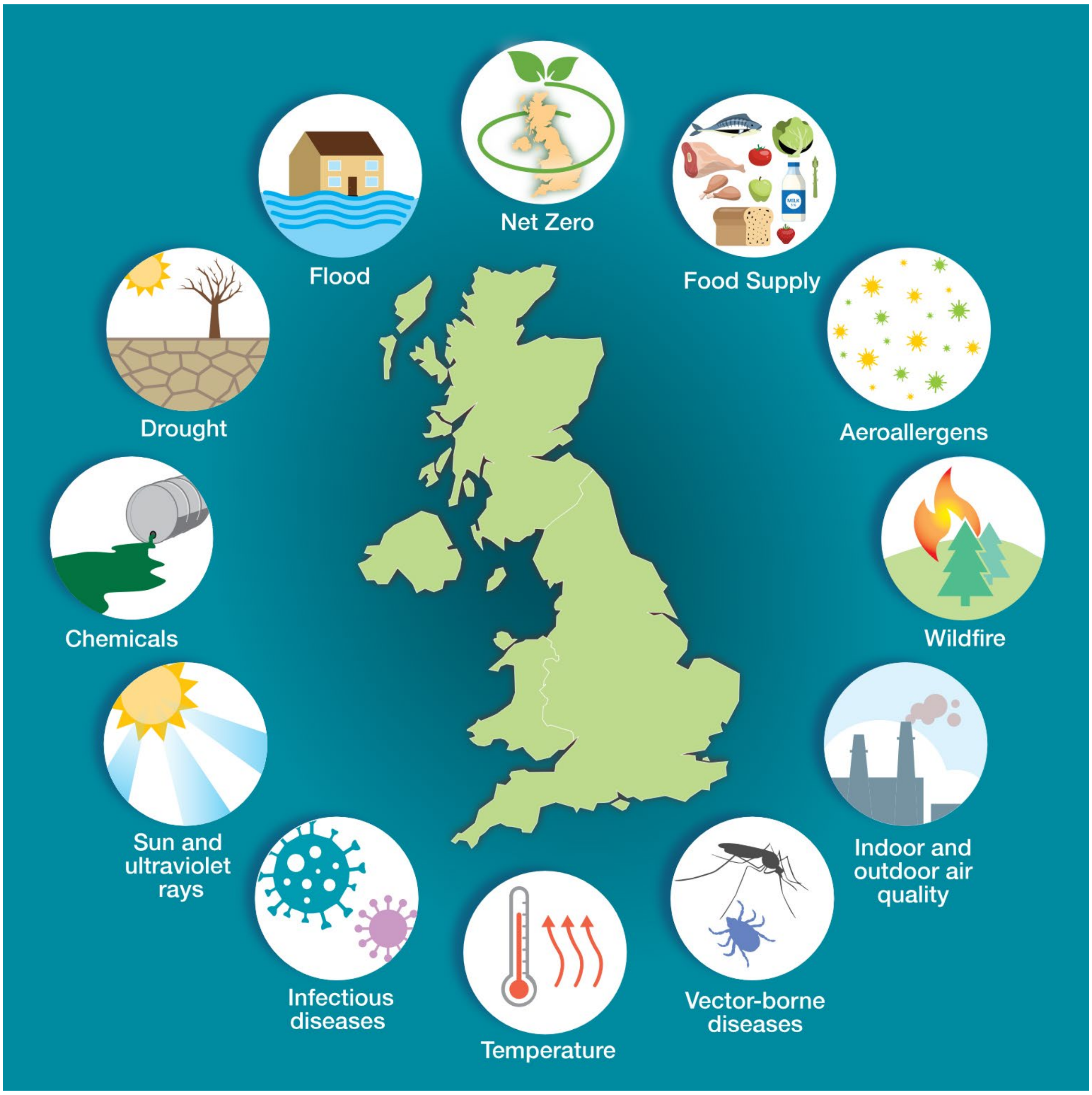
Health Effects of Climate Change (HECC) in the UK: 2023 report

Chapter 9. Climate change and food supply



Summary

Climate change has the potential to disrupt food supply systems with consequent risks to public health. Chapter 9 focuses on the impact that climate change may have on future food supply in the UK and sequentially on health. It presents new empirical analyses and synthesis of existing literature, including an analysis of UK food supply data from 1986 to 2019, an assessment of the extent to which foods are sourced from climate-vulnerable countries, and quantification of the vulnerability of UK food supply to future climate shocks up to 2030 and 2050. The authors offer insight into the role that climate-related disruptions to the UK food supply system might have on our dietary recommendations. The chapter was led by expert academics from the London School of Hygiene and Tropical Medicine, with contributions from the Department for Health and Social Care Office for Health Improvement and Disparities (OHID). This is the first time that a chapter in the 'Health Effects of Climate Change in the UK' report has focused on the vulnerability of the UK's food supply to climate change.

There are potential risks to health in the UK from disruption to the supply of foods required for a healthy diet. In general, the UK's food supply appears relatively climate-stable despite a low level of self-sufficiency, particularly in relation to plant-based foods. However, dependence on climate-vulnerable food-producing countries is projected to increase in the future as more food is sourced from abroad resulting in potential shortfalls.

Nearly half of the UK's food is imported from overseas, with greater importation rates of some food groups such as fruit and vegetables (78%). The UK reliance on imported food has increased, with more cereals, dairy, fruit, meat, starchy roots, sugar and vegetables being imported in 2019 compared to 1986. Unless domestic production is increased, the UK's dependence on imported food is expected to continue to increase, particularly for some plant-based foods. In the event of limited supplies of healthy foods, there is a risk that that saturated fat, sugars and salt could make up a greater proportion of diets, adversely impacting the proportion of the UK population meeting the government dietary recommendations.

Climate change affects crop and livestock production through extreme weather events, reduced availability of ground and surface water, changes in soil quality and exposure to contaminants. In the short- and medium-term, there may be positive impacts on UK food production, with warmer and drier conditions increasing the variety of food products that can be grown in the UK, benefiting crop yields, extending the growing season and reducing costs of housing livestock during warmer winters. However, without the introduction of sufficient adaptation measures to climate change, increasing temperatures are expected to reduce net crop yields in the longer term.

The authors use published studies to consider how climate change may affect yields of different food groups. Positive yield changes are projected for nuts and seeds, but there are declines for vegetables, starchy roots and legumes in some regions. The authors combined the projected yield changes with projected supply data for food groups to meet the UK government dietary

requirements and found that by 2050, 52% of legumes and 47% of fruit would be imported from climate-vulnerable countries. Supply of vegetables, fruit and legumes is projected to fall short of what would be needed to meet UK dietary recommendations.

The chapter reveals 2 key public health insights. Firstly, the UK is already reliant on imports for a range of foods that align with a healthy diet, and the proportion of our foods that come from climate-vulnerable countries is increasing. As the climate warms and impacts are felt, this is likely to mean that food imports and prices will be more volatile. This may further constrain consumption of healthy foods and prevent people from meeting dietary recommendations. Secondly, many healthy foods are associated with lower greenhouse gas emissions. For example, red meat typically generates more greenhouse gas emissions than many plant-based foods, so there are substantial potential co-benefits to health from switching to a healthier diet. Supply of both home-grown and imported fruit, vegetables and legumes will need to increase to meet the UK's dietary and health requirements, but there are potential risks arising from climate-related reductions in yields elsewhere.

This chapter highlights several research gaps and priorities including the need to:

- quantify the potential health and environmental effects of increasing the domestic production of fruits, vegetables and legumes alongside sustainable imports, including scenarios for cost reductions for starting and continuing fruit, vegetable and legume production for farmers
- map resilient production systems and assess the feasibility of relying on climate-resilient trade partnerships
- increase understanding of externalities (such as high water use in water-scarce settings) occurring in trade partner countries related to the production of foods meant for the UK market, which will enable informed decision-making in the UK around procurement of foods that enable healthy diets and reduce adverse effects of climate and environmental change on health
- determine the impact of past food system shocks, such as floods, droughts and pests on yields and production, and broaden climate and yield models to include non-cereal food groups to strengthen projections of future food security
- monitor climate resilience of food system interventions to assess potential co-benefits and trade-offs of any resilience gains for human health and environmental sustainability
- investigate the impact on health of increased supply and consumption of novel plant-based foods (such as vegan meat alternatives or plant-based milks)

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Chapter 9. Climate change and food supply

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1. Background: climate change, food and global health

A healthy diet is essential for human health: when considered together, the health risks from obesity, poor diet in adulthood and undernutrition among mothers and children, overshadows other causes of ill health (1), with disease outcomes including cardiovascular disease, type II diabetes, cancer and micronutrient deficiencies (2). In 2021, 26% of all adult deaths globally were related to poor diet (3).

The processes and actors that combine to produce and deliver food to where it is needed is referred to as a 'food system'. These systems can be local, national or international, but many researchers also consider there to be a single global food system given the high levels of international trade in food commodities and the domination of the agri-food industry by multinational companies involved in seed production, manufacturing and retail (4). The current global food system has developed in response to a rapidly growing global population and through technological innovation has been able to reduce levels of undernutrition. However, such innovation has been possible partly through a move towards fewer large food manufacturers and retailers with shareholders looking for greater profit for reduced costs. This has come at the price of an increasing inequalities, as well as reliance on fewer staple crops (rice, wheat and maize) (5) along with a move towards increasingly homogenised diets (due to greater exposure to international cultures) which are higher in calories, saturated fat, salt and sugars (3, 6). These developments have contributed to a global epidemic of obesity, which is burgeoning even in low- and middle-income countries, while undernutrition persists in many populations (7).

Climate change poses an additional challenge for the global food system to handle. Risks to food supplies are one of the most frequently listed human health impacts of climate change, with the Intergovernmental Panel on Climate Change (IPCC) reporting high confidence that there will be increasing effects on global food security in the future (8). The Lancet recently declared a global syndemic of undernutrition, obesity and climate change which would be the greatest challenge for humanity and the planet in the 21st century (9). A world of unchecked climate change is one in which undernutrition is on the rise in low- and middle-income countries due to crop failures and yield declines. Meanwhile, obesity may continue to rise in both low- and high-income populations due to increasing prices of fresh fruits and vegetables, which can lead to increased reliance on cheaper and more calorie-dense foods (10).

The scale of the problem is clear at the global level. However, specific effects on health in high-income countries can be particularly difficult to model and quantify due to the highly complex nature of their national food systems. Supply chains are often global and adaptable, with produce coming from different parts of the world at different times of the year, so as to provide a continuous year-round supply of the same foods. Wealthier countries are also in a better position to absorb global food price volatility, which may result in an increased cost of living when prices spike, but blunts the immediate impact of crop failures on food security (11). Assessment of the vulnerability of countries such as the UK to current and future food system disruption is therefore a challenge. Despite this, the recent shortages that the UK has experienced due to extreme weather in many supplying countries have made it clear that impacts on food supply require further investigation. With restrictions on the purchase of fresh fruits and vegetables throughout the UK becoming a reality in early 2023, and the 2022 National Food Strategy independent review stating that “the next big shock to our food supply will almost certainly be caused by climate change in the form of extreme weather events and catastrophic harvest failures” (12), this chapter presents a timely first analysis for a ‘Health Effects of Climate Change in the UK (HECC)’ report.

1.1 HECC reports and food

This is the first time that a HECC report has explicitly considered risks to food supply as a result of climate change. The previous report in 2012 focused primarily on climate-related risk to human health from foodborne disease through seasonal variations, food consumption behaviour and the surveillance or control of outbreaks, and did not present any analysis of diets or food supply (13). However, it also outlined the potential increased risk of food price rises and vulnerability of food supply due to the increased probability of extreme weather events. A key concern highlighted in the 2012 HECC report was that climate change-induced food price rises may reduce the nutritional quality of dietary intakes in the UK and lower the nutritional status of some population groups due to foods with higher salt, sugar and saturated fat content frequently being cheaper and less vulnerable to food price changes (13).

Due to the recent instability of the global food system, including supply shocks from conflict and extreme weather events, as well as protectionist policies restricting exports from some countries, the policy focus on UK food security has significantly increased since the publication of the previous HECC report in 2012. There is now a commitment to regular reporting on UK food security as a result of the Agriculture Act, and future HECC reports will be able to track and report on this data in addition to the food supply data presented here.

The chapter is a new addition to the HECC report, and is in several aspects somewhat different from other chapters in the report. The health effects of climate change are indirect and mediated through impacts on food production (of crops and livestock), imports and exports, processing by the food industry, storage and transport and retail, as well as food preparation at household or institutional level, consumption and waste management. The climate change impacts on food supply will likely have an impact on food prices, food security and diet-mediated health. Given the complex supply system and diverse trade flows, the causal attribution of food system mediated health effects of climate change is difficult to quantify. It can be argued, however, that a sufficient and resilient supply of healthier and more sustainable foods is – at a minimum – a prerequisite for enabling access to healthier and more sustainable diets at population level. Thus, this chapter focuses on the climate change impacts on, and risks to, the supply of healthier and more sustainable food in and to the UK but does not cover an assessment of the complex pathways that link reduced supply to diet and health. As more data emerge it is hoped that future HECC reports will be able to analyse these pathways in greater detail.

Since this chapter is a first attempt at modelling future climate risks to nutrition and health in the UK through food supply, it has necessarily taken a limited perspective and does not incorporate all the complexities of the UK food system (see section 2, below). The analysis focuses solely on food supply and does not take into account effects on food availability through changing prices or other mechanisms that may affect actual consumption. Due to the aggregate nature of the available data, impacts on human health cannot be modelled. This chapter can only indicate potential future reductions in availability of healthier and more sustainable foods. This chapter therefore presents an initial analysis of potential future vulnerability of food supply based on forward projections and estimated vulnerabilities to climate change in food-producing areas of the world.

This chapter aims to:

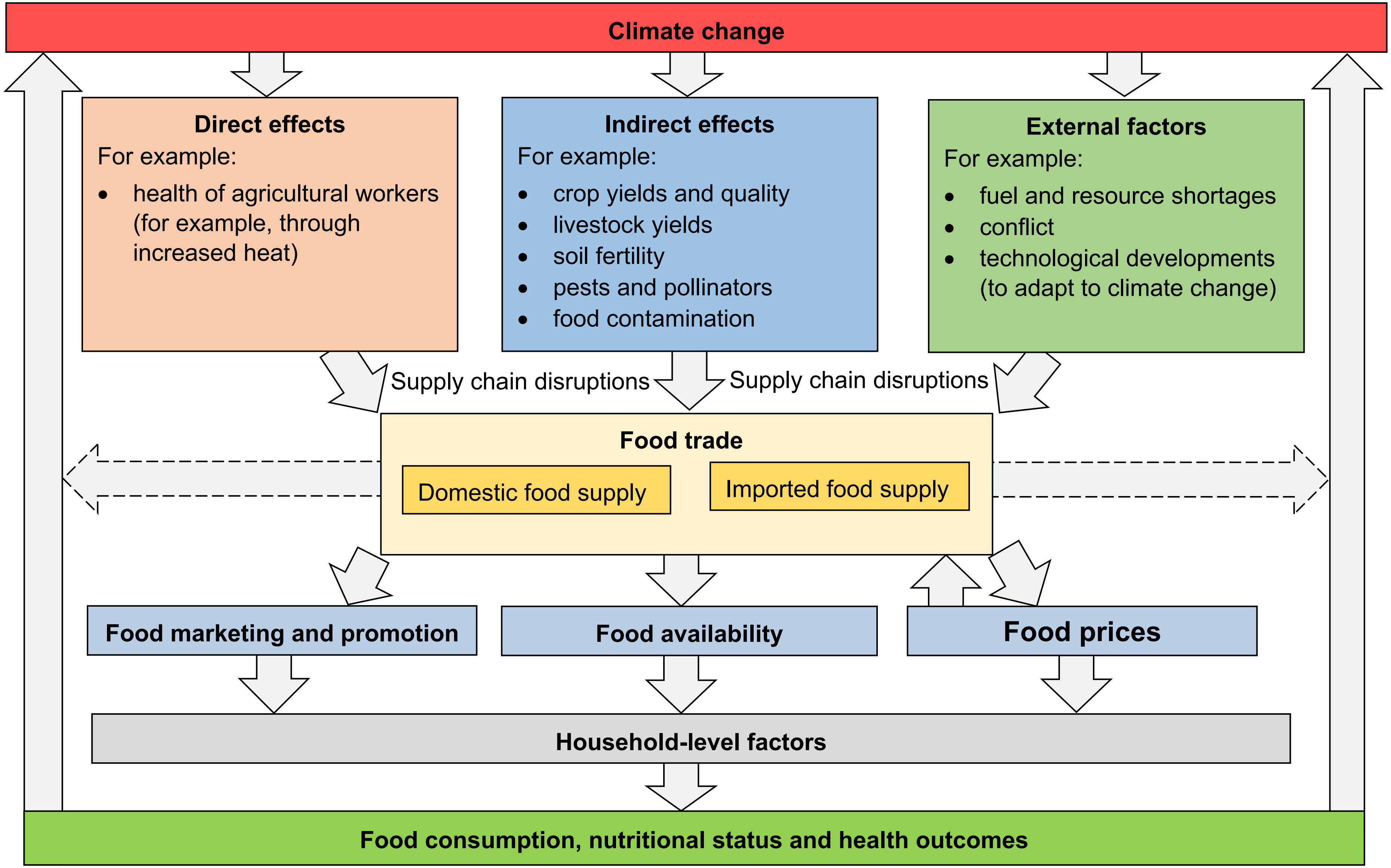
- review the evidence on current and future risks from climate change to UK food supply, both domestically and through food trade
- model projections of UK food supply from domestic and international sources up to 2030 and 2050
- estimate the vulnerability of the UK's future food supply as a whole, and of different food groups, to future climate shocks
- assess the risks for adoption of healthy eating guidelines in the context of future climate change

2. The UK food system

The UK has a highly complex food system, with long supply chains resulting from a diet high in processed foods and a wide variety of available brands (14). Despite this complexity, the system is highly concentrated with just 10 large retailers and 5 main manufacturers supplying the vast majority of food consumed in the home, while 2 major contract caterers and a number of US multinationals dominate out-of-home consumption (14). These large companies have sophisticated methods for ensuring continuity of supply, including diversifying supply chains and streamlining operations. However, the prevailing model is a 'just-in-time' approach (15). This approach, in which little or no food is stockpiled, can leave the food system greatly exposed to even minor disruptions impacting the supply chain.

The main pathways through which climate change could create disruption to the UK food system are illustrated in Figure 1. Direct impacts of climate change on health through the food system will largely affect labour productivity among agricultural workers in areas where temperatures will become too high to work long periods of the year. Indirect impacts will be more widespread and will include changes to crop and livestock productivity, soil fertility, impacts on pests and pollinators and disruptions to supply chains including transport and storage facilities. These indirect climate impacts, along with external factors including resource issues such as energy prices, conflict-related disruptions to supply chains and technological developments (which are included in the figure but considered peripheral to this chapter), could all affect the supply of food into the UK. Supply is divided into domestic and imported food, since climate and other factors are likely to affect these 2 sources of supply differently. For example, in the near-term, heat stress among agricultural workers is unlikely to affect domestic food supply but may begin to affect imported supply. However, the majority of risks identified in Figure 1 will apply to both domestic and imported supply to some degree. Trade is also included as a mediating factor for imported food supply since climate impacts on yields may lead to other countries (and potentially the UK itself) reducing exports to fulfil domestic demand. International supply issues may also result in a rise in prices, which can open up new import markets, as seen in response to the 2022 supply disruptions of oils from Russia and Ukraine.

Figure 1. Simplified framework of climate change impacts on the UK food system



Text version of Figure 1.

Climate change will have direct effects (such as impact on the health of agriculture workers through increased heat); indirect effects (for example impact upon crop yields and quality, livestock yields, soil fertility, pests and pollinations and food contamination); impact on external factors, for example: fuel and resource shortages, conflict and technological developments. This will in turn impact on domestic and imported food supply through supply chain disruptions. This will impact on the food trade by affecting food marketing and promotion, food availability and food prices, which in combination with household-level factors will lead to changes in food consumption, nutritional status and health outcomes.

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There are a number of pathways from food supply to consumption and health, and these are beyond the scope of the analysis in this chapter and so discussed only briefly here. They include effects on food prices, which will have a major impact on consumption particularly among lower income groups. A 2022 report from the Energy Intelligence Unit identified that the combination of rising energy prices (which increase the cost of food production and can also divert agricultural production away from food and towards biofuels) and climate shocks had resulted in major food price rises passed through to UK consumers and that these were forecast to continue (16). As a net importer of food, the UK is more vulnerable than many countries to price shocks on the international market, such as the Ukraine war and COVID-19 (17, 18). The 2008 food price crisis (partly weather-related) saw international food prices of cereals in many cases more than double from 2005 to 2008 as a result of shocks to staple crop yields and subsequent policy responses, including export bans from key producing countries to protect supply (19, 20). Other pathways include marketing and promotion, which may be employed as a strategy to shift demand to more available (but not necessarily healthier) foods in the event of reduced supply of some foods. There will also be a number of household factors that will mediate the relationship between supply and consumption, including income levels, social and cultural preferences and local food environments which will influence access to food. Exploring these factors in detail is beyond the scope of this chapter, but it should be borne in mind that changes to supply can have highly variable effects on diet and health depending on all the pathways noted here.

The following section briefly reviews the evidence on links between climate change and both domestic and imported food supply to the UK, before summarising the links with diet and health.

2.1 State of the current evidence

2.1.1 Domestic and international food supply

Total food supply in the UK, measured in the quantity of food produced domestically and the origin and quantity of food produced elsewhere, varies greatly by type of food and season. Commonly cited statistics state that around 46% of the UK's food is obtained from overseas

(21), but there is some evidence that this is underestimated due to origins of processed foods being inadequately accounted for, and imports of fruit and vegetables may be up to 78% of total supply (22). Furthermore, many processed foods that are produced in one country (with ingredients typically obtained from several countries), are likely exported to another country for processing and packaging, and then imported into the UK for consumption. Some foods are also UK-produced, exported for processing, and then re-imported. Climate shocks can therefore impact the system at any stage of the supply chain and can be experienced domestically or globally (23).

Climate change can affect both crop and livestock production through exposure to extreme temperatures, changes in rainfall patterns, reduced availability of ground and surface water sources and changes in soil quality. It can also affect food supply through changes in distribution of pests and pollinators, differing exposures to food contaminants such as mycotoxins, and livestock health through changing exposure to zoonotic diseases (see Figure 1). The evidence on the UK's exposure to these risks both domestically and through imports is summarised below.

2.1.2 Risks of climate change for domestic food production

Climate change is projected to have a positive effect on food production in the UK in the short- to medium-term, with drier and warmer days and nights benefitting the yields for crops such as wheat (24). Global heating presents the opportunity of growing new crops, including new varieties of fruit that thrive in warmer climates, while preventing reduction in yield losses due to frost (21). It enables longer growing seasons, likely to lead to greater yields for a variety of domestically produced crops. There may also be positive impacts on animal agriculture, with lower winter feed and energy costs from livestock housing resulting from warmer winters (25).

However, towards the end of the century climate change impacts such as heat, floods and drought will have reached a tipping point and – without the introduction of sufficient adaptation measures, such as climate resilient varieties – will result in major reductions in UK crop yields (26). Moreover, some extreme climate events including heatwaves and extreme rainfall may outweigh the projected benefits of gradual climate change over a much shorter timeframe in various locations in the UK, with climate vulnerable crops and livestock products likely to be most affected. The 'Third Climate Change Risk Assessment' (CCRA3), published in 2022, acknowledges the climate change risks to UK domestic food supply (26). While the risk to domestic production is currently scored in the assessment as 'medium', the CCRA3 outlined that it is expected that this risk will increase to 'high' by 2050 if no adequate action on climate change adaptation and mitigation is taken (26).

The impact of extreme weather events and sea-level rise has already affected the UK's domestic food supply in recent years, with UK farmers reporting heat, drought, and flooding (often accompanied by soil erosion and run-off) as major threats to their businesses (27). For example, the heatwave and drought in 2018 led to shortages of domestically produced cereals, carrots, potatoes and livestock fodder (28). Furthermore, under a middle-of-the road emissions scenario, coastal flooding and erosion are projected to reduce the UK land surface classified as ‘high quality farmland’ from an average of 38% during the period 1961 to 1990, to 11% by 2050 (21). This will disproportionately affect clay soils which are highly suitable for the cultivation of many shallow-rooted vegetables.

Several additional risks, including increased occurrence of pests due to altered environmental conditions, may aggravate climate change impacts on UK production in the years to come. These may include changes to the seasonality of helminth parasites, liver fluke and other parasites that can reduce productivity and increase livestock disease (25). Furthermore, the measures taken to reduce the above risks, such as the (increased) application of pesticides may increase exposure to residues including carcinogenic substances, which pose additional public health and ecological concerns (29, 30). Climate changes and extreme weather events may also affect the quantity and quality of pasture available for grazing livestock, and in summer there is likely to be an increased risk of heat stress for animals which will reduce their productivity (25). For crops, there are risks from a warmer climate leading to the UK becoming more habitable to pests that are currently not indigenous, as well as a danger of reducing habitats for beneficial species including pollinators and pest regulators. However, the evidence for much of these relationships is uncertain (31). Finally, whilst CO_2 has a well-documented role in plant photosynthesis, evidence suggests it may also alter plant chemistry which could lead to a substantial decrease in nutritional composition of plants and their harvestable parts. More evidence is needed to quantify the effect this may have on population health, especially for sub-populations around the world that are already facing food insecurity problems, but it is an important issue to consider in the development of future food system strategies (32, 33).

2.1.3 Risk of climate change on food imported to the UK

Mainland Europe is a major import market for UK food. Projections for climate impacts on crop and livestock yields are widely variable depending on the part of Europe concerned, since the continent spans a number of agro-ecological zones.

Previous research has attributed a decline in wheat and barley yields of 2.5% and 3.8% respectively to increased temperatures since 1989, and while this is a small overall reduction it masks larger declines in the Mediterranean region (34). Other crops less sensitive to temperature increases, such as maize and sugar beet, experienced a slight increase in yields over the same time period. Projections to 2050 suggest that carbon dioxide (CO_2) fertilisation may ameliorate yield reductions among autumn-sown crops such as wheat, but bigger reductions are likely in yields of spring-sown crops such as maize due to shortened growth periods and reduced rainfall (35).

Climate shocks have also negatively affected food production in Europe in recent years. Yields of crops that are predominantly grown in the South and East of Europe have tended to experience more disruption: for example, orange production reached its lowest level in nearly a decade following adverse weather conditions in Spain (36). Evidence from the European Commission on the 2022 summer heatwave reported crop failures and an approximate average

5% yield reduction over the 5-year average across many European countries, including the yields of several varieties of fruits and vegetables (36).

While trade partners can usually be found elsewhere in case of major European harvest failures, reduced availability of some fruit and vegetables has been experienced in UK supermarkets on occasions when the failures have been more severe. Shortages of lettuce, courgettes, tomatoes and peppers were experienced in 2017 due to unusually wet weather in Spain (37), and brassica shortages in 2019 due to heat and excessive rainfall in mainland Europe (38). In the early months of 2023, there were gaps in fruit and vegetable shelves and supermarkets rationed vegetable purchases for a number of weeks, due to extreme weather in Southern Europe and North Africa (39). While reports indicate that consumers were mostly able to substitute other varieties of fruit and vegetables or switch supermarkets to obtain what they needed, the likelihood is that such shortages will become more frequent and widespread (40).

Imports from outside Europe tend to comprise a smaller proportion of fresh food supply, but climate risks to yields are often higher. For example, following late harvests, floods and droughts in Mexico, California and Peru in 2017 global supplies of avocados were significantly reduced, leading to wholesale price surges of over 50% in the UK (41). Additionally, the recent flooding and cold temperatures over the winter of 2022 to 2023 in Morocco led to disrupted harvests of some fruits and vegetables, including tomatoes (42). Following Brexit, importers have increasingly used Morocco as a source for some fruits and vegetables, reducing reliance on trade of fresh produce from Europe. Due to the limits in supply, many UK supermarkets introduced purchase restrictions and rising prices with the cost of a kilogram of tomatoes rising by 41% from January 2020 to January 2023 (43). A recent review of global food supply chains and their resilience to environmental shocks found that vulnerability was particularly pronounced in smallholder agricultural systems and rainfed production systems (44). These systems are predominantly found in Africa, Asia and South America, and imports from these regions may therefore be at particular risk in future.

The evidence on climate risks to domestic and imported food indicates that in many cases, risks may combine to reduce the supply available to the UK. For example, the 2023 fruit and vegetable shortages have been attributed to a combination of factors including high domestic energy costs reducing glasshouse production, poor harvests in exporting countries and Brexit affecting the UK’s ability to source from alternative markets (45). The risk of a future ‘perfect storm’ that would substantially affect the ability of UK consumers to purchase enough food is unknown, but climate change is likely to play an increasing part in any events where multiple risks converge in future.

2.1.4 Food supply and nutrition

Data from the Food and Agriculture Organization (FAO), a frequently used resource for national data, indicates that the UK has a more than sufficient supply of calories to feed its population and has done so since records began in 1961 (though the data set has known limitations, including overreporting due to the inclusion of retail waste (46)). Based on energy supply alone, they in fact report an oversupply of calories per person (46). However, this does not necessarily translate to supply of all nutrients in line with UK dietary guidelines.

The self-sufficiency of the UK is highly variable depending on the type of food. Currently, the UK is predominantly self-sufficient in its production of grains, meat, milk and eggs, with average yields broadly remaining stable in recent years (21). However, domestic supply of fruits, vegetables and legumes as well as fish is far lower leading to a heavy reliance on imports for these foods (47).

The available evidence therefore indicates that there may be a particular risk to future supply of some plant-based foods since these foods are most likely to be imported and have also been subject to a number of climate-related supply shocks in recent years. While the UK's dietary guidelines (summarised in the Eatwell Guide as a visual image (48)) recommend that the population consume at least 5 portions (400g) of a variety of fruit and vegetables per day (49), the average UK adult intake is currently 4.1 portions (50). Increasing reliance on imports of fruit and vegetables from climate-vulnerable countries may pose difficulties for raising the proportion of the UK population who meet government dietary recommendations should the climate risks highlighted above become manifest. Similarly, UK adults continue to exceed recommendations to consume less than 10% of calories from saturated fat, less than 5% of calories from free sugars and no more than 6g of salt per day (44). Should climate change negatively impact the availability of fruit and vegetables, there is potential for an increasing proportion of diets to come from foods high in saturated fat, sugar and salt, further worsening diets and associated ill-health (22).

The remainder of this chapter presents new analyses quantifying the vulnerability of the UK's food supply to future climate shocks up to 2030 and 2050 and discusses the implications this may have for the availability of foods consistent with UK dietary recommendations.

3. Data and methods

The analysis in this chapter combines publicly available data sources on UK food production and supply, countries of origin of imported foods, and climate vulnerability of those countries. Combining these data sources enables assessment of:

- current and potential future supply of foods to the UK
- the extent to which foods supplied to the UK are sourced from climate vulnerable countries
- the levels of vulnerability to climate change of current and future food supplies to support Eatwell Guide guidelines

3.1 Data on food production and supply

The FAO's Food Balances and Trade data (51) were used to map trends in the production or supply of different food groups to the UK. The Food Balances database comprises information on food imports, exports, stock, losses, and so on, providing other helpful sub-domains, such as separate quantities for food (for human consumption) and feed. Whilst a helpful resource, the database has a number of limitations as it relies partially, and for some countries, on modelled data and is often criticised for overestimating intakes when supply is used as a proxy for consumption (52). However, data quality of the Food Balances data for the UK is expected to be high as data on domestic production are directly reported by the UK Department for Environment, Food and Rural Affairs (Defra) and import data by the Office for National Statistics (ONS). FAO Food Balances data on domestic production in the UK was compared with the equivalent Defra statistics for the same years and were found to be identical for most food groups, with small discrepancies only for fruit and vegetable production (53).

Complete data sets of the Food Balances database for the UK from 1961 to 2019 for all primary food groups were obtained for the following categories:

- domestic supply (in 1,000 tonnes per year)
- imported supply (in 1,000 tonnes per year)
- food supply quantity (in kg per capita per year)
- total energy supply (in kcal per capita per day)

Food groups that do not provide any significant nutrients to the diet were excluded (tea, coffee, cocoa, herbs and spices).

The obtained FAO data was adjusted for estimated levels of household waste to provide an approximation of the amounts of each food group likely to be consumed within households. Estimations of edible food waste were obtained from the Waste and Resources Action Programme (WRAP) (54). Some aggregation of food groups was needed to match waste estimations onto FAO food groups. Where food groups were combined, averages (or where possible weighted averages) were used as a best estimate of waste for that particular food group aggregate. Starchy root vegetables and legumes were included in the vegetables category, and nuts and seeds were included in the staple foods category as these are not reported separately in the WRAP estimates on waste by food group. Bread and other baked goods were categorised under the staple foods category rather than the bakery category (as defined in the WRAP database) as this was not a separate category in the Food Balances database.

The FAO Trade database on imports (in 1,000 tonnes per year) was used for each food group, and was divided by total domestic supply for the same food group to obtain the proportion of imports by food group. In a small number of cases, the amount of imports were larger than total domestic supply (where the proportion exceeded one), which was likely the result of reporting errors in the data set. In these cases, the imports proportion was capped at one.

3.2 Data on countries of origin of imported foods

Countries of production for each food group supplied to the UK were determined using a previously developed accounting method (55). The methods are described in detail elsewhere, but in summary: the FAO databases on bilateral trade flows and production (51) were used to estimate the trade of foods from the country of production to the country of final consumption (in this case the UK) and excluded 'transit countries' in which food processing, storage or shipping dispatch commonly distort official trade statistics. As the method relies on primary foods only, processed and composite products are first converted into primary food equivalents. Furthermore, it is assumed that domestic supply of a given food is the result of domestic production plus imports minus exports (55). The method uses matrix algebra and assumes that domestic production and imports of a given crop proportionally contribute to domestic consumption and to exports. The calculations resulted in a database of foods (primary crop by tonnes) estimated to have been supplied to the UK on an annual basis and by country of production (including domestic production).

Individual foods were subsequently categorised into 11 food groups: cereals, fruits, vegetables, starchy root vegetables, legumes, nuts and seeds, eggs, dairy, red meat, white meat, and sugar crops. It was deemed beyond scope of this chapter to differentiate between vegetable oils and oil-producing raw crops, and therefore a twelfth category was created for vegetable oils by assuming the same geographical distribution of production countries for oils as for oil-producing crops, including rapeseed, mustard, palm oil, soyabean, sunflower, olive, maize germ, coconut, groundnut, and sesame seed. For analysis of production regions for each food group, countries were aggregated into the following regions defined by the World Health Organization (WHO): Africa, the Americas, the Eastern Mediterranean, Europe, South-East Asia, and the Western Pacific.

3.3 Data on climate change vulnerability

Vulnerability to climate change of a producing country or region was determined using the Notre Dame Global Adaptation Initiative (ND-GAIN) country-index, which measures a country's vulnerability to climate change, as well as its readiness to adapt to climate disruptions (56). In total, 36 indicators contribute to ND-GAIN's measure of vulnerability and 9 indicators contribute to the measure of readiness. The inclusion of adaptive capacity means the ND-GAIN index is considered a comprehensive proxy for overall risk, and the only thorough effort to quantify resilience at a national level (57). The scores are updated annually, with analysis in this chapter relying on the most recent scores (2020). Scores theoretically range between 0 (most climate vulnerable) and 100 (least climate vulnerable), but the 2020 scores range between 26.7 and 75.4. Quintiles were calculated for this range to categorise differing degrees of relative climate vulnerability ranging from 1 (most vulnerable) to 5 (least vulnerable).

Weighted average ND-GAIN scores of food group supplies were calculated, where weights assigned were proportional to a country's contribution to supply. The country-of-origin accounting method (as described above) does not include country of origin data for fish, and hence this food group was excluded from all climate vulnerability analyses. Nonetheless, evidence suggests that fish is one of the food groups most vulnerable to climate change, and therefore existing literature was used to provide a brief description of this below.

Current aquatic systems are already affected by climate change, overfishing and other factors. There is medium to high confidence that climate change will significantly impact production of global ocean-based and aquaculture systems (58). More than 60% of the UK fish supply depends on imports from the European market, followed by North America and Asia. Global estimates of risks to fish, fishers, and fisheries at country level have found that geographical risks are not evenly distributed across countries, and that therefore, the UK should focus on long-term adaptation strategies and change trade policies to safeguard supply of aquatic products (59). No specific data on the countries of origin for fish are available from the database from Kastner and colleagues (55). In addition, the ND-GAIN index does not apply to fish since it is a country-based index that does not take account of the specific climate change impacts on oceans. Therefore, fish could not be included in our quantitative estimates of climate vulnerability, but it is important to stress that meeting the requirements of increased fish consumption for diets to conform to UK recommendations may conflict with requirements to reduce overfishing and aquaculture.

3.4 Statistical analysis

Trends in total supply of each food group in grammes per person per day were projected into the future using ARIMA models. A number of different models were tested on the first half of the available time series (the period 1961 to 1980) to see which provided the most accurate predictions of the second half of the time series (the period 1981 to 2019). The model that best explained the data was a (0,1,0) ARIMA model, corresponding to a random walk model with a single degree of differencing and no autoregressive or moving-average component. This model (which explained the data better than either a simple regression model or a true ARIMA model) was applied to project the trends for all food groups up to the year 2050.

Identical random walk models were used to project the proportion of each food group that would be domestically produced and imported in future based on current trends. This allowed us to determine how trends in UK trade for each food group might further affect food supply and vulnerability to climate change.

Total supply of selected food groups (those where supply would need to substantially increase to meet UK dietary guidelines) from climate vulnerable and climate stable countries in 2030 and 2050 was estimated by combining projected supply with the country-of-origin database and the weighted ND-GAIN scores of 2019. Country of origin data was extracted for countries contributing at least 1% to supply of each food group, and then scaled up to represent 100% of supplies. Future projections of the proportion of each food group produced domestically were used to account for changes in trade patterns between 2019 and 2030 or 2050, but the proportional contributions of each country within the imported food supply were held constant.

Previously published model results were used to determine amounts of each food group that should be consumed by adults on average to meet the proportions shown in the UK's Eatwell Guide (60). This was then converted from amounts to proportions, to estimate supply of each food group that would be required to ensure sufficient availability of these food groups to support adherence to the Eatwell Guide in 2050. Country of origin data was applied to these proportions as described above to produce estimates of the overall vulnerability of supply consistent with Eatwell Guide-compliant diets, as well as food supply in 2019, 2030 and 2050.

Climate impacts on yields are highly variable across geography and crop type (58). Hence, to investigate how future climate change might affect yields in the most climate vulnerable countries, a database on projected climate change impacts on yields was compiled based on existing literature, by global region and food group:

- for cereal crops, the mean value of global projections was calculated (61) and regional estimates from linear regression relationships measuring climate and reported crop data (62)
- for vegetables, fruits, and nuts and seeds, the mean value of synthesised projections for each food group was calculated (63, 64)
- for starchy roots, the mean value of estimated yield changes for potatoes (Europe, (65) or global, (66)) was calculated together with synthesised projections for vegetables (63)
- for legumes, the mean value of synthesised projections was calculated (63) with regional estimates (62)

For vegetable oils and sugar crops, only regional estimates were used (62). As studies researching the impacts of climate change on livestock are limited, potential livestock yield change was estimated based on future feed availability: cereal estimates for ruminants and poultry (62), and regional rangeland projections for ruminants (67).

Climate vulnerable countries were defined as those falling in the top 3 quintiles of ND-GAIN scores (1 to 3), where for selected food groups there was a clear shortfall between supply and UK dietary recommendations (fruit, vegetables and legumes[1]). Imports from these countries were calculated for 2019, 2030 and 2050, as well as for supply compliant with (theoretical) population wide adherence to the Eatwell Guide. Total UK supply in tonnes of each food group for 2019, 2030, 2050 and Eatwell-Guide compliant supply was estimated and adjusted for projected yield changes under climate change in order to assess the potential shortfall of supply (see Table 1).

[1] UK recommendations on fruit and vegetable intake is to consume 5 (80g) portions of a variety of fruit and vegetables. Fruit, vegetables (including legumes), nuts and seeds can count towards the 5-a-day recommendation. Food balance sheet data aggregates fruit, vegetables and legumes separately and for this reason this chapter adopts this approach. FAO data does not allow nuts and seeds to be provided as a separate group and thus are not analysed further in this chapter.

4. Results

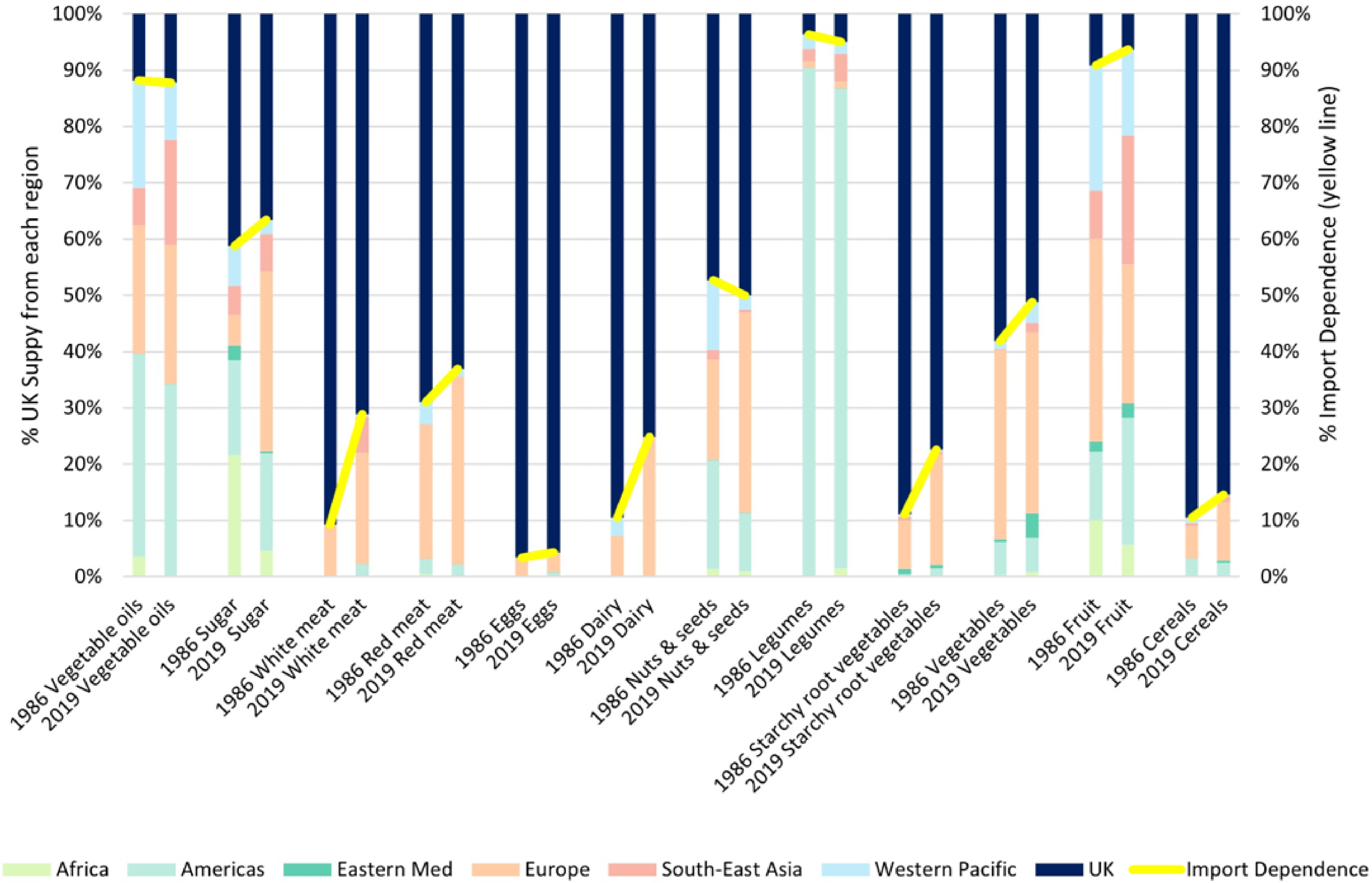
4.1 Origins of current food supply in the UK

The self-sufficiency of the UK varies greatly depending on the food group, but generally, the UK's dependence on food imports appears to have increased in the last 30 years, with more cereals, meat, dairy, sugar, starchy roots, fruit and vegetables being imported in 2019 compared with 1986 (Figure 2). For cereals, the rise in imports is likely to be driven by greater maize imports since domestic wheat production has increased over the last 30 years. Dependence on imports declined somewhat for vegetable oils, nuts and seeds and legumes, but remained at over 50% for all these food groups.

Food groups that were predominantly produced in the UK in 2019 included eggs (95.7%), cereals (85.5%), starchy root vegetables (mostly potatoes, 77.4%), dairy (75.1%) and white meat (71.1%). Food groups that were predominantly imported included legumes, fruit and vegetable oils with 4.9%, 6.3% and 12.2% of supply produced in the UK, respectively. Animal-source foods were more likely to be domestically produced than plant-based food groups, with the exception of cereals due to extensive wheat production in the UK.

Europe was a significant source of imports for most food groups, particularly fruit and vegetables, while significant amounts of fruit, nuts and seeds were also imported from Africa and the Western Pacific. Along with increased imports from Europe, several food groups showed a trend of increasing imports from South-East Asia, while imports from Africa tended to decrease. No data was available on countries of origin for fish (see Box 2).

Figure 2. UK supply by food group and region in 1986 and 2019

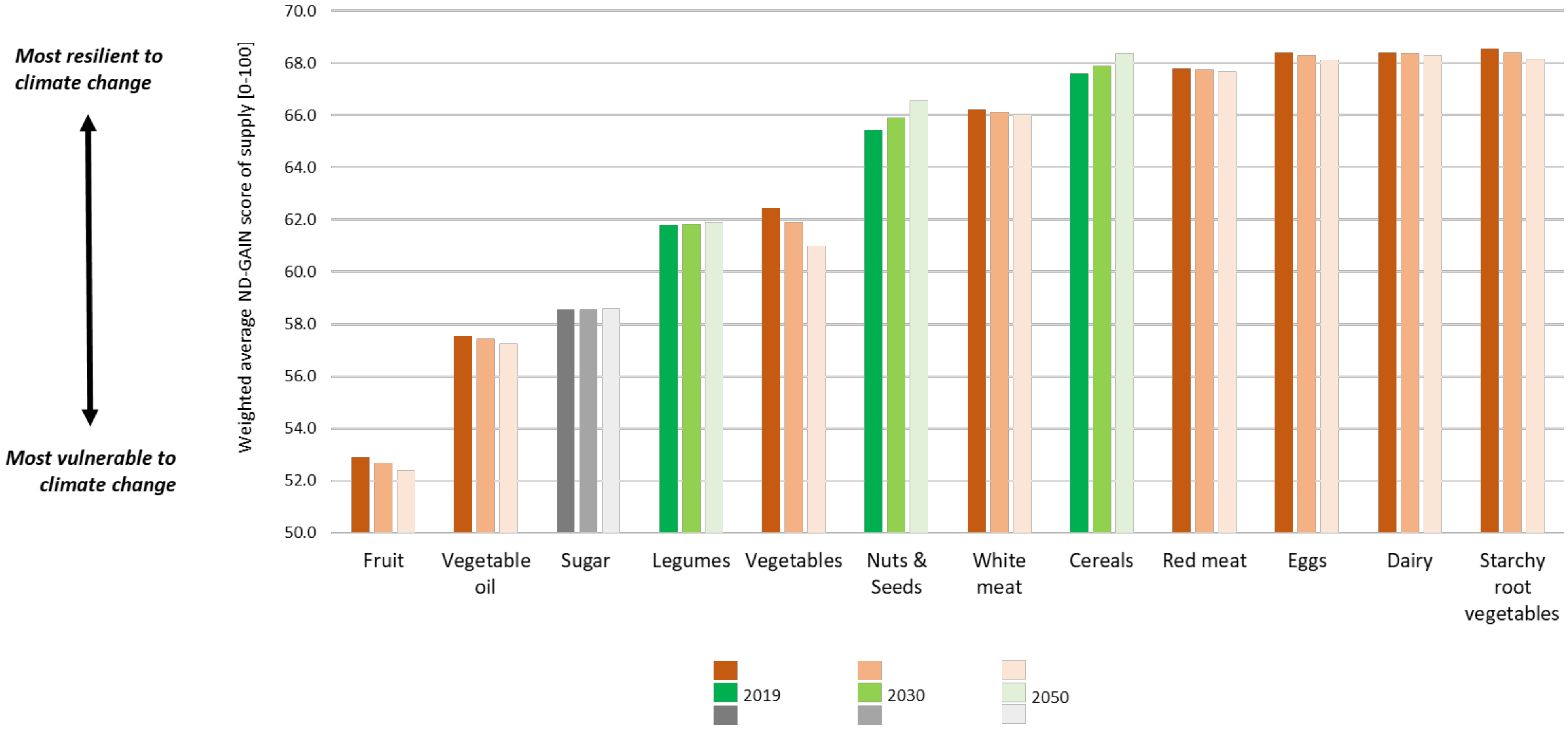


4.2 Climate vulnerability of food supply

Comparing overall climate vulnerability of the UK's supply by food group reveals that plant-based food groups tend to show higher levels of vulnerability to climate change than anima-sourced foods (Figure 3). These include fruit, vegetables and vegetable oils, for which the imported supply shows a substantial degree of climate vulnerability. Vegetable oils are among the more substitutable food groups as it can be relatively easy to switch the oils contained in many processed foods, but substitution of fruits and vegetables tends to be more difficult and the vulnerability of these food groups to climate change is therefore more likely to lead to shortages. The most climate-stable food groups are mostly animal-source foods (predominantly sourced from the less-vulnerable UK and Europe), with cereals and starchy root vegetables also having low levels of vulnerability. White meat is the most climate-vulnerable animal-sourced food, largely due to the proportion of supply obtained from South-East Asia.

Figure 3. Climate change vulnerability (weighted averages of ND-GAIN country index scores [0 to 100]) of food production by food group, in 2019 and projected to 2030 and 2050

Orange bars indicate increasing vulnerability to climate change (decreasing ND-GAIN scores) with time, green bars indicate decreasing vulnerability (increasing ND-GAIN scores), and grey bars indicate no change.



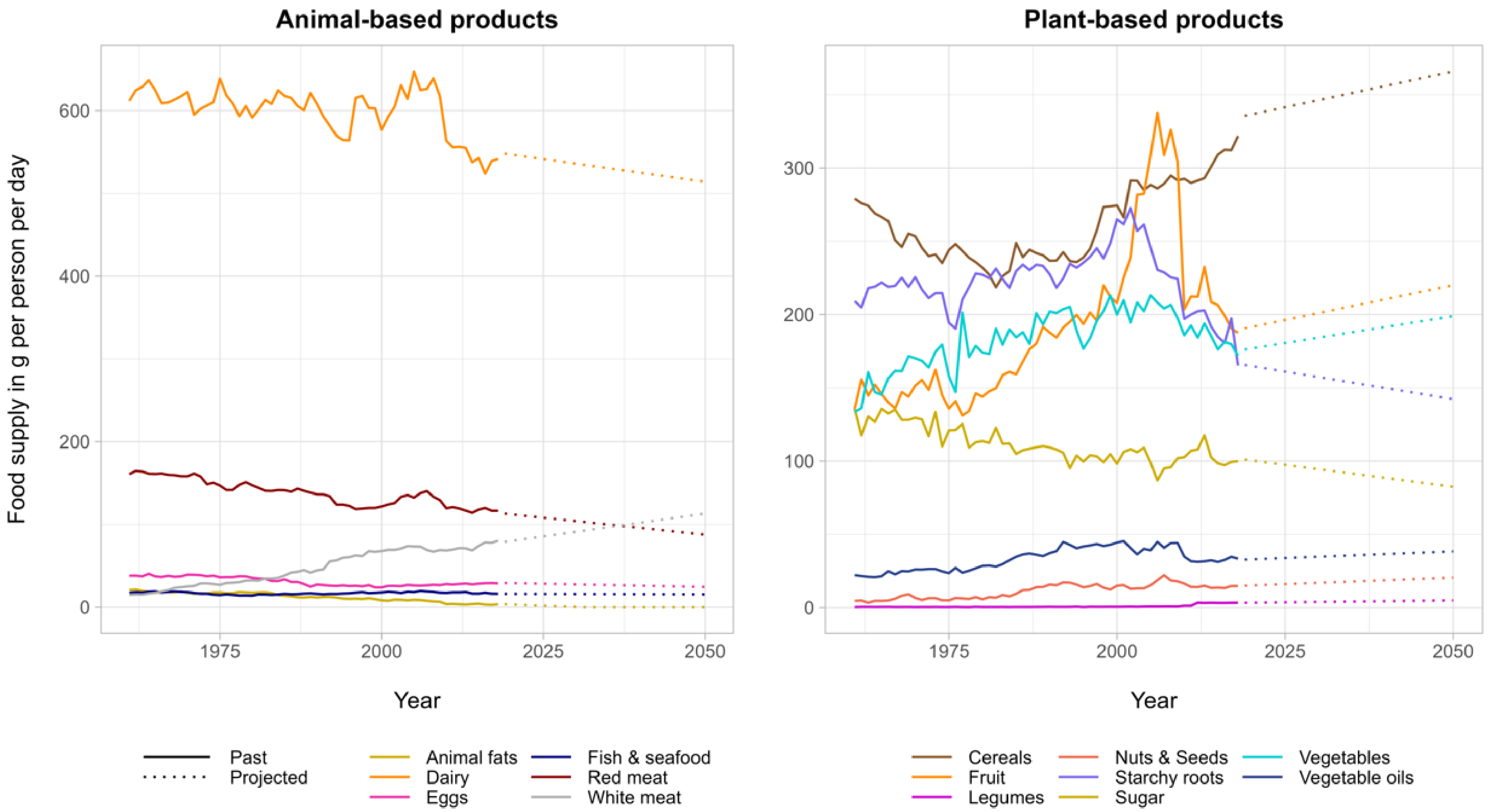
Supply of most food groups is projected to become more climate vulnerable by 2050, most notably for vegetables which show a trend towards increasing imports from outside Europe (Figure 2). Supply of cereals, nuts and seeds is projected to become less vulnerable – mostly the result of increasing domestic production of these food groups (and in the case of cereals increasing imports from Europe rather than other regions of the world – it is possible that changing trends since Brexit will mean that these increased imports from Europe will not materialise, and this is a limitation of the analysis referred to in the discussion section).

4.3 Future projections of food supply to 2050

Our future projections of total UK food supply show that supply of most plant-based foods is likely to increase (Figure 4). By 2050, in the absence of major policy or availability changes, there will be greater supply of fruit and vegetables, more cereals and slightly more legumes. Supply of starchy roots and sugar will decline, while vegetable oils will increase. These trends indicate that the overall supply of food to the UK is generally becoming healthier and more in line with the UK dietary recommendations (with the exception of starchy roots which fit into a segment of the Eatwell Guide that is currently under-consumed), although in practice this may not necessarily translate into adequate consumption of a healthier diet among all population groups.

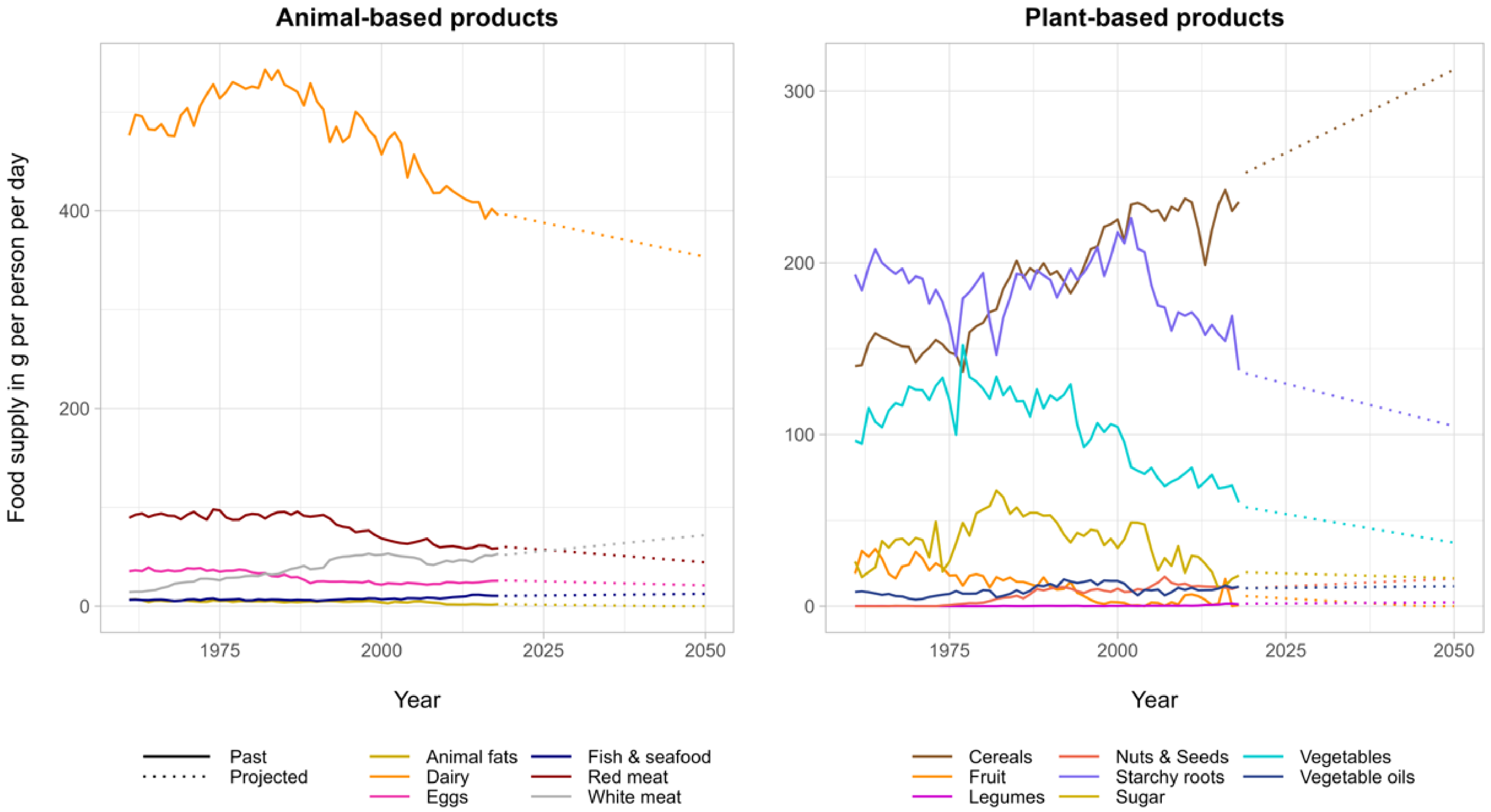
Among animal-source foods, a decline in red meat supply but an increase in white meat supply is projected, with supply of white meat projected to overtake that of red meat around the year 2037. Dairy supply is projected to decline following a trend which began in the early 2000s, while supply of fish and seafood is projected to remain stable. Again, this shows an increased consistency of supply with government recommendations on consumption, with the exception of fish which is being under-consumed in relation to the UK dietary recommendations.

Figure 4. Past and projected total supply of animal-based and plant-based foods in the UK



Despite a projected increase in overall supply, domestically-produced fruit, vegetables and legumes are projected to decline, with vegetable supply reducing to a very low level (around 40g per person per day) by 2050 (Figure 5), suggesting an increased dependence on imports. Domestic supply of most animal-based foods, such as dairy, eggs and animal fats, also shows a projected decline.

Figure 5. Past and projected domestic supply of animal-based and plant-based foods in the UK



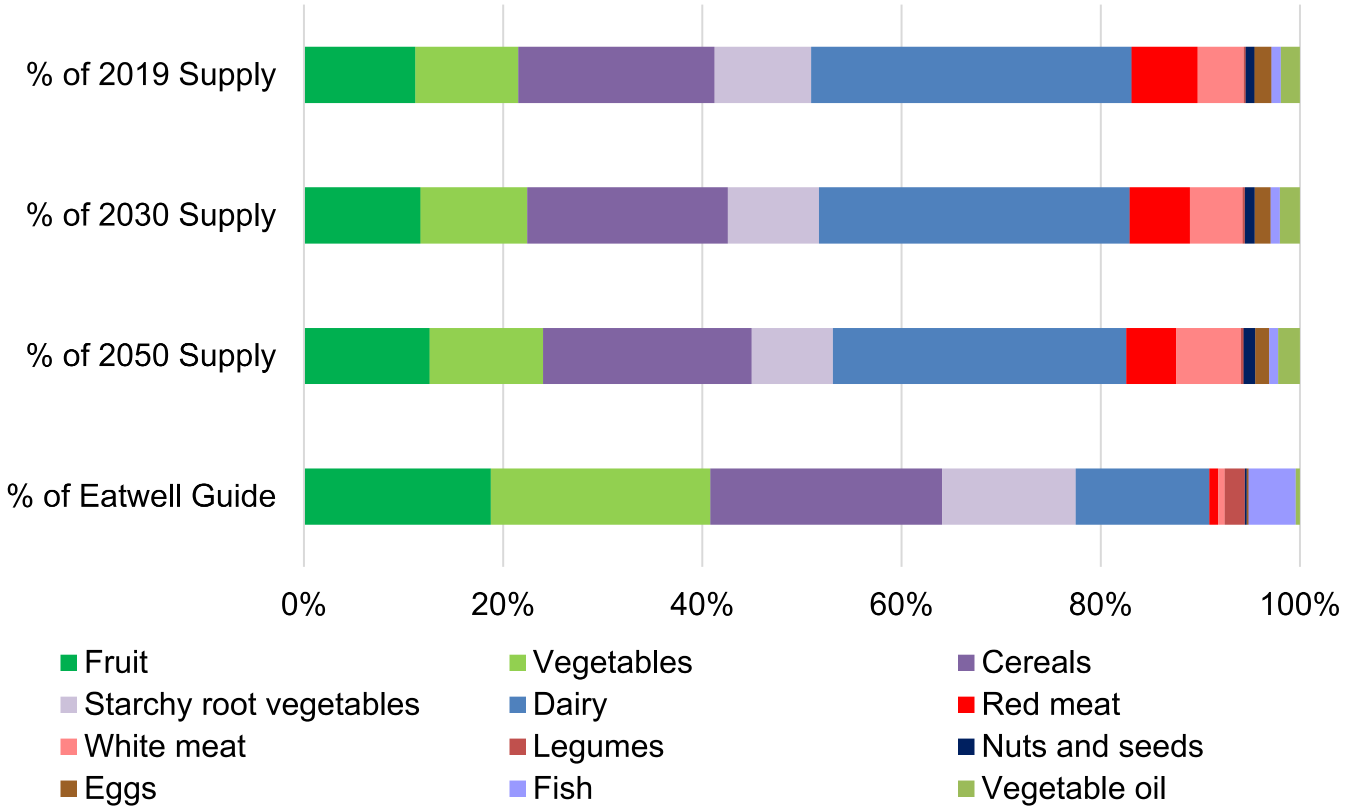
Our projections indicate that in the absence of policy to increase domestic production, the UK's dependence on imported food is likely to increase, more than doubling for some plant-based foods by 2050. This may compound the UK's increasing exposure to climate risks among imported food groups as indicated by the trends in Figure 3. The following section combines the projection data on total and domestic food supply with data on projected vulnerability to estimate the overall climate vulnerability of UK food supply in future.

4.4 Total projected food supply and dietary guidelines

Analyses show that substantial changes to the composition of the UK's food supply would be required for supply to be consistent with the UK dietary recommendations as compared to the predicted changes based on current trends (Figure 6).

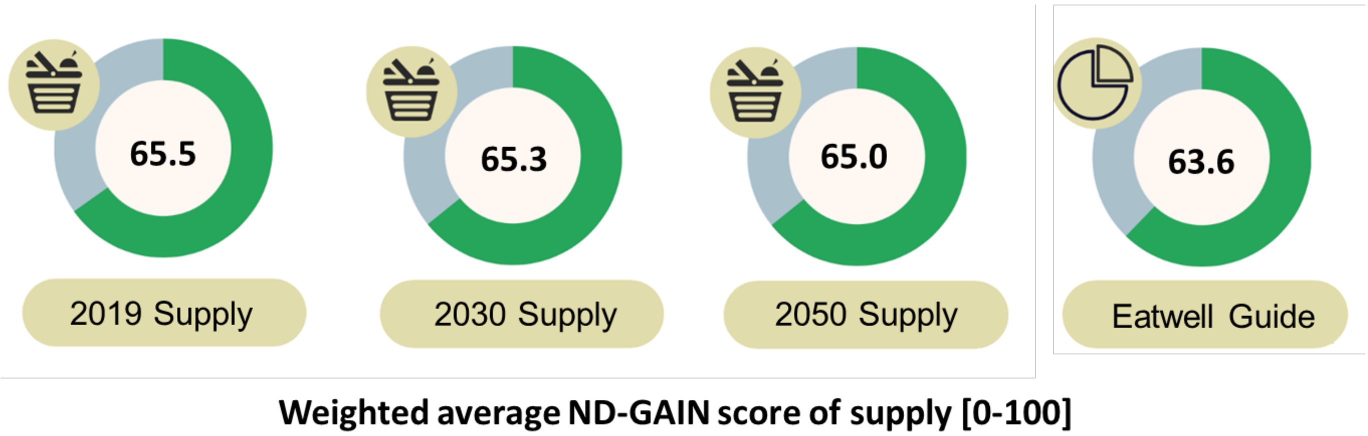
The key food groups that would particularly fall short in supply include fruit and vegetables (where future supply would need to roughly double to ensure sufficient supply), starchy root vegetables, legumes and fish. For other food groups, including meat, dairy and vegetable oils, supply is projected to be sufficient to meet UK dietary recommendations. In fact, most of these food groups are currently oversupplied in comparison to the UK dietary recommendations.

Figure 6. Proportions of different food groups in UK food supply in 2019, compared with projected supply for 2030, 2050, and Eatwell Guide recommendations



Despite these changes to the composition of food supply, there would be only minimal variation in the overall climate vulnerability of the UK's food supply between 2019, 2030, 2050 and an Eatwell Guide-consistent supply (Figure 7). All 3 future scenarios appear relatively climate resilient (any score above 58.8 indicates low vulnerability). However, current supply is most resilient to climate change, with an ND-GAIN score of 65.5. By 2050 supply is projected to become slightly more vulnerable to climate change, with an overall score of 65.0 but supply consistent with the Eatwell Guide would further increase vulnerability to an ND-GAIN score of 63.6, primarily due to the need for increased supply of fruit and vegetables from more vulnerable countries.

Figure 7. Overall weighted climate change vulnerability index (ND-GAIN country index score [0 to 100]) for the UK's food supply in 2019, compared with projected food supply in 2030, 2050, and Eatwell Guide recommendations



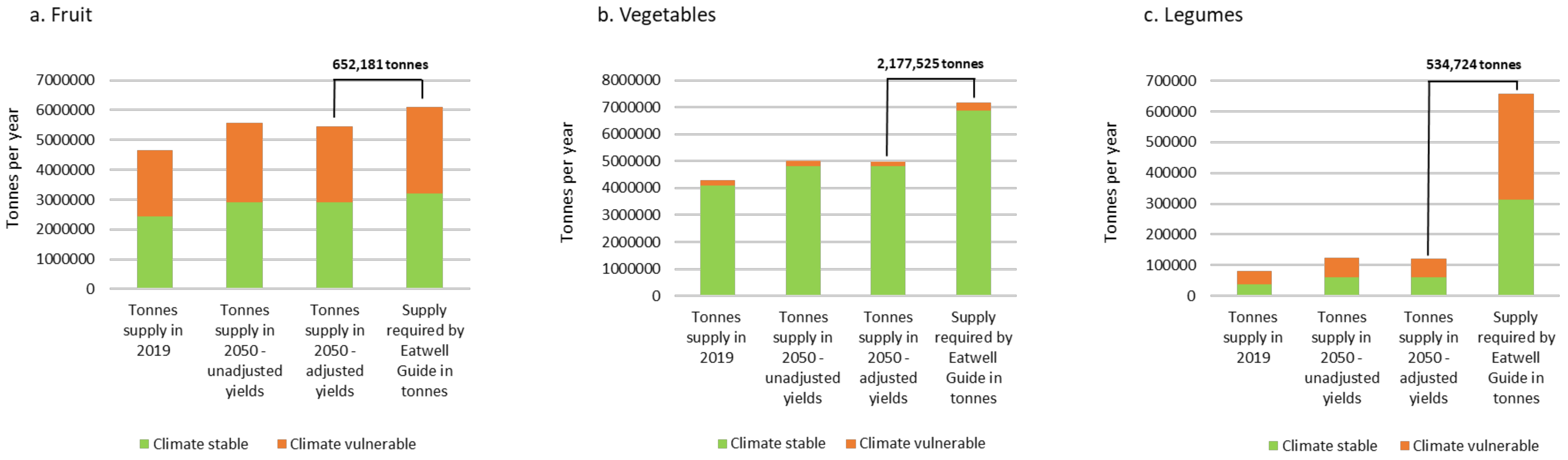
Data compiled from previous studies revealed that the largest yield declines under climate change were predicted for vegetables, with starchy roots and legumes also showing large projected declines in some regions (Table 1). Positive yield changes were projected for nuts and seeds in all regions, but a much more mixed picture was revealed for all other food groups. Although fish is not included due to data limitations, negative climate projections outweighed positive ones for both global wild fish and aquaculture.

Table 1. Global agriculture estimated yields (%) under future climate change impacts
Orange cells represent yield reductions and pink cells represent yield increases; darker shades are greater changes (where a = (62) b = (64), c = (63), d = (65), e = (67), f = (66), g = same values as cereals, h = (61)).

Food group	Africa	Americas	South-East Asia	Europe	Eastern Mediterranean	Western Pacific
Cereals	1.43 [ah]	2.33[ah]	1.68[ah]	-2.7[ah]	4.45[ah]	0.41[ah]
Fruit	-3.70[b]	-3.70[b]	-3.70[b]	-3.70[b]	-3.70[b]	-3.70b
Vegetables	-13.28[c]	-13.28[c]	-13.28[c]	-13.28[c]	-13.28[c]	-13.28[c]
Starchy roots	-11.14[cf]	-11.14[cf]	-11.14[cf]	-2.64[cd]	-11.14[cf]	-11.14[cf]
Legumes	-7.44[ac]	-4.46[ac]	-8.24[ac]	-12.89[ac]	-3.86[ac]	-9.01[ac]
Nuts and seeds	10.10[b]	10.10[b]	10.10[b]	10.10[b]	10.10[b]	10.10[b]
Dairy	-5.79[eg]	1.16[eg]	-1.41[eg]	8.15[eg]	-3.03[eg]	-6.80[eg]
Eggs	1.43[g]	2.33[g]	1.68[g]	-2.70[g]	4.45[g]	0.41[g]
Red meat	-5.79[eg]	1.16[eg]	-1.41[eg]	8.15[eg]	-3.03[eg]	-6.80[eg]
White meat	1.43[g]	2.33[g]	1.68[g]	-2.70[g]	4.45[g]	0.41[g]
Sugar	-3.90[a]	2.10[a]	-0.60[a]	2.70[a]	0.10[a]	-0.10[a]
Vegetable oils	12.45[a]	-0.35[a]	-7.00[a]	-4.15[a]	2.75[a]	-4.47[a]

Combining these projected yield changes with the projected supply data for the food groups where the largest increase would be required to meet UK government recommendations (fruit, vegetables and legumes), results showed that legumes had the largest proportion of supply coming from climate-vulnerable countries (52%), leading to 42,752 tonnes per year being considered vulnerable (Figure 8). This was closely followed by fruit, whereby 47% of supply, equivalent to 2,202,676 tonnes, came from climate-vulnerable countries. When the supply necessary to fulfil the requirements of UK government recommendations from these food groups was estimated, results showed that fruit would have the largest amount of supply coming from climate-vulnerable countries (2,897,104 tonnes) if the countries of origin remained the same as current patterns of supply. By 2050, supply of all 3 food groups falls short of what would be needed to meet UK recommendations, but this is greatest for vegetables whereby the shortfall is around 2.2 million tonnes if the yield changes estimated in Table 1 were to occur.

Figure 8. Projected supply of a) fruit, b) vegetables, and c) legumes from climate stable (green) and climate vulnerable (orange) countries, and projected shortfalls in supply based on yield reductions in vulnerable countries



These results indicate that climate change impacts on yields may contribute to a shortfall in supply of healthier foods in future, although current projections show the impacts on yields in vulnerable countries to be relatively small. These projections do not take into account potential extreme climate events that would have a much greater impact on yields and are therefore highly likely to underestimate the climate-related shortfall.

5. Discussion

5.1 Summary of findings

This is the first chapter of a HECC report to focus on the potential vulnerability of the UK's food supply to climate change. Analyses confirm that the UK is obtaining more than half of its food supply from overseas, and, using a separate countries of origin database, indicates that the proportion of imported food tends to be underestimated in most official data sets. Cereals and animal-sourced foods are by far the most domestically-produced foods, with less than half of most other foods being produced in the UK. The 2 food groups that show the highest proportion of imports in their total supply are fruit and legumes. The prevailing trend is towards a further increase in future imports of these and several other foods. Europe is a major import market but trade with the Americas and South-East Asia is growing. The diversity of countries of origin for many food groups has increased over time, which may confer some resilience in the overall supply, but only in the absence of major climate events occurring in multiple world regions.

Current trends indicate that total supply of food groups such as fruit, vegetables and legumes may increase by 2050, but that domestic supply will continue to reduce. Total supply will therefore be increasingly dependent on imports, some of which are coming from climate-vulnerable countries. Overall vulnerability of the UK's food supply to climate change is currently relatively low, but intermediate for some food groups including fruit and legumes. In future, the proportion of supply of these foods coming from climate-vulnerable countries is also projected to increase unless trade patterns are changed. Given that these foods are already among the most vulnerable to climate change, the potential increased supply of fruit and vegetables indicated by current trends may not become manifest. Although it was not included in the quantitative analyses of climate vulnerability due to lack of data, fish is another food group that is already facing reduced supply due to climate change, and these impacts are projected to increase in future (68).

Consumption of fruit, vegetables and legumes would need to increase substantially to meet the targets of the UK dietary recommendations; yet there is a continuing trend of increasing imports for these food groups while domestic production is static or declining. This may create a supply gap in future, where the UK would not be able to source enough of these foods to meet UK dietary guidelines There is a concern that if plant-based foods become more expensive and/or less available due to climate impacts on their yields, this may lead to increased consumption of meat, dairy and refined cereals due to their more stable supply. This in turn could further reduce the likelihood of UK diets complying with guidelines for health and sustainability.

All these challenges pose a risk to the UK's ability to achieve food supply consistent with the Eatwell Guide. Our estimates of the climate vulnerability of Eatwell Guide-compliant food supply indicate that a healthy and sustainable diet would have increased climate vulnerability compared to current diets unless substantial changes were made to trade patterns and/or domestic production strategies. Based on predictions of yield changes among climate vulnerable countries, this could result in supply shortfalls and/or price rises for foods that are already under-consumed and could ultimately pose risks to UK food security.

5.2 Strengths and limitations

This is the first analysis to explore the vulnerability of the UK's total food supply to climate change based on the origins of food groups. By combining data sets in novel ways, it was possible to identify countries of origin of foods consumed in the UK and their levels of climate vulnerability, as well as exploring potential trade patterns and consequences in the future. However, there are limitations due to data availability and quality and uncertainties in estimating future impacts of climate change on yields of crops, livestock and fish.

FAO Food Balance Sheet data is known to overestimate food availability compared to actual consumption data when using the data as a proxy for consumption. To account for this, food supply data for household-level food waste according to food group were adjusted by taking into account average waste levels. Analysis did not account for any future policies to reduce food waste which might improve household-level food availability resulting from the same amount of food supply. Quality of reporting on food supply varies greatly by country and, while domestic supply data for the UK are generally accurate, some error is expected around data on imported foods. Further standardisation of food supply metrics might reduce this error in the future. Supply data is provided at country level, and hence analysis on within country inequalities in food availability cannot be performed based on FAO data.

Some foods were grouped differently in the FAO data compared to the groupings used in UK dietary recommendations. The FAO data allow for the segregation of food groups into their components (for example, separating vegetable oils into different oil types) and it is therefore possible to assess supply with regard to dietary recommendations for saturated versus unsaturated fats, for example in the future. The UK dietary guidelines also include upper recommendations for red and processed meat separately, as well as recommendations on fibre and oily fish; however, due to the format of the data sets used, these were not included as separate end points in the analyses.

The country-of-origin database, while providing an extension to the FAO Food Balances data in terms of countries of origin of foods, is based on a modelling algorithm and hence could be subject to some uncertainties. Furthermore, it does not contain data for some food groups, particularly fish. Therefore, fish had to be excluded from the majority of analyses and it is important to acknowledge the nutritional importance of this food group. Yield change proxies had to be used for the yield change calculations of starchy vegetables when linking the FAO data with the Eatwell recommendations, as potatoes and starchy vegetables are represented in one group in the Food Balance data but represent different Eatwell groups. This could have introduced some inaccuracies in the analyses around starchy root vegetables.

There were limits to the data used in that the most recent year available is 2019, and therefore the impacts of the COVID-19 pandemic and the conflict in Ukraine on food supply and diets have not been captured. Some effects of Brexit are likely to be evident in the most recent years of data, but post-Brexit trade deals and other changes that might affect diets or food supply will not yet have passed through.

The future projections of food supply are based on recent trends (also up to 2019), and do not take into account potential future disruptions to production or trade, nor the changes that have already occurred to production and trade since 2020, including the impacts of Brexit. As for all forecasting, estimation and projection models, the projections should therefore be taken only as a broad estimate of how UK food supply and production may evolve in the coming years.

The ND-GAIN index offers a unique metric that combines vulnerability and adaptive capacity, but its scores are assigned at country level. This high level of aggregation limits the possibility to look at vulnerability at sub-national level and hence details might be missed: for example, fruit and vegetables are often cultivated on relatively high-quality agricultural land and if the country ND-GAIN score is somewhat low, this may overestimate the climate vulnerability of fruit and vegetable supply from that specific country. ND-GAIN is also not specific to agricultural vulnerability, and some countries may therefore have specific agricultural vulnerabilities that are not adequately captured by the index.

Likewise, the projections presented here of the effects of climate change on crop and livestock yields only provide a broad estimate of the food groups and countries most likely to be affected and least likely to adapt. Yield adjustments were based on a review of published literature, but the evidence base in this area is rapidly evolving. The estimates used also focus on general yield declines in crops and livestock products and do not account for sudden shocks that might result in losses of entire yields in some countries in particular years. It is likely that due to this method of estimating yield changes, the analysis has underestimated the vulnerability of the UK's food supply and future yield losses under climate change. Our estimates should therefore be taken as a first step towards assessing the vulnerability of the UK's food supply to climate change, and not as accurate predictions.

Finally, ensuring that the UK population has access to a sufficient quantity of healthier food is much more complicated than merely ensuring supply at the national level. The greatest impact of climate change on UK food security may be mediated through food prices: detailed data on changing prices are currently not available and there are also other complex elements of food purchasing and consumption behaviour that cannot be captured using aggregate or food diary data. Given that our main focus was on vulnerability of supply, these were beyond the scope of the current analysis. Risks from climate change are likely to interact with other future risks including global conflict, energy prices and other changes to the cost of living, however it was not possible to take this into account during the analysis of future supply.

5.3 Policy review

Food policy in the UK does not easily fall under a single branch of government as it involves farming, the environment, business, trade, education and health. However, historically, Defra has been responsible for most of the policy-making regarding the UK's food production, and this has extended into international supply, with the emergence of concerns about the risk posed by climate change. This chapter therefore focuses on Defra-led policies relating to food supply, summarised in the list below. Policies beyond food supply, addressing the many other aspects of food systems, have historically been shared between various government departments. Given the focus of this chapter we have restricted the national (UK) overview to food supply policies only.

5.3.1 Department for Environment, Food and Rural Affairs (Defra) policies related to food supply

Agriculture and fisheries

- Rural development programme for England – funding scheme to improve environment, increase productivity and grow rural economy
- Agriculture Act (2020)
- Fishing Act (2020)
- agri-tech strategy and catalyst funding – support UK to become world-leader in agricultural technology
- marine conservation zones

Environment

- Environmental Principles and Governance Bill – independent environmental watchdog to hold government to account on environmental ambitions
- 25 Year Environment Plan – government action to improve natural world and regain good health
- Adaptation Sub-Committee – part of Committee on Climate Change
- Climate Change Risk Assessment – 5-year cycle of requirements laid down in Climate Change Act 2008
- National Adaptation Programme – government response to Climate Change Risk Assessment outlines response to the impacts of climate change on domestic and international food production and trade
- review and publish UK Food Security Assessment every 3 years
- Resources and waste strategy

Food security

- Public Sector Security and Resilience Plan – Defra contributes a section on food as one of 13 'Critical National Infrastructure Sectors'
- Food Standards Act (1999) – protect public health in relation to food at any stage in food production and supply chain (FSA Policy)

Government Food Strategy

- objective to "deliver a sustainable, nature positive, affordable food system" and "use the Agriculture Act (2020), Fisheries Act (2020) and Environment Act (2021) as frameworks to incentivise farmers and food producers to adopt more sustainable practices"

Food trade and imports

- Post-Brexit trade agreements

One of the main policies set out in the Agriculture Act of 2020 was the need to publish a UK Food Security Assessment every 3 years, with the first report published in December 2021. According to the UK Food Security Assessment report, the UK food system is currently considered resilient to potential shocks in its supply chain (21). However, the report also stated that the 'just-in-time' food supply chain is reliant on consumer demands remaining stable and that consumer stockpiling behaviours could disrupt the supply of some foods. Additionally, food prices were identified as being volatile in response to shocks, specifically financial crises, disease outbreaks and extreme weather events which could negatively impact production and consumption costs.

Policy responsibility related to food system sustainability and resilience is largely devolved to Northern Ireland, Scotland and Wales. However, food systems in all 4 countries are intrinsically linked, not in the least because decisions on trade and taxations policies are made at UK-level and several hundreds of farms comprise land areas that cross the Welsh-English and Scottish-English borders. Therefore, a large number of policy documents developed with a focus on England are likely to be (partially) relevant for all 4 countries. However, the many socio-economic and geographical differences across the devolved administration add complexity to addressing the health effects of climate change through the food system and show the need for national and sub-national approaches besides UK-wide policies and strategies. The following section outlines influential programmes and strategies from the devolved administrations

5.3.2 Programmes and strategies from the devolved administrations related to food environments

Scotland

- The second Scottish Climate Change Adaptation Programme (SCCAP): outlines Scotland's preparations for the impacts of climate change over the period to 2024, and addresses changes in domestic production, as well as resilience through Scottish international food trade among others
- Good Food Nation (Scotland) Bill 2021 to 2022 passed by the Scottish Government in June 2022 – upgraded to Good Food Nation (Scotland) Act 2022 in July 2022
- Common Agricultural Policy: European programme of funding and support that Scottish farmers and crofters, as well as rural businesses and communities, can access through the Scottish Government
- Food Standards Scotland Strategy 2021 to 2026
- The Food (Scotland) Act 2015 – Established Food Standards Scotland in 2015

Wales

- Vision for the Food and Drink industry: Welsh government's strategy for developing the food and drink manufacturing and processing industry
- Agriculture (Wales) Bill 2022
- Horticulture Development Scheme: competitive capital grants for both existing businesses and those wishing to enter this industry
- Beyond Recycling strategy 2021: sets to reduce food waste by a third by 2030
- Wales Community Food Strategy (CFS) (under development)

Northern Ireland

- Northern Ireland Food Strategy Framework (2021): public consultation document for the currently developed Northern Ireland Food Strategy
- Northern Ireland Agricultural Policy (under development)

In an attempt to address some of the issues identified in the 2021 Food Security Assessment, as well as many other concerns relating to the food system, the first cross-governmental Food Strategy (again led by Defra) was published in 2022 (12). While the geographic scope of the National Food Strategy was England (with the relationship with the devolved administrations extensively considered), the subsequent government Food Strategy is focused on the whole of the UK. There is a strong focus on food security throughout the Food Strategy, but so far limited policy commitments to ensuring this. Key measures are summarised in the section below, and include a commitment to increasing domestic food production particularly in the horticulture and seafood sectors.

5.3.3 Key measures from the Government Food Strategy (12)

Theme 1. Prosperous agriculture and seafood sector to ensure secure food supply (levelling up agenda)

- continued production of healthier, high quality, tasty food and drink domestically – aim to maintain levels of domestic production through productivity gain and new farming schemes
- enable growth in key sectors which include horticulture and seafood – post-Brexit opportunities
- committed £270 million through Farming Innovation Programme and supporting £120 million investment in research across food system (UKRI)
- develop joint vision with industry for agro-food innovation and identify shared priority areas for investment and coordination
- funding and improvement of regulatory frameworks post-Brexit, for example, alternative proteins, gene editing
- launch call for evidence of the use of feed additives to reduce methane emission from livestock

- work with agricultural sector to develop What Works Centre to provide farmers with evidence that supports adoption and on-farm take up of new innovations

Theme 2. Deliver sustainable, nature positive, affordable food system that provides choice and access to high quality products that support healthier and home-grown diets for all

- use Agriculture Act (2020), Fisheries Act (2020) and Environment Act (2021) as frameworks for farmers and food producers to adopt sustainable practices
- publish land use framework in 2023 to ensure meeting net zero and biodiversity targets
- undertake programme of randomised controlled trials to develop a suite of evidence based and value for money interventions to encourage and enable healthier and more sustainable diets
- Food Data Transparency Partnership – consult on implementing mandatory public reporting against a set of health metrics and explore a similar approach to sustainability and animal welfare

The UK food policy landscape is likely to undergo several further changes in the coming years, including implementation of the Environmental Land Management schemes (ELMs) which will replace the current system of subsidies based on food production and replace them with incentives to protect and restore natural environments. There are some questions over whether these schemes will improve food security as they may remove incentives to improve domestic food production, but many details of the schemes are not yet known (69). Dietary changes away from animal-sourced foods will also be necessary to reduce the pressures on the global food system. The current food strategy contains little in the way of diet and nutrition policy, although there is a commitment to a programme of randomised trials to discover which interventions might work best in terms of behaviour change.

5.4 Priorities for research

Given the many aspects of the food system this Chapter was unable to capture using publicly available data, our research priorities mainly focus on ways in which these aspects could be incorporated in future. Data from other sources including food purchase data and more complex models could be used to explore in more detail the complex effects climate change may have on UK food supply and also food security. Our main priorities are outlined below.

5.4.1 Quantify, in detail, the potential health and environmental effects of increasing the domestic production of fruits, vegetables and legumes

In theory, increasing domestic production of fruit, vegetables and legumes (as outlined in the Food Strategy (12)). However, in practice its success will be dependent on possibilities to use or convert land currently used for domestic animal production for horticultural production. Exploring scenarios with reduced costs for UK fruit, vegetable and legume farmers (or grants for those that would like to convert to horticultural farming, such as current offered in Wales), in a time where there are significant concerns on work availability and rising input costs, could shed light on how this would balance production against consumer demand and scenarios of successful increases in domestic production.

UK domestic production of fruit, vegetables and legumes is currently very limited, comprising only 1% of agricultural land. In addition, current UK production focuses on only a few varieties, with the majority of horticulture (70%) consisting of vegetables grown outdoors (largely lettuce, carrots and tomatoes) (70). In 2021, 14% of horticulture was devoted to orchard fruit, and only 2% was devoted to crops grown under glass. Given current diverse tastes in fruit and vegetables, and the need for year-round supply, the UK may benefit from a comprehensive horticulture strategy that would incorporate both outdoor and indoor controlled environments, growing in both rural and urban areas. The evidence generated by scenario analysis may help policy-makers take informed decisions in this area. Scenarios could also explore which areas of land could be freed up for horticulture due to the declining demand for red and processed meat, and other techniques (including vertical farming) that could be used in areas of the UK suitable for grazing but not horticulture.

5.4.2. Assess the feasibility of reliance on climate resilient trade partnerships that promote health and environmental sustainability

Creating resilient supply chains for the UK that are aligned with UK dietary guidelines (49) and enhance environmental sustainability will go beyond increasing domestic production, since it is unrealistic for the UK to be wholly self-sufficient in horticulture across all seasons. It is therefore pivotal that trade agreements factor in population health, sustainability and climate resilience, reduce reliance on single sourcing regions, and shift to exporting partners featuring agroecological production systems wherever possible. Importing companies often have limited information on the resilience of individual farms or production systems with whom they are doing business, and there is no national or global governance in place that would prevent trade deals with highly unsustainable producers from happening. Mapping resilient production systems, assessing the feasibility of relying on such systems for imports and a ‘live’ or frequently updated inventory of resilient production systems could be a useful tool for companies to help them make informed choices.

5.4.3 Map externalities of UK food supply

The increased risk of supply disruptions is not the only disadvantage of trading with highly environmentally unsustainable businesses overseas. Particularly in resource poor settings, unsustainable production systems often compete for resources with smallholder or subsistence farmers. Continuing trade with such businesses could therefore contribute to the challenges smallholder and subsistence farmers face around scarce resources, such as water. Increasing understanding of externalities occurring in trade partner countries related to the production of foods for the UK market will enable informed decision-making in the UK for the procurement of foods that enable health diets and reduce the adverse effects of climate change on health. This exercise should include fish and fish oil products – despite the fact that much less data is available for these food groups – as unsustainable fisheries play an important role in food system sustainability and are often of vital importance to individual livelihoods.

5.4.4 Trace impact of past food system shocks on land use change, food production and supply chains, to gauge impacts

The study of the UK food system's resilience to climate change is in its infancy, partly due to the large number of food system actors involved and the complexity of their relationships. Much of the UK runs on a 'just in time' basis in terms of food supply, and the COVID-19 pandemic showed that these supply chains can become disrupted by shocks, including pests, droughts and floods, but there is limited evidence on how supply chains adapt and how quickly. Future research should further assess the impact of different types of shocks on land use, food production, as well as detailed analysis across supply chains using supermarket or large longitudinal panel data, which will include information on purchase patterns and price fluctuations, to determine whether their primary impact is on price or whether there are more widespread disruptions to supply.

5.4.5 Broaden climate and yield models to include non-cereal food groups

Further evidence on future yield projections for different food groups and regions is needed, considering other climate factors that may affect food production and safety, such as potential losses due to increased pests and diseases, pesticide run-offs and others. Current projections are widely variable depending on the models used, and in future initiatives such as the Agricultural Model Intercomparison and Improvement Project (AgMIP) could improve our ability to determine future food security by including nutritionally important crops such as fruits and vegetables (including legumes) as well as the major cereals for which more detailed data is already available.

5.4.6 Incorporate assessments of climate resilience into food system interventions

The Economic and Social Research Council (ESRC) is funding a series of food system trials in 2023 in response to the UK Food Strategy, to investigate how behaviour change can be achieved in various population groups. These trials will measure outcomes for health and sustainability, but there is also an opportunity for them to measure changes in climate resilience, for example, by recording changes in the origins of foods consumed. Such measurements could also be incorporated into other planned trials in future to help ensure congruence between the aims of benefiting health, sustainability and climate resilience.

5.4.7 Investigate the impact of an increased supply and consumption of novel plant-based foods on health, environmental sustainability and climate change resilience

Novel plant-based foods, such as plant-based meat, fish and dairy alternatives, are commonly regarded as a more sustainable alternative to animal sourced foods. Despite the fact that their consumption has been increasing exponentially over the past decades, little is known about their (longer term) health implications, though a scoping review by Scientific Advisory Committee on Nutrition and a systematic review (71) are expected in the summer of 2023. Furthermore, the climate resilience of production of novel plant-based foods remains unclear: food groups that often form their main ingredients, such as fruit, vegetable, legume and vegetable oil crops are predominantly sourced from outside of the UK and are potentially subject to high climate vulnerability. Given their growing market demand and supply in the UK and their increasing significance in UK diets, more investigations into the health, sustainability and resilience aspects of novel plant-based foods will be vital.

5.4.8 Make greater use of complex systems analysis methods to capture more aspects of the food system

The recent report of the Global Food Security (GFS) research programme on resilience of the UK food system noted that resilience should encompass domestic production, trade and individual diets in order to tackle food security systemically (72). To include all 3 aspects in a single piece of research is challenging as the many limitations of the present analysis have shown, but developments in complex systems analysis could make this challenge increasingly achievable and enable consideration of co-benefits and trade-offs between health, sustainability and resilience of the food system. Better alignment of data systems to capture relevant information would be key and would enable more in-depth full system analysis in the future.

5.5 Implications for public health practice and procurement

5.5.1 Promote adherence to UK dietary recommendations

Promoting adherence to dietary recommendations will be important to improve resilience to climate change. Whilst not promoted in isolation of other measures, successful promotion of adherence to dietary guidelines combined with a commitment to increasing domestic production of fruits and vegetables (including legumes) could be pivotal for food system transformations. Furthermore, better adherence to the UK dietary recommendations has been associated with reduced mortality, reduced health inequalities, as well as lower dietary greenhouse gas emissions (22). UK dietary recommendations, which are summarised visually in the Eatwell Guide, are currently not being followed by the vast majority of the population in the UK, and there is widespread support among public health bodies to promote diets that are sustainable as well as healthy. Furthermore, the Climate Change Committee gives some additional guidance on reducing dietary footprints, whilst observing healthy dietary guidelines and could be promoted alongside the UK dietary recommendations. These should continue to be a priority for cross-government action.

5.5.2 Ensure adoption of sustainable government food procurement standards

There are opportunities to improve access to healthier, more sustainable food and drink. Updated nutrition standards included with Government Buying Standards for Food and Catering Services (GBSF) have been published. A consultation to update the GBSF further to deliver positive health, animal welfare, environmental and socio-economic impacts has recently ended. GBSF aims to help the population meet dietary recommendations and to support the environmental sustainability of publicly procured food. Widespread adoption of these new standards and reporting of compliance would help reduce the risk of dietary-related diseases and improve climate resilience of the food supply.

5.5.3 Diversify buying power to resilient production systems for different foods or products

Diversifying buying power for public procurement towards multiple sources and more resilient production systems where foods cannot be obtained from the UK would further increase climate resilience of the publicly procured food supply.

5.6 Conclusions

There are potential risks to nutrition-related health in the UK through disruptions to the supply of foods consistent with a healthier diet. In general, the UK's food supply appears relatively climate-stable despite a low level of self-sufficiency, particularly in relation to plant-based foods. However, dependence on climate-vulnerable food-producing countries is projected to increase in the future as more food is sourced from abroad. This could lead to potential shortfalls in supply and difficulties with ensuring a stable supply of foods that are consistent with a healthier diet, including fruits, vegetables and legumes. With the Government Food Strategy recently published, this is a crucial time for promoting more UK production where appropriate, and consider climate resilience and externalities related to food imports in all trade activities.

Acronyms and abbreviations

Abbreviation	Meaning
Defra	Department for Environment, Food and Rural Affairs
DHSC	Department of Health and Social Care
HECC	Health Effects of Climate Change in the UK report
CCRA	Climate Change Risk Assessment
FAO	Food and Agriculture Organization
FSA	Food Standards Agency
GBSF	Government Buying Standards for Food and Catering Services
ND-GAIN	Notre Dame Global Adaptation Initiative
WRAP	Waste and Resources Action Programme

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