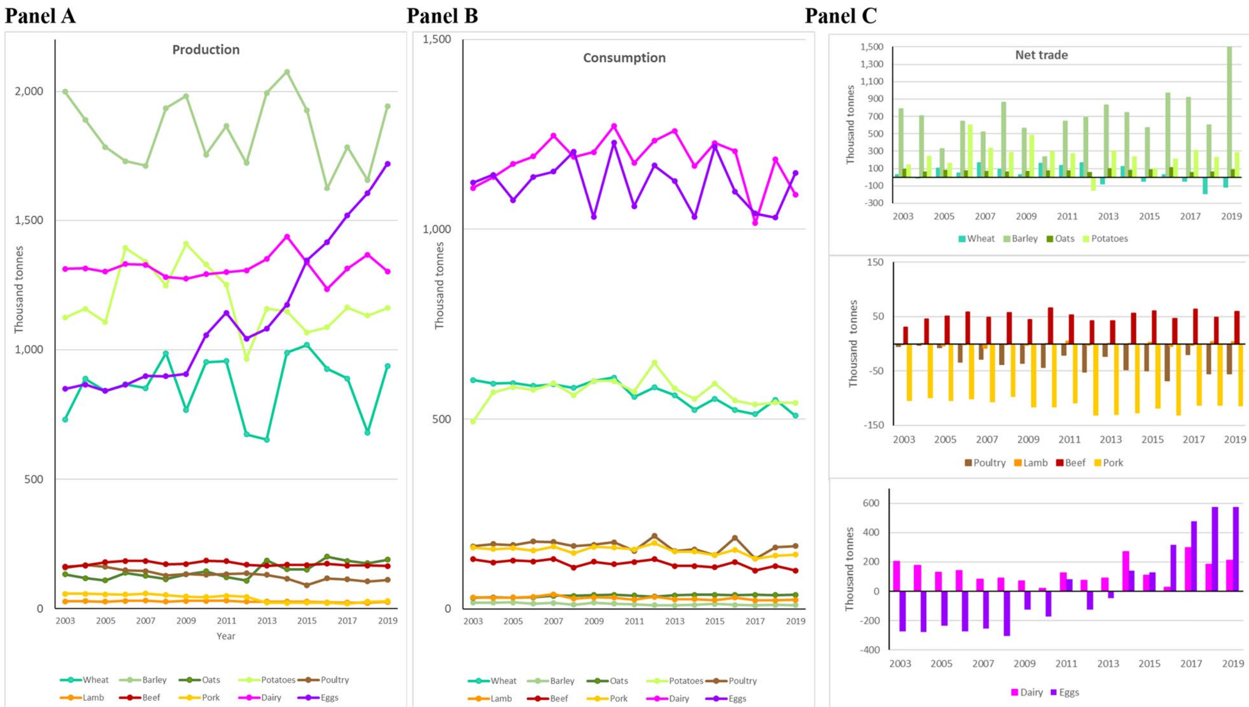


Fig. 2 Production (Panel A), human consumption (Panel B), and net trade (Panel C) of major food commodities in Scotland. Own computation based on Scottish government data and Family Food statistics. Net trade = Exports—Imports

edible weight, f_E: fat by unit of edible weight*)* were obtained from food composition tables of the FAO [43] report published in 2008.

$$Q_{it}^{ES\ per\ capita\ annual} = f_E \times Q_{it}^{food\ per\ capita\ annual} \quad (10)$$

$$Q_{it}^{PRS\ per\ capita\ annual} = f_P \times Q_{it}^{food\ per\ capita\ annual} \quad (11)$$

$$Q_{it}^{FS\ per\ capita\ annual} = f_F \times Q_{it}^{food\ per\ capita\ annual} \quad (12)$$

Results and discussion

Figure 2 shows the production, human consumption, and net trade of cereal, potatoes, meat, dairy, and eggs in Scotland. All these data were derived from our estimated FBS as shown in Sect. "Estimating Scotland's FBS". Scotland is one of the main barley-growing locations in the UK and it has a long history of producing barley [57]. The predominant cereal crop grown in Scotland is spring barley, with an estimated growing area of 134,744 ha. Over half (58%) of the land used for cereal production was used for spring barley. Scotland's climate and soil make it an ideal place to grow barley. The main uses of barley cultivation are for the production of animal feed, malt for the whisky industry, and human consumption (pearl barley) (NFU [33, 58]). The second most popular crop production was winter wheat, in terms of area, in 2019, totalling 64,856 ha. At 28%, this is just over a quarter of all land used for cereal production. Winter barley production areas totalled 30,996 ha, accounting for 13%, and were the third most popular crop. Spring oats production made up less than one per cent of all areas, using only 1054 ha [59]. As can be seen in Panel A of Fig. 2, over the course of 17 years from 2003 to 2019, Scotland's agricultural landscape witnessed important shifts in the production of key food commodities. As can be seen, there was a notable increase in wheat production from 2003 to 2008, with production peaking in 2008. The production values vary between a low of 652.9 thousand tons in 2013 to a high of 1,019.2 thousand tons in 2015. While oats production soared by approximately 42%, showcasing a substantial increase, barley production saw a modest decline of around 3%, over this period. Scotland is known for producing high-quality potatoes, especially seed potatoes, mostly in eastern and central regions, which are exported globally. Scotland exports seed and ware potatoes to more than 40 different countries [60]. According to AHDB48, in 2015, 21% of Great Britain's planted potato area was in Scotland, with 45% of that area planted for seed. According to our analysis, the production of potatoes also displayed fluctuations over the years, with variations in annual production levels. Potato production showed a noticeable dip between 2009 and 2012.[4] The UK's declining fresh potato consumption—which dropped by 27% in the ten years leading up to 2013—may be the cause of part of this decreased production [60].

Scotland's livestock sector is a vital component of its agricultural industry and plays a significant role in the country's economy and culture. Livestock farming in Scotland encompasses the raising of various types of animals, primarily cattle, sheep, and poultry [58]. The country is known for its native Scottish breeds such as the Highland cattle and Aberdeen Angus, prized for their hardiness and quality. Beef farming accounts for about a quarter of the total value of agricultural gross output. There are over 500,000 breeding beef cows and heifers in Scotland and beef cattle farming takes place on over 9,500 holdings, whereas there are approximately 198,000 dairy cows on about 1800 holdings [61]. There are approximately 7.4 million sheep on approximately 13,600 holdings in Scotland. Sheep farming is another essential aspect of Scotland's livestock sector. Scotland represents over 20% of the UK's total sheep flock [60]. Scottish Blackface and Cheviot are some of the popular breeds raised for their meat and wool. The rugged terrain of the Scottish Highlands is well-suited for sheep farming, and it has a long history in the region [61]. As can be seen in Panel A of Fig. 2, of all major food commodities, egg production rose most significantly. Poultry production declined by nearly 30% over the past decade, reflecting a notable decrease. Additionally, pork production witnessed a substantial drop in production of approximately 48%, indicating challenges in this segment. The decline in domestic poultry and pork production reflects a significant decrease in self-sufficiency, resulting in increased reliance on imports to meet consumption needs. This increased reliance on imported poultry and pork makes the food supply chain more vulnerable to external disruptions such as trade barriers or supply chain disruptions [62].

Panel B of Fig. 2 shows the consumption of major food commodities (in thousand tons) for each year from 2003 to 2019. As can be seen from the figure, in Scotland, dairy and egg consumption was the highest across all commodities (upwards of 1000 thousand tons per year). Barley, oats and lamb consumption was the lowest. Over the course of 17 years, Scotland's consumption patterns for key food categories witnessed significant shifts. Notably, the consumption of cereal crops such as wheat and barley experienced declines of approximately 16% and 40%, respectively. However, oats consumption saw a notable increase of around 27%, possibly due to growing awareness of their health benefits [63]. Consumption of potatoes rose by approximately 10%, indicating their enduring popularity. According to reports by DEFRA [64] and Dogbe and Revoredo-Giha [65], the average weekly consumption of fresh potatoes in the UK plummeted by 68% between 1974 and 2018. Conversely, the consumption of processed potatoes surged by 109% during this timeframe. However, it is important to note that our estimates regarding potato consumption in Scotland encompass both fresh and processed potatoes. In the realm of meat consumption, both lamb and beef experienced notable declines of approximately 23% and 23%, respectively, suggesting shifts in meat preferences. Pork consumption also decreased by approximately 12%. Dairy consumption showed relative stability with a modest decrease of about 1.6%. Despite substantial variation in egg consumption, average consumption increased by 2%. Stewart et al. [66] reports a slight decline in meat consumption (− 17%), while Alae-Carew et al. [67] report a smaller decline in milk and milk product consumption (− 2%) in the UK over the previous ten years. Our results thus confirm the literature mentioned above. These trends are encouraging in the context of sustainable food consumption in Scotland, as red meat production typically carries a higher emissions footprint per calorie produced compared to other food categories [68, 69],and [70].

Panel C of Fig. 3 represents the net trade—in thousands of tons—for these food commodities (cereals, potatoes, meat, dairy, and eggs) over the years from 2003 to 2019. A positive value indicates that the country exported more of that commodity than it imported, while a negative value indicates that the country imported more than it exported. Scotland's net trade in key food commodities underwent significant transformations over the 17-year period. For instance, Scotland was previously a net exporter of wheat but since 2012, became a net importer. Despite annual variation, Scotland is a net exporter of barley and oats. Since 2003, Scotland had a net trade surplus of potatoes, exporting more potatoes than it imported. In 2015–2016, Scotland exported seed potatoes to 24 countries including Egypt (64% of exports), followed by Morocco (11%) the Canary Islands (6%) and Saudi Arabia (6%) [71].

Scotland's net trade in meat commodities exhibited several notable shifts over the 17 years. Scotland is a net exporter (59.4 thousand tons in 2019) of beef, but a net importer of pork and poultry. Scotland has been a net exporter of dairy products over this entire period. According to AHDB [72], of the total milk production in the UK, 84% was processed in Scotland and 16% was transported into England for processing. Of the volume

[4] Domestic utilization (food, feed and seed) figures of wheat, barley, oats and potatoes can be found in Appendix 1.

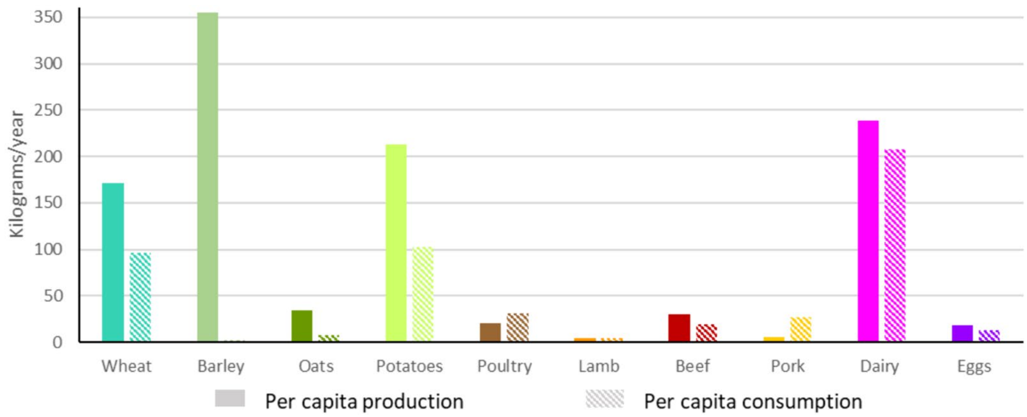


Fig. 3 A comparison of per capita production and consumption of major food commodities in Scotland in 2019. Own computation based on Scottish government data and Family Food statistics

processed in Scotland, around 530 m liters was processed into cheese, and some 730 m liters into other products, the majority of which was liquid milk. It transitioned from being a net importer of eggs in 2003 to becoming a net exporter, with a remarkable shift occurring from 2012 onwards. The net trade values of eggs range from a low of -306.2 thousand tons in 2008 to a high of 574.5 thousand tons in 2018.

Figure 3 shows a comparison of per capita production and consumption of major food commodities in Scotland in 2019. In the context of per capita production and per capita food consumption in Scotland, significant disparities emerge among various food categories. Barley stands out with the highest per capita production, producing 356 kg per person, while dairy takes the lead in per capita consumption at 207 kg per person. Lamb has the lowest production per capita at 4.8 kg, while barley records the lowest per capita food consumption at 1.9 kg. Per capita production of wheat, potatoes and dairy products is greater than consumption, indicating a strong surplus or export market. Per capita consumption of oats and barley are lower than per capita production because they are important components of animal feed and industrial usage (see Appendix 1). Lamb production closely matches consumption, suggesting a balanced market. Pork per capita consumption far exceeds per capita production, likely leading to a reliance on imports to meet demand.

Table 1 shows the self-sufficiency ratio for various food products over several years. The standard deviation of the self-sufficiency ratios varies across different food products, indicating varying degrees of self-sufficiency. A higher coefficient of variation (CV) suggests more variability relative to the mean. According to the formula we used to calculate SSR, A food self-sufficiency ratio below 100% signifies insufficient food production to meet population demand; 100% suggests production capacity meets population needs, while above 100% indicates surplus domestic production surpassing domestic requirements [73].

The cereals show self-sufficiency ratios close to or above 100, suggesting a relatively high level of production to meet consumption. The self-sufficiency ratio for potatoes is around 127.8, indicating a consistent trend of producing more than consumed. The meat products generally show self-sufficiency ratios ranging from 26 to 146, with some fluctuations. The variability might be due to factors like imports and seasonal changes. The dairy self-sufficiency ratio is around 112, indicating that the region produces slightly more dairy products than it consumes. The self-sufficiency ratio for eggs is around 102, indicating that egg production meets consumption needs.

Over the years, most of the food products show varying degrees of self-sufficiency. Some products consistently maintain ratios above 100, indicating overproduction. Barley, oats, potatoes, beef and dairy consistently exhibit self-sufficiency ratios well above 100, indicating a strong ability to produce them domestically. While Scotland maintains self-sufficiency in oats, the degree of self-sufficiency has decreased from 2003 to 2019. Although domestic oat production has risen from 132.8 thousand tons to 189.1 thousand tons during this period (as illustrated in Panel A of Fig. 2), oat consumption in Scotland has concurrently increased by 27%. This rise in consumption might be contributing to the decline in the self-sufficiency ratio. Some products like poultry, lamb, and pork show fluctuating self-sufficiency ratios. For instance, the decrease in self-sufficiency rates for poultry (from 95.6% to 67.3%) and pork (from 35.8% to 20.9%) primarily resulted from declines in domestic poultry and pork

Table 1 Self-sufficiency ratio of major food commodities in Scotland (percentages)

Year	Wheat	Barley	Oats	Potatoes	Poultry	Lamb	Beef	Pork	Dairy	Eggs
2003	103.5	148.6	304.3	131.2	95.6	91.9	123.5	35.8	118.4	75.7
2004	108.4	156.0	211.3	126.0	98.6	101.1	136.3	36.6	115.6	75.7
2005	103.3	133.8	232.1	121.1	96.1	91.1	140.6	34.8	111.1	78.2
2006	116.5	152.5	233.7	141.6	83.6	95.1	148.1	35.5	111.7	76.0
2007	117.5	147.9	199.9	136.7	82.6	80.3	140.6	35.9	106.6	78.1
2008	118.8	160.1	202.1	134.0	77.3	101.3	157.4	36.1	107.7	74.6
2009	97.1	138.5	244.7	138.8	79.3	100.3	138.2	28.5	106.0	87.8
2010	111.7	133.0	177.4	133.7	74.8	100.8	157.9	27.9	101.6	86.0
2011	126.8	154.7	228.4	130.5	87.8	124.5	148.2	31.8	110.6	107.8
2012	98.9	164.1	203.6	100.6	71.2	86.7	129.2	26.2	106.0	89.3
2013	103.2	157.6	323.8	123.6	86.3	108.0	146.5	15.5	107.3	95.9
2014	134.0	149.1	226.8	127.0	73.9	107.8	149.7	15.3	123.3	113.7
2015	119.4	144.2	243.0	114.7	64.4	116.6	154.1	16.5	108.9	110.5
2016	100.0	224.2	214.0	122.8	62.6	81.2	140.1	14.7	102.4	129.0
2017	92.5	211.2	173.7	130.8	85.6	102.5	165.3	15.2	129.3	146.0
2018	65.2	180.5	149.3	128.4	65.4	100.2	147.2	19.9	115.5	155.7
2019	110.7	268.2	216.2	130.5	67.3	108.5	163.5	20.9	119.4	149.9
Mean	107.5	166.1	222.6	127.8	79.5	99.9	146.3	26.3	111.8	101.8
Standard deviation	15.5	36.1	42.9	9.7	11.4	11.7	11.4	8.8	7.5	28.2
Coefficient of variation	14.5	21.7	19.3	7.6	14.3	11.7	7.8	33.5	6.7	27.7

Own computation based on Scottish government data and Family Food statistics

production between 2003 and 2019 (as depicted in panels A and B of Fig. 2). Fluctuations in self-sufficiency ratios for meat products suggest susceptibility to factors such as imports and seasonal changes, highlighting vulnerabilities in these sectors In addition to the influence of domestic production and consumption changes, the variability in self-sufficiency ratios across different food products could be attributed to factors such as weather conditions, market dynamics, technological advancements, and trade policies. [73–76].

In summary, the country has a strong level of self-sufficiency in grains, potatoes, lamb, beef, dairy and eggs. There is room for improvement in achieving self-sufficiency in poultry and pork, where the SSR is relatively low. When comparing our findings to DEFRA's UK Food Security Report [76], it is evident that the UK is largely self-sufficient in grain production, exceeding 100% of domestic consumption for oats and barley, over 90% for wheat, and around 70% for potatoes. In terms of meat, milk, and eggs, the UK produces approximately the same volume as it consumes. However, self-sufficiency for pigmeat is the lowest, standing at 66% of consumption. The report also highlights consistent egg production in the UK meeting between 89 and 98% of domestic demand, with a significant increase over the last decade despite the transition to free-range methods, which now account for about half of production.

Figure 4 shows the energy, protein and fat supply in per capita in 2019 for various food products in Scotland. Our study on energy and macronutrient supply in Scotland offers valuable insights for comparing local consumption patterns with those across the UK. However, due to the absence of estimates for other regions in the UK utilizing the same methodology (attributed to insufficient data on interregional trade), comparisons must rely on alternative sources. One such source is the FAO food balance sheet for the UK. The FAO's estimate for wheat energy supply in the UK in 2019 (288,492 kcal/person/year) differs from ours, mainly due to methodological variations. For example, in our calculation of per capita wheat consumption, we accounted for all final food commodities containing wheat, which were then converted back into wheat using appropriate conversion factors as detailed in Sect. "Estimating Scotland's FBS" of our study. As shown in Fig. 4, our estimates are divided into two categories: total supply and supply from Scottish origin. For instance, the total energy supply values represent the total amount of energy provided by each food product on a per capita basis in kilocalories per year. These values reflect the overall energy contribution of each food product to the diet of the population. The energy supply from Scottish-origin values represents the portion of energy supplied by each food product that is produced within Scotland. These values provide insights into the

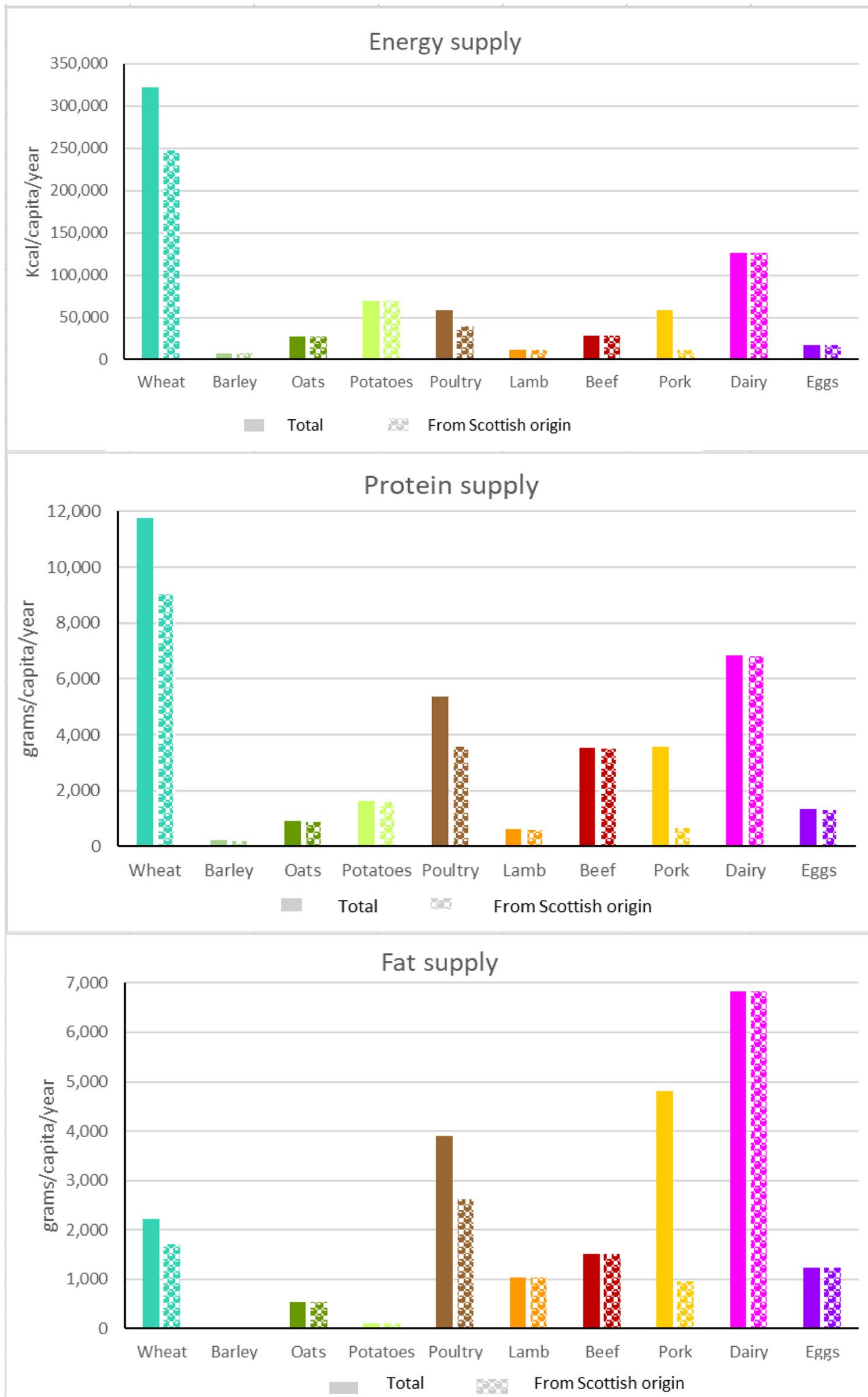


Fig. 4 Comparison of the food sources supplying energy and macronutrients available for consumption in Scotland in 2019. Own computation based on Scottish government data and Family Food survey data

contribution of locally produced food to the nutrition intake of the population.

Wheat contributes significantly to the total energy supply, with a substantial portion of it coming from Scottish origin. It is a staple food and a major source of dietary energy, as well as being our most important source of dietary protein. Diary, all of Scottish origin, is the second most important contributor to total energy supply, and dietary protein, and the most important source of dietary fat. Barley, oats, and potatoes also contribute to the energy supply, and their entire supply is of Scottish origin. Meat products are notable sources of protein and fat, with varying proportions of Scottish origin. Of all meat varieties, poultry provides the most substantial protein content, while pork offers the highest fat content. When considering recommended energy and protein intakes, it becomes evident that Scottish-origin wheat makes a substantial contribution, accounting for approximately 30% of energy and 50% of protein requirements in Scotland. Macdiarmid et al. [41] examined the trends in national nutrition security and the role of imports in nutrition security within the UK. They utilized FAO food balance sheet data spanning from 1961 to 2011 along with national food composition tables. According to their findings, the supply of total carbohydrates has remained relatively stable over the decades, with a higher proportion sourced from domestically produced food than previous years. Additionally, their study indicates that the UK achieved self-sufficiency in the supply of protein.

Conclusions and policy implications

The Scottish food system demonstrates a diverse and adaptable landscape, showcasing varying degrees of self-sufficiency across different commodities, which can impact its vulnerability to external factors. While cereals, potatoes, lamb, beef, dairy, and eggs demonstrate relatively high self-sufficiency ratios, indicating a strong ability to meet domestic demand, vulnerabilities are apparent in poultry and pork supply, where self-sufficiency ratios are lower.

Our findings on production, consumption, net trade, and self-sufficiency provide a comprehensive understanding of the interconnected aspects of the Scottish food system. Understanding food supply patterns can aid in dietary planning, food security considerations, and supporting local agricultural production. Estimated food balance sheets will help to model future food production and consumption scenarios, including the optimization of its nutritional value and the minimization of its environmental impacts, enabling the quantification of impacts of a transition to more healthy and sustainable dietary options. Our self-sufficiency ratio estimates provide a more accurate assessment of the extent of food localization in Scotland. In general, this assessment can serve as a foundation for evidence-based decision-making in Scotland's agricultural and food policy. It provides insights into where investments and support may be needed to enhance domestic production and promote a resilient and sustainable food system.

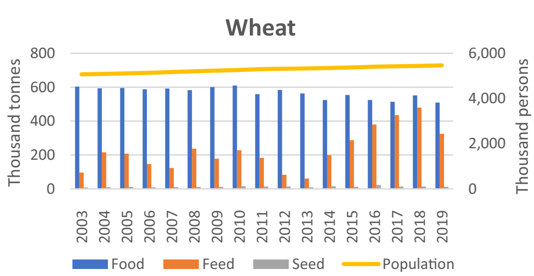
However, balancing the goal of self-sufficiency with environmental sustainability, ensuring that increased food production does not come at the expense of the planet's health, is a key challenge for policymakers and farmers. According to Beltran-Peña et al. [73], under a sustainability scenario, half of the world's countries will be self-sufficient while the other half will be dependent on food imports. Currently, food systems contribute around a third (~35%) to global greenhouse gas emissions (GHGE) [2]. Agriculture and related land use accounted for just under a quarter of total GHG emissions in Scotland in 2017 (Scottish government 2019a), and this contribution would be higher if the wider food manufacturing and processing emissions associated with getting food from "farms to our forks" were included [77]. Therefore, sustainable farming practices should be promoted to increase productivity while minimizing its environmental impact. Climate change, on the other hand, will have a direct impact on what types of farming can be done, and what crops can be grown, as well as shaping how farming operates. For instance, it may also offer some opportunities for Scottish agriculture as rising temperatures could extend the growing seasons for crops [78]. However, climate change is likely to increase many pest, weed, and disease problems on crops in Scotland [79].

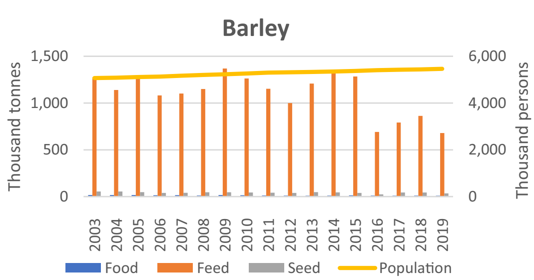
The self-sufficiency estimates can be misleading if they do not account for the imported inputs that are essential to domestic production. The reliance on imported fertilizer and feed in the agricultural sector can impact food production and security. Therefore, we acknowledge this constraint. In many earlier studies, self-sufficiency statistics are calculated by value, not by volume or caloric content. However, given the volatility of prices and currency exchange rates, this may distort the ratios. As a result, it is stated that "a better measure of self-sufficiency might use volume measures or even nutritional values" [80]. In our study, we evaluated self-sufficiency using quantities and nutritional values. Moreover, our approach is based on consumption of final food products, and we converted all their constituent ingredients to primary commodities.

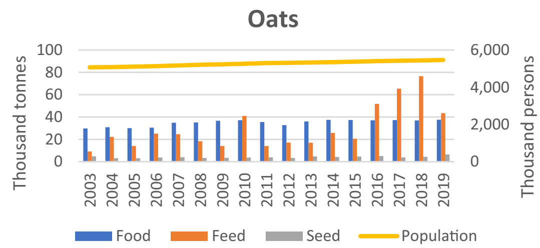
Regional studies on food self-sufficiency face unique challenges due to the complexities of political and institutional frameworks that often span both national and supra-national levels. As a result, the availability of data for such regional analyses is comparatively limited when compared to national-level studies. This scarcity of data has translated into a scarcity of studies dedicated to exploring local and regional food self-sufficiency and self-reliance. Our study introduces a novel method designed to bridge this data gap. The approach we have developed holds promise as a valuable tool for future research studies, enabling the estimation of regional-level food self-sufficiency even when trade data and food balance sheets are not readily accessible. While our study successfully evaluated the self-sufficiency of essential food categories, including cereals, potatoes, meat, dairy, and eggs, it is essential to acknowledge that the broader landscape of food self-sufficiency encompasses a more diverse range of products, notably seafood and fruits and vegetables. For a more comprehensive understanding of a region's or nation's self-sufficiency in meeting its dietary needs, it becomes evident that future research efforts should expand their focus to encompass these additional food categories. By doing so, we can ensure a more holistic and complete assessment of food self-sufficiency and resilience in the face of varying challenges.

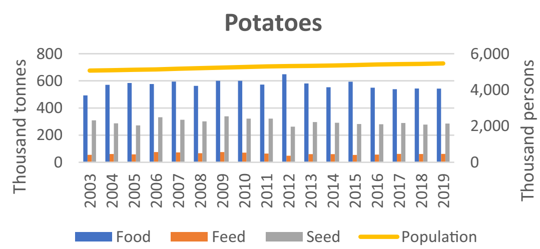
Appendix 1

Domestic utilization of cereal and potatoes in Scotland









Acknowledgements
The authors would like to thank the anonymous referees and the editor of this journal for their constructive comments on an earlier version of the paper.

Author contributions
SDR: conceptualization, data preparation, investigation, visualization, formal analysis, writing—original draft, writing—review, and editing. CR-G: conceptualization, investigation, visualization, formal analysis, writing—review, and editing. BdR: investigation, visualization, writing—review, and editing.

Funding
This research was funded by the Rural and Environment Science and Analytical Services Division 363 (RESAS) of the Scottish Government, project RI-B5-04.

Availability of data and materials
Data are available upon request.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

Received: 8 December 2023 Accepted: 14 May 2024
Published online: 22 August 2024

References

1. Clancy K, Ruhf K. 2010. Is local enough? Some arguments for regional food systems. Choices. 25(1).
2. Crippa M, Solazzo E, Guizzardi D, Monforti-Ferrario F, Tubiello FN, Leip AJNF. Food systems are responsible for a third of global anthropogenic GHG emissions. Nat Food. 2021;2(3):198–209.
3. Griffin T, Conrad Z, Peters C, Ridberg R, Tyler EP. Regional self-reliance of the Northeast food system. Renew Agric Food Syst. 2015;30(4):349–63.

4. McCarthy AC, Griffin TS, Srinivasan S, Peters CJ. Capacity for national and regional self-reliance in fruit and vegetable production in the United States. Agron J. 2023;115(2):647–57.
5. Ruhf KZ. Regionalism: a new england recipe for a resilient food system. J Environ Stud Sci. 2015;5(4):650–60.
6. Bisoffi S, Ahrné L, Aschemann-Witzel J, Báldi A, Cuhls K, DeClerck F, Duncan J, Hansen HO, Hudson RL, Kohl J, Ruiz B. COVID-19 and sustainable food systems: what should we learn before the next emergency. Front Sustain Food Syst. 2021;5:650987.
7. Kaufmann L, Mayer A, Matej S, Kalt G, Lauk C, Theurl MC, Erb KH. Regional self-sufficiency: a multi-dimensional analysis relating agricultural production and consumption in the European Union. Sustain Prod Consum. 2022;34:12–25.
8. Sonnino R. Local foodscapes: place and power in the agri-food system. Acta Agric Scandinavica Sect B-Soil Plant Sci. 2013;63(sup1):2–7.
9. Sylla M, Świąder M, Vicente-Vicente JL, Arciniegas G, Wascher D. Assessing food self-sufficiency of selected European Functional Urban Areas vs metropolitan areas. Landsc Urban Plan. 2022;228:104584.
10. Brekken CA, Fiegener R, Duncan S. Linking regional food networks to ecological resilience. Choices. 2018;33(2):1–10.
11. Keegan S, Reis K, Roiko A, Desha C. Exploring resilience concepts and strategies within regional food systems: a systematic literature review. Food Sec. 2023. https://doi.org/10.1007/s12571-023-01418-9.
12. Palmer A, Santo R, Berlin L, Bonanno A, Clancy K, Giesecke C, Hinrichs CC, Lee R, McNab P, Rocker S. Between global and local: exploring regional food systems from the perspectives of four communities in the US Northeast. J Agri Food Syst Commun Dev. 2017;7(4):187–205.
13. Clapp J. Food self-sufficiency: making sense of it, and when it makes sense. Food Policy. 2017;66:88–96.
14. FAO. Implications of economic policy for food security: a training manual. 1999. http://www.fao.org/docrep/004/x3936e/x3936e03.html. Accessed 8 Aug 2023.
15. Hubbard LJ, Hubbard C. Food security in the United Kingdom: External supply risks. Food Policy. 2013;43:142–7.
16. Kriewald S, Pradhan P, Costa L, Ros AG, Kropp JP. Hungry cities: how local food self-sufficiency relates to climate change, diets, and urbanisation. Environ Res Lett. 2019;14(9):094007.
17. Kinnunen P, Guillaume JH, Taka M, D'odorico P, Siebert S, Puma MJ, Jalava M, Kummu M. Local food crop production can fulfil demand for less than one-third of the population. Nat Food. 2020;1(4):229–37.
18. Kummu M, Kinnunen P, Lehikoinen E, Porkka M, Queiroz C, Röös E, Troell M, Weil C. Interplay of trade and food system resilience: gains on supply diversity over time at the cost of trade independency. Glob Food Sec. 2020;24:100360.
19. Naylor RL, Falcon WP. Food security in an era of economic volatility. Popul Dev Rev. 2010;36(4):693–723.
20. Helleiner E. The return of national self-sufficiency? Excavating autarkic thought in a de-globalizing era. Int Stud Rev. 2021;23(3):933–57.
21. Hobbs JE. Food supply chains during the COVID-19 pandemic. Canadian J Agri Econom/Revue Canadienne D'agroeconomie. 2020;68(2):171–6.
22. Roubík H, Lošťák M, Ketuama CT, Procházka P, Soukupová J, Hakl J, Karlík P, Hejcman M. Current coronavirus crisis and past pandemics-what can happen in post-COVID-19 agriculture? Sustain Prod Consum. 2022;30:752–60.
23. Billen G, Aguilera E, Einarsson R, Garnier J, Gingrich S, Grizzetti B, Lassaletta L, Le Noë J, Sanz-Cobena A. Reshaping the european agro-food system and closing its nitrogen cycle: the potential of combining dietary change, agroecology, and circularity. One Earth. 2021;4(6):839–50.
24. Pradhan P, Kriewald S, Costa L, Rybski D, Benton TG, Fischer G, Kropp JP. Urban food systems: how regionalization can contribute to climate change mitigation. Environ Sci Technol. 2020;54(17):10551–60.
25. Barham J, Tropp D, Enterline K, Farbman J, Fisk J, Kiraly S. Regional food hub resource guide. Washington, DC: U.S. Department of Agriculture, Agricultural Marketing Service; 2012.
26. Fan S, Linxiu Z, Xiaobo Z. Growth and poverty in rural china: the role of public investments. Washington DC: EPTD discus. Pap., Int Food Policy Research Institute; 2002.
27. Jónsdóttir S, Gísladóttir G. Land use planning, sustainable food production and rural development: a literature analysis. Geograp Sustain. 2023;4:391–403.
28. Godenau D, Caceres-Hernandez JJ, Martin-Rodriguez G, Gonzalez-Gomez JI. A consumption-oriented approach to measuring regional food self-sufficiency. Food Secur. 2020;12(5):1049–63.
29. Li Y, Sun Z, Accatino F. Spatial distribution and driving factors determining local food and feed self-sufficiency in the eastern regions of China. Food Energy Sec. 2021;10(3):e296.
30. Quinn B, Seaman C. Artisan food production, small family business and the Scottish food paradox. Nutr Food Sci. 2019;49(3):455–63.
31. Scottish Government. Agricultural Land Use in Scotland 2017. https://www2.gov.scot/Topics/Statistics/Browse/Agriculture-Fisheries/agritopics/LandUseAll. Accessed 7 Oct 2023
32. RSPB. Farming in Scotland. 2019. https://www.rspb.org.uk/about-the-rspb/at-home-and-abroad/scotland/farminginscotland/. Accessed 2 Oct 2023.
33. NFU Scotland. Farming Facts 2019. https://www.nfus.org.uk/farming-facts.aspx. Accessed 05 Sep 2023.
34. Scottish Government. Good Food Nation Bill Passed 2022. https://www.gov.scot/publications/good-food-nation-proposals-legislation-consultation-analysis-report/. Accessed 5 Oct 2023.
35. Hubbard C, Davis J, Feng S, Harvey D, Liddon A, Moxey A, Ojo M, Patton M, Philippidis G, Scott C, Shrestha S. Brexit: how will UK agriculture fare? EuroChoices. 2018;17(2):19–26.
36. Wach E. The potentials for agroecology and food sovereignty in the Scottish uplands. PhD Dissertation. Coventry: University of Coventry; 2019.
37. DEFRA. Agriculture in the United Kingdom 2015. https://assets.publishing.service.gov.uk/media/5a8042b740f0b6230269276d/AUK-2015-05oct16.pdf. Accessed 8 May 2023.
38. Edwards-Jones G. Does eating local food reduce the environmental impact of food production and enhance consumer health? Proce Nutr Soc. 2010;69(4):582–91.
39. Kirwan J, Maye D. Food security framings within the UK and the integration of local food systems. J Rural Stud. 2013;29:91–100.
40. MacMillan T, Dowler E. Just and sustainable? Examining the rhetoric and potential realities of UK food security. J Agric Environ Ethics. 2012;25:181–204.
41. Macdiarmid JI, Clark H, Whybrow S, De Ruiter H, McNeill G. Assessing national nutrition security: the UK reliance on imports to meet population energy and nutrient recommendations. PLoS ONE. 2018;13(2):e0192649.
42. FAO. Technical conversion factors for agricultural commodities; Report 2003. https://www.fao.org/fileadmin/templates/ess/documents/methodology/tcf.pdf. Accessed 10 Mar 2023.
43. FAO. Food Balance Sheets: a handbook; 2001. http://www.fao.org/docrep/003/X9892E/X9892E00.HTM. Accessed 02 Apr 2023.
44. Arnoult MH, Jones PJ, Tranter RB, Tiffin R, Traill WB, Tzanopoulos J. Modelling the likely impact of healthy eating guidelines on agricultural production and land use in England and wales. Land Use Policy. 2010;27(4):1046–55.
45. Fitzpatrick E. Agricultural self-sufficiency in Southeast Asia: Malaysia and Thailand. In: Ruppel FJ, Kellogg ED, editors. National and regional self-sufficiency goals. Boulder & London: Lynne Rienner; 1991.
46. Luan Y, Cui X, Ferrat M. Historical trends of food self-sufficiency in Africa. Food Sec. 2013;5:393–405.
47. Loke MK, Leung P. Hawai'i's food consumption and supply sources: benchmark estimates and measurement issues. Agri Food Econ. 2013;1:1–8.
48. Morrison KT, Nelson TA, Nathoo FS, Ostry AS. Application of Bayesian spatial smoothing models to assess agricultural self-sufficiency. Int J Geogr Inf Sci. 2012;26(7):1213–29.
49. Ostry A, Morrision K. A method for estimating the extent of regional food self-sufficiency and dietary ill health in the province of British Columbia Canada. Sustainability. 2013;5(11):4949–60.
50. Puma MJ, Bose S, Chon SY, Cook BI. Assessing the evolving fragility of the global food system. Environ Res Lett. 2015;10(2):024007.
51. Kako T. Sharp decline in the food self-sufficiency ratio in Japan and its future prospects. Paper presented at the International Association of Agricultural Economists Conference, Beijing, China. 2009.
52. Holm D, Rogers R, Lass D. Food self-sufficiency in the New England states, 1975–1997. Department of Resource Economics. Amherst: University of Massachusetts; 2000.

53. DEFRA. Food statistics pocket book 2008. http://webarchive.nationalarchives.gov.uk/20130123162956/http:/www.defra.gov.uk/statistics/files/defra-statsfoodfarm-food-pocketbook-2008.pdf. Accessed 8 May 2023.
54. DEFRA. Food security and the UK: An evidence and analysis paper. Food Chain Analysis Group. 2006. http://archive.defra.gov.uk/evidence/economics/foodfarm/reports/documents/foodsecurity.Pdf. Accessed 10 May 2023.
55. FAO. 2012. FAO Statistical Yearbook 2012—World Food and Agriculture Available at: http://www.fao.org/docrep/015/i2490e/i2490e00.htm. Accessed 12 Aug 2023.
56. Clapp J. Food self-sufficiency and international trade: a false dichotomy? State of agricultural commodity markets—in depth. Rome: FAO; 2023.
57. Cammarano D, Hawes C, Squire G, Holland J, Rivington M, Murgia T, Roggero PP, Fontana F, Casa R, Ronga D. Rainfall and temperature impacts on barley Hordeum vulgare L. yield and malting quality in Scotland. Field Crops Res. 2019;241:107559.
58. Leinonen I, Iannetta PP, MacLeod M, Rees RM, Russell W, Watson C, Barnes AP. Regional land use efficiency and nutritional quality of protein production. Glob Food Sec. 2020;26:100386.
59. Scottish Government. Scottish Crop Map 2019. https://www.gov.scot/publications/scottish-crop-map-2019/. Accessed 5 Sep 2023
60. Skerratt S, Atterton J, Mccracken DI, McMorran R, Thomson SG. Rural Scotland in focus-2016. Edinburgh: Scotland Rural College; 2016.
61. Scotland Environment Protection Agency. Sector-specific issues 2022. https://www.sepa.org.uk/regulations/land/agriculture/sector-specific-issues/. Accessed 10 Oct 2023.
62. Garnett P, Doherty B, Heron T. Vulnerability of the United Kingdom's food supply chains exposed by COVID-19. Nature Food. 2020;1(6):315–8.
63. Ross AB, van der Kamp JW, King R, Lê KA, Mejborn H, Seal CJ, Thielecke F. Perspective: a definition for whole-grain food products—recommendations from the healthgrain forum. Adv Nutr. 2017;8(4):525–31.
64. DEFRA. Family Food Datasets. GOV.UK. 2020. https://www.gov.uk/government/statistical-data-sets/family-food-datasets. Accessed 11 Mar 2024.
65. Dogbe W, Revoredo-Giha C. Nutritional implications of trade-offs between fresh and processed potato products in the United Kingdom (UK). Front Nutr. 2021;7:614176.
66. Stewart C, Piernas C, Cook B, Jebb SA. Trends in UK meat consumption: analysis of data from years 1–11 (2008–09 to 2018–19) of the National Diet and Nutrition Survey rolling programme. Lancet Planetary Health. 2021;5(10):e699-708.
67. Alae-Carew C, Green R, Stewart C, Cook B, Dangour AD, Scheelbeek PF. The role of plant-based alternative foods in sustainable and healthy food systems: consumption trends in the UK. Sci Total Environ. 2022;807:151041.
68. González-García S, Esteve-Llorens X, Moreira MT, Feijoo G. Carbon footprint and nutritional quality of different human dietary choices. Sci Total Environ. 2018;644:77–94.
69. Perignon M, Vieux F, Soler LG, Masset G, Darmon N. Improving diet sustainability through evolution of food choices: review of epidemiological studies on the environmental impact of diets. Nutr Rev. 2017;75(1):2–17.
70. González N, Marquès M, Nadal M, Domingo JL. Meat consumption: Which are the current global risks? A review of recent (2010–2020) evidence. Food Res Int. 2020;137:109341.
71. Scottish Government. A plan for Scotland; The Government's programme for Scotland 2016–17. https://www.gov.scot/binaries/content/documents/govscot/publications/strategy-plan/2016/09/plan-scotland-scottish-governments-programme-scotland-2016-17/documents/00505210-pdf/00505210-pdf/govscot%3Adocument/00505210.pdf. Accessed 12 Mar 2024.
72. AHDB. Scottish Milk Balance 2021. https://ahdb.org.uk/news/scottish-milk-balance/. Accessed 10 Mar 2023.
73. Beltran-Peña A, Rosa L, D'Odorico P. Global food self-sufficiency in the 21st century under sustainable intensification of agriculture. Environ Res Lett. 2020;15(9):095004.
74. Baer-Nawrocka A, Sadowski A. Food security and food self-sufficiency around the world: a typology of countries. PLoS ONE. 2019;14(3):e0213448.
75. Niu Y, Xie G, Xiao Y, Liu J, Zou H, Qin K, Wang Y, Huang M. The story of grain self-sufficiency: China's food security and food for thought. Food Energy Sec. 2022;11(1):e344.
76. DEFRA. United Kingdom Food Security Report 2021: Theme 2: UK Food Supply Sources. https://www.gov.uk/government/statistics/united-kingdom-food-security-report-2021/united-kingdom-food-security-report-2021-theme-2-uk-food-supply-sources#united-kingdom-food-security-report-2021-theme2-indicator-2-1-6. Accessed 11 March 2024
77. Reay DS, Warnatzsch EA, Craig E, Dawson L, George S, Norman R, Ritchie P. From farm to fork: growing a Scottish food system that doesn't cost the planet. Front Sustain Food Syst. 2020;22(4):72.
78. Scottish Government. Climate Ready Scotland: climate change adaptation programme 2019–2024. 2019. https://www.gov.scot/publications/climate-ready-scotland-second-scottish-climate-change-adaptation-programme-2019-2024/pages/10/. Accessed 12 Mar 2019.
79. SRUC. Impact of climate change in Scotland on crop pests, weeds and disease. Perth: The Scottish Agricultural College; 2007.
80. Barling D, Sharpe R, Lang T. Rethinking Britain's food security A report prepared for The Soil Association. Bristol: City University London; 2008.
81. Vepsäläinen H, Nevalainen J, Kinnunen S, Itkonen ST, Meinilä J, Männistö S, Uusitalo L, Fogelholm M, Erkkola M. Do we eat what we buy? Relative validity of grocery purchase data as an indicator of food consumption in the LoCard study. Br J Nutr. 2022;128(9):1780–8.

Publisher's Note

Shashika D. Rathnayaka is a research fellow and applied economist at the Rowett Institute, University of Aberdeen, UK. She holds a Ph.D. from Griffith University, Australia. Before the University of Aberdeen, she worked as a Senior Lecturer in Agricultural Economics at the Uva Wellassa University of Sri Lanka and a Teaching Fellow at Griffith Business School, Griffith University, Australia. Her research interests include Consumer Demand Analysis, Food and Agricultural Economics, and Econometric Modelling.

Cesar Revoredo-Giha is a professor, senior economist and head of the Food Marketing Research Team in the Rural Economy, Environment and Society Department at Scotland's Rural College (SRUC), based at the King's Buildings Campus in Edinburgh. He received a PhD from the University of California, Davis in 2001 and subsequently worked at the University of Georgia, The University of Cambridge before moving to SRUC (then Scottish Agricultural College) in 2005. His areas of specialisation are industrial organisation of food markets, international trade, and econometrics. His main areas of interest are food economics and the operation and performance of agri-food supply chains (domestic and international).

Baukje de Roos is a professor at the Rowett Institute, University of Aberdeen, UK. She is an internationally recognised nutrition scientist having > 25 years of experience in the design and delivery of dietary intervention studies. Her current Scottish Government-funded work focuses on the mapping of fish, crop, dairy and meat supply chains, and modelling transitions to more sustainable production and consumption patterns; exploratory modelling of relationships between 'healthiness', 'carbon footprint', 'level of processing' and 'cost' of UK diets; and barriers and facilitators to adopt effective food swaps to make an individual's diet more healthy and environmentally sustainable in real-time. Her expertise in the area of diet and health has formed the basis of contracts and consultancies with large food companies, food levy boards, the food and drink support sector, and national UK television.