FSA Science Council Working Group 6 Final Report Food Safety in the Net Zero Era

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A Report by Working Group 6 of the FSA Science Council to investigate the potential food safety implications arising from changes in primary food production.

This report was prepared and endorsed by the Science Council Working Group on Food Safety and Net Zero Carbon (Working Group 6) April 2023.

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Interests Declaration:

In line with FSA Guidance on managing interests of its scientific advisers, the interests of members of the Working Group were assessed to identify any potential conflicts with the work of this Group. No such interests were identified.

1. Foreword

We face a future climate that will be quite different and more volatile than the one we have known. Avoiding the catastrophic consequences of runaway climate change requires wholesale change across all of society, including to our food system. The UK's net zero target is an important ambition to reduce our carbon emissions to net zero carbon. To achieve this whilst continuing to feed a growing population requires the most significant change to industry since the industrial revolution, and food production is a significant part of that. Reducing net greenhouse gas emissions across the agri-food sector demands huge shifts in focus and funding towards innovative approaches and new technologies to build a more sustainable food system.

As we evolve this new, more sustainable food system, it is critical that we do so in a way that continues to maintain the highest standards of food safety and authenticity, as well as protecting values, such as animal welfare, that we know consumers hold dear.

This was why the Food Standards Agency (FSA) asked the Science Council to take a broad look at how potential changes to food production aimed at moving towards net zero carbon may also impact on food and animal feed safety.

In the following pages you will read their findings, which set out some clear overarching messages about food safety in a changing, more sustainable food production system. It highlights the importance of interactions between different regulatory and government bodies who all need to understand and react to those changes. Finally, it identifies some key technologies and approaches where extra attention may be needed to ensure that the potential sustainability gains do not come at the cost of reduced food safety.

I am very grateful to the Science Council for the hard work that went into this report, which expands the FSA’s understanding of this rapidly evolving area and delves deeper to understand how we need to change our approach to ensure food safety and consumer interests continue to be protected through this intense period of change.

Prof Robin May,

Chief Scientific Advisor to the Food Standards Agency.

2. Executive Summary

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These are challenging, but exciting times for the agri-food sector food as it embraces the opportunity to contribute toward the goal of reducing carbon emissions. Moving towards net zero carbon will inevitably mean considerable changes in the way that food is produced in the UK. Some of these changes are already underway and some may enhance food safety and quality, as well as aiming to benefit the environment. However, as with any large-scale change in food production methods, there is also the possibility of unintended and unforeseen consequences for feed and food safety. It is important that the FSA

has foresight over any emerging risks and adopts a thorough and systematic approach to help identify these.

This study seeks to provide a better understanding of the potential risks to food and animal feed safety contingent on changed food production practices aimed at achieving net zero carbon and highlight areas where vigilance is needed. It was conducted in four phases and involved structured interviews with academic and business experts, a workshop with people with wide-ranging experience of food production and food safety issues, a workshop with civil servants across government departments with net zero carbon and food responsibilities, and a review of relevant papers, books and reports by international and UK agencies.

Many current developments in primary production practices are not driven by carbon reduction *per se*. If carbon reduction targets are supported by such developments, this may sustain or even accelerate their adoption. Thus, any assessment of the possible impact of carbon reduction measures should include the additional impact of those enabling technologies.

Three categories of changes in primary production towards net zero carbon which might have implications for food and animal feed safety were defined: evolution of production systems for specific ends (and markets); novel or major changes to existing production systems; and new products developed in anticipation of consumer/market demands.

Potential food and feed safety risks associated with changing production systems (e.g. vertical farming), new food raw material and ingredients (e.g. novel proteins; insects; cultured meat) and the increasing emphasis on the circular economy were assessed.

This study has not identified any unknown safety hazard to food and feed arising from anticipated changes to achieve net zero carbon, but it has found that the degree and balance of known risks may change. It is possible as new technologies and production systems continue to develop that new hazards could yet emerge.

Eight inter-related conclusions about food and animal feed safety were reached, including:

- moves towards net zero carbon may change the degree and balance of known existing risks where novel technologies are employed;
- new entrants to novel technologies for food production may be unfamiliar with the food safety and other regulations which currently exist;

- existing regulations, codes of practice and guidelines should be sufficient, if fully implemented, to reduce food safety risks to acceptable levels, but there is evidence that not all are rigorously enforced;
- involvement of multiple government departments in the regulation of the UK food system requires collaboration between departments and regular horizon scanning to ensure that rapidly evolving primary production practices do not compromise food safety.

Eight recommendations grouped under three themes are made to the FSA:

Theme 1: Surveillance of emerging technologies and engagement with producers and consumers

- maintains active surveillance of likely areas of production changes in response to net zero carbon policies and encourages food and feed businesses to embed responsibility for food safety into their innovation projects.

- develops guidance that will ensure safe food at the site of production through active engagement with new food-production technologies.
- develops and communicates advice for primary producers and consumers on how to minimise food safety risks when producing or consuming foods that they perceive as contributing towards net zero carbon or sustainability.

Theme 2: Inter-departmental cooperation and regulatory review

- Engages with other government departments to assess the effectiveness of current regulation, enforcement, codes of practice and guidance in assuring future food and feed safety and whether the balance and scope of these assurance mechanisms is appropriate to cope with the changes underway in primary production.
- Ensures that the regulatory framework for animal feed is sufficiently agile to cope with fast-moving changes and any accompanying risks.
- Rapidly establishes whether the current risk analysis and regulatory frameworks in place are able to cope with the novel technologies, ingredients and products which might be used in food.
- Reviews the potential impacts on food safety arising from the use of manure, compost, slurry, sewage sludge and food by-products applied to land to determine whether current regulatory frameworks are fit for purpose.

Theme 3: Research and horizon scanning

- Undertakes a systematic analysis of research gaps to identify where scientific evidence is needed to understand the risks and benefits associated with production and consumption of food and feed in a low carbon economy.

Finally, work already underway in the FSA and by Defra to address some of the potential food and feed safety issues raised in this report is identified.

3. Introduction

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Globally, the food system (including agriculture, food manufacturing and processing, distribution and retail) produces greenhouse gas (GHG) emissions of about 18 Gigatonnes CO2 equivalents (GtCO2e) per year – about one-third of total

emissions and second only to the energy sector (Ward, 2023). In 2015, 71% of these emissions came from the land-based sector, defined as agriculture and associated land use and land use change (LULUC; sometimes combined with forestry as LULUCF). Primary production of food and animal feed is, therefore, a significant contributor to GHG emissions.

In the UK, the food system accounts for 23% of GHG emissions, a percentage that has remained almost constant since 1990. Although emissions from primary production of food and feed decreased from 66.9 Megatonnes CO_2 equivalents ($MtCO_2e$) per year in 1990 – 1999 to 54.9 $MtCO_2e$ per year in 2010 - 2018, their overall contribution to food system emissions increased from 42.6% to 48.3% in the same period (Ward, 2023). It is generally recognised that reducing GHG emissions from the food system has lagged behind that of sectors such as electricity generation and road transport (OECD, 2019). As decarbonisation proceeds there is likely to be a greater focus on both the absolute and relative contributions of GHG emissions from the food system to total GHG emissions.

The UK’s Net Zero Strategy (BEIS, 2021) sets out the UK government’s ambitions to decarbonise the economy, reduce the extent of climate change and associated extremes of weather and build a greener, climate-resilient economy. Emissions from agriculture and LULUCF are expected to contribute reductions over the next decade (Figure 1). The strategy acknowledges that primary production (agriculture) ‘will be difficult to decarbonise completely by 2050’, but that the processes of carbon fixation embedded in agriculture can make a significant contribution to mitigating total GHG emissions.

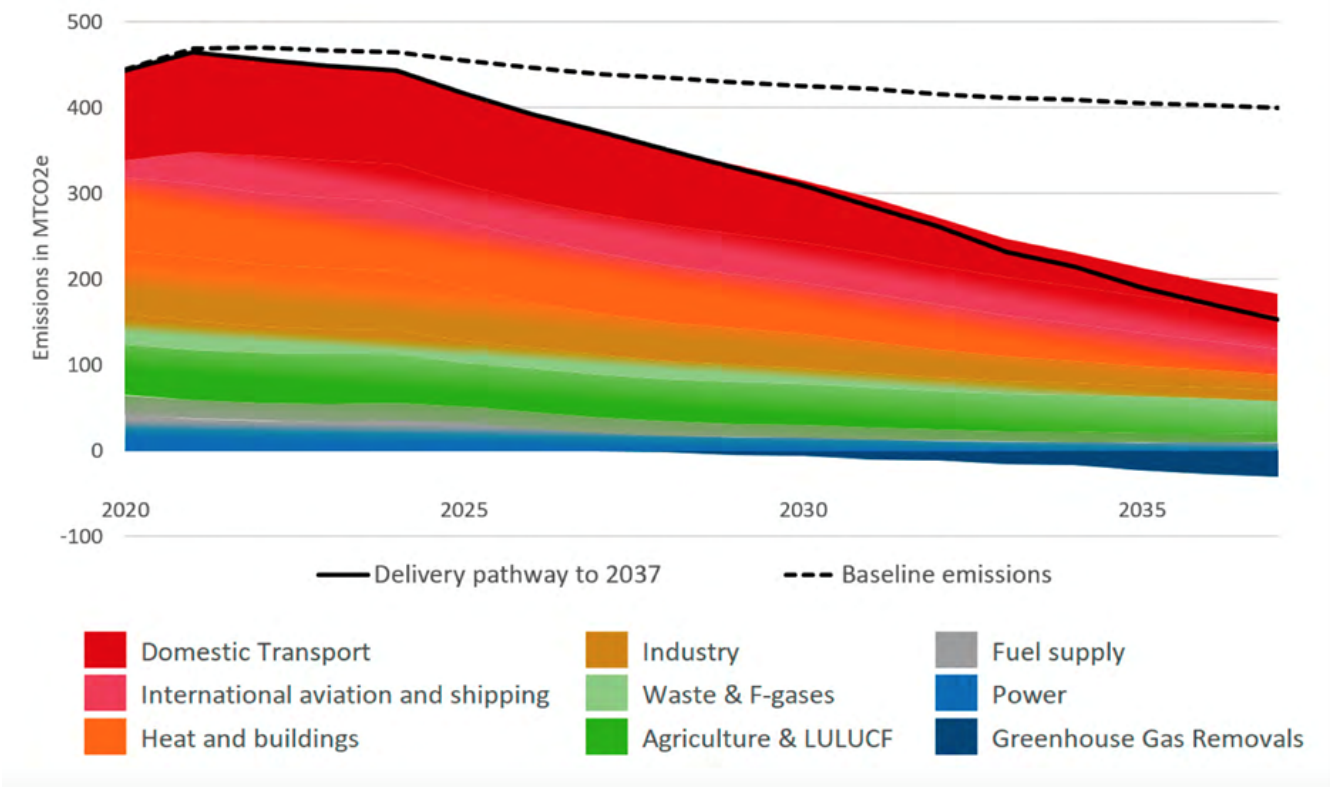

Figure 1. The anticipated contributions of different sectors to reducing UK GHG emissions (BEIS, 2021). Note that the years on the x-axis should be placed below the -100 line.

In early discussions to scope the work detailed in this report, the FSA Science Council Secretariat agreed with Defra that there are many new developments occurring in primary food production aimed at achieving net zero carbon that may have implications for food safety. The Science Council decided, therefore, to focus on changes expected in the primary production of food in the next decade concentrating on, but not limited to, production in the UK. Similar production systems elsewhere are likely to produce similar potential food safety risks for imported food. For the purposes of this review, primary food production includes the growing and harvesting of plants as food for humans or feed for animals, and the rearing and slaughter of animals (livestock, fish and a wide variety of aquatic and marine organisms). It also encompasses simple processing of agricultural products ‘on farm’ such as grinding grain for flour, pasteurising milk and packaging of fresh fruit and vegetables for sale, as well as the development of new production systems including insects and cell culture for growing meat, fish and milks. Whenever production systems change, potential food safety risks change too, either because new risks are introduced and/or the balance of already known risks is altered. This study aimed to determine the potential risks

to food safety contingent on changed food production practices aimed at achieving net zero carbon and highlight areas where vigilance is needed.

A Science Council Working Group 6 (WG6) began work in summer 2021, led by Science Council members Mrs Claire Nicholson (WG6 Chair) and Prof Jonathan Wastling (WG6 Deputy Chair) with advice and support from Profs Peter Gregory, Simon Pearson and John O'Brien; Secretariat support was from Mr P Nunn. Its aim was:

'to investigate the potential food safety implications arising from changes in primary food production practices and technologies introduced in the UK aimed at reducing carbon emissions in the next decade.'

The work programme comprised four phases with an interim report published in July 2022 (FSA, 2022c). The interim report summarised the first two phases and provided a preliminary indication to the FSA of changes to practice already underway and an early view of possible food safety issues. Interviews with scientists and leading industry stakeholders were conducted in three tranches interspersed with two workshops with academic, industry and government department representatives, together with a review of academic, industry and government publications. A full description of the methodology employed is given in Annex 1.

In undertaking this work, the WG6 employed the FSA's standard approach to risk assessment. Risk assessment involves using a scientific approach to identify and define hazards, and to estimate potential risk to human and/or animal health. This includes evaluating the likely exposure to risks from food and other sources. New technologies may give rise to emerging risks defined as 'a risk resulting from a newly identified hazard to which a significant exposure may occur or from which an unexpected new or increased significant exposure and/or susceptibility to a known hazard' (EFSA, 2011). Innovations to support carbon reduction may have both positive and negative consequences for food safety and there is a dynamic, two-way relationship between environmental impacts and food safety. Potential health risks and routes to exposure to known hazards may change in response to net zero carbon measures necessitating changes in control practices or product and process standards.

This final report covers all four phases of the WG6's activities. It identifies many rapid changes occurring in primary food production practices that will contribute to the realisation of net zero carbon, and the potential food and animal feed safety issues arising from them. It highlights the significant areas of uncertainty

that will require ongoing monitoring, and which may necessitate a rapid response. Finally, it makes recommendations to the FSA of areas for further action or investigation and highlights the need for work in partnership with other government departments to manage potential food safety risks.

4. Changes underway in UK primary food and feed production

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Changes to primary production practices in the UK are being influenced by a variety of interacting and sometimes competing, technical, social, political and commercial interests. For example, many of the practices linked to reduced GHG emissions such as conserving soil carbon were established in the context of biodiversity and good land stewardship. Similarly, there has been a long-standing interest in reducing fishmeal as a component of fish feed in aquaculture driven by the need to conserve wild fish stocks, and in reducing the soya bean content of animal feed to reduce dependency on a single protein source (Fiorella *et al*., 2021; Wilkinson and Young, 2020). Most recently, the incentive to reduce energy consumption in the UK has been driven by the rising costs of energy rather than net zero carbon goals. This means that many of the changes currently being researched and implemented were prioritised primarily for purposes other than the specific achievement of net zero carbon. If carbon reduction targets are supported by such developments, this may sustain or even accelerate their adoption. Thus, any assessment of the possible impact of carbon reduction measures should include the additional impact of those enabling technologies.

4.1 Technological changes already underway

Technological changes in primary food production have been summarised in the FSA's Rapid Evidence Assessment of emerging technologies impacting the UK food system (FSA, 2021) and are also evident in projects supported by Innovate UK. Boxes 1 – 3 highlight some features of three developing areas of technology (vertical farming, aquaculture, and alternative and novel proteins) chosen because of the contrasting potential food safety issues they raise. Vertical farming includes a variety of technologies used in indoor food production; aquaculture encompasses marine and freshwater cultivation and multi-trophic systems; alternative and novel proteins are diverse and produced using many different production systems.

Box 1 Vertical Farming

Vertical farming, where crops are produced indoors with the use of LED lighting systems, has received significant private equity investment over the last five years (van Gerrewey *et al*., 2022). The majority of crops produced are salads, leafy greens and herbs with a growing interest in the production of soft fruits including strawberries. Vertical farms are often promoted on the basis of claims about their sustainability which suggest food can be produced locally, including in urban settings, with reduced use of pesticides and water. These advantages have to be offset against their need for electricity to power LED and air conditioning systems, plus overall capital costs. Crops are typically grown in a hydro or aeroponic system and can use large buildings and cellars in urban areas. Vertical farms with multiple horizontal layers can produce as much as 10-20 times biomass per unit area as conventional field-based farming. They have the potential to deliver high-quality fresh produce into urban areas with minimal transport costs with associated contribution to net zero carbon. The environment within each farm is controlled and developers suggest that there is a significant reduction in crop water use. A controlled environment reduces the risk of food contamination from, for example, pathogens, contamination from birds and soil microorganisms, but the materials used to provide the controlled environment and how they are maintained may bring other risks. Warm, high-humidity production environments may be conducive to the formation of biofilms on equipment and building surfaces that may harbour pathogenic organisms (Chiaranunt and White, 2023). Dust and nutrients in solution can support the growth of such organisms.

Box 2 Aquaculture

Aquaculture is the cultivation of aquatic organisms. It is not a new technology, but practices are changing to accommodate net zero carbon. The two biggest production issues for fish cultivation worldwide are the ingredients for feed mixes and the control of fish death in pens. The raw materials in feed mixes account for 65% of the GHG footprint of the value chain. Big changes have already occurred to fish (principally salmon) feeds in the last 30 years, with calories now coming mainly from vegetable oils (rape and soya bean), with fish oil as a source of long-chain omega 3 acids; progress towards net zero carbon is likely to see these trends continue. While the UK farmed salmon industry is using about the same amount of fish meal and oil as 30 years ago, it is producing 10 times as much product. Two recent changes in the production process have reduced food safety risks. First, the move of salmon farms further offshore has reduced the risk of exposure to contaminated water leading to higher quality fish and less exposure to pollutants; and second, new materials such as copper alloys are being used to construct fish nets leading to less use of toxic cleaning materials and lower safety risks due to contamination. The use of cleaner fish such as wrasse and lumpfish in pens has also reduced sea lice infections, salmon death and the use of chemicals to control the lice (Skiftesvik *et al*., 2014). While new systems of fish production are being explored internationally (e.g., recirculation systems, submersible crates and integrated multi-trophic aquaculture), these have currently only been deployed in a very limited way in the UK. Integrated multi-trophic aquaculture (IMTA) systems permit the simultaneous cultivation of multiple products with by-products (e.g., uneaten feed or nutrients in faeces) from one aquatic species used as inputs for another (e.g. sea bream (fed organism) and molluscs or seaweed (extractive organism); Rossi *et al*., 2021). However, it is important to prevent contamination of finished products.

Box 3 Alternative and novel proteins

Current major sources of protein in the UK include beef, pork, lamb, chicken, fish, egg, dairy products, pulses and nuts, with meat providing most dietary protein (34%). Although animal protein sources are generally of superior nutritional quality and digestibility to plant proteins, meat production systems are being challenged from several directions because of their associated GHG emissions (UKCCC, 2020; IPCC, 2022) and research is underway to diversify protein sources and reduce consumption of red meat, in particular. Considerable investment is funding the development of alternatives that can be used in human, animal and pet food products. These include plant-based meat substitutes, novel protein sources such as insects and microalgae, proteins and biomass synthesised by microbes and cultured meat (FSA, 2022a). Each production system has its own food and feed safety issues. For example, plant-based meat substitutes typically contain at least one known allergen such as soya bean or wheat gluten. While pulses such as peas and beans have a long history of production in the UK with known food safety risks, commercial production of insects is new and potential food safety risks arise from contamination of both substrates (insect feed) and the production system, and species dependent factors (see section 6.1.3). With the exception of cultured meat, most of the novel protein sources being explored are not new to parts of the world (although new to the UK) so health and food safety risks are generally known elsewhere and well understood. However, experience of industrial scale production of these proteins is very limited with vigilance essential.

Many changes to primary production systems are occurring very rapidly in the UK with potential impacts on food safety, although it is important to note that such impacts may have positive as well as negative outcomes. Table 1 shows projected growth in selected production systems covering several of the technological innovations highlighted by Innovate UK and the FSA’s Rapid Evidence Review (2021) of emerging technologies that will impact on the UK food system. Precision farming includes the use of sensors, data and artificial intelligence to direct inputs to sites where they can be most effective. Vertical farming is an indoor production system for high value crops and food waste management includes the production of by-products from waste. The growth estimates vary between analysts, but the values cited are indicative of the anticipated rates for the different production systems and types of food.

Table 1. Global market trends for some primary food production technologies; CAGR is Cumulative Annual Growth Rate. Sources are reports from Markets and Markets (e.g. https://www.researchandmarkets.com/tag/vertical-farming?ac=true with information sourced on 02/11/2022) and the FSA Rapid Evidence Review (2021).

Technology	Start	Value	Finish	Value	Source
Precision farming (global) CAGR 7.9%	2022	$US 8.5 billion	2030	$US 15.6 billion	Markets and Markets
Vertical farming (global) CAGR 25%	2021	$US 3.1 billion	2026 2030	$US 9.7 $US 20 – 30 Billion	Markets and Markets
Edible insects (global) CAGR 24.4%	2019	Not stated	2030	$US 8 billion	FSA Rapid Evidence Review
Food waste management (global) CAGR 5.4%	2019	$US 34.2 billion	2027	$US 49.4 billion	FSA Rapid Evidence Review
Cultured meat (global) CAGR 15.7%	2025	$US 214 million	2032	$US 593 million	Markets and Markets

4.2 The policy context

The policy context underpinning changes in UK primary production is complex and includes several related, but separate, policy-related elements which include the UK Government's Food Strategy (Defra, 2022), the report of the UK Committee on Climate Change (UKCCC, 2020) and a possible, forthcoming land use framework from the Government. These contextual aspects and more details of the technological changes under development are described in Annex 2.

The UKCCC (UKCCC, 2020) has suggested that, without radical changes in land use, GHG emissions from agriculture will not be reduced substantially and that the UK will be unlikely to approach net zero carbon by 2050. Although the actions suggested by UKCCC (2020) will not be fully implemented for 25 years, some of these changes are expected to occur in the next decade and the implications for food and feed safety require consideration now.

4.3 Categorisation of changes to primary food and feed production

In the Science Council's interim report to the FSA (FSA, 2022c), three categories of changes in primary production related to the delivery of net zero carbon were identified which might have implications for food safety. The selection of these three groups remains unchanged, although there has been some revision to take account of further research. They are as follows:

1. **Evolution of production systems for specific ends (and markets)** – agriculture in the UK is currently subject to multiple influences with producers (and food sellers) employing a range of adjectives to describe their mode of production. Precision, sustainable, organic, conventional, sustainably intensive, rewilded, regenerative, climate smart and low carbon are all in play. In this complex milieu, change from one production system to another may either increase or decrease food safety concerns, or even introduce new ones, depending on the circumstances. The experience and skills of the producer and the standards required by the proposed market can have substantial consequences on food safety risks.
2. **Novel or major changes to existing production systems** – vertical farming, climate-controlled animal and plant production systems, and large-scale recirculation systems and integrated multi-trophic systems in aquaculture are all technologies either adopted or under development for use in the UK. Known food safety risks are dealt with using existing protocols, but experience of such systems to date is limited. There is no evidence that food produced by such means is more, or less safe. However, as with any new technology, vigilance is needed to respond to a changing production environment.
3. **New products developed in anticipation of consumer/market demands** – many consumers wish to purchase food products which are perceived to be beneficial for the environment and/or health, or which meet ethical or religious requirements. For example, this might be a plant-based

diet or seafood that is ‘friendly’ to dolphins. These descriptions may encompass the practices of primary food producers, and the impact of anticipated consumer behaviour is, therefore, included in this review. Some elements of consumer choices in response to climate change are discussed in a report of the FSA Advisory Committee for Social Science (FSA, 2022b).

5. What food and feed safety risks have been identified?

In this guide

At the time of writing, no published material on potential food safety risks arising from changes in production practices aimed at achieving net zero carbon was

identified. This means that the potential food safety risks arising from changes in primary production described below have been inferred from the known hazards, the likelihood of risks associated with production techniques, and expert knowledge.

While no previously unknown safety hazard specific to changes to achieve net zero carbon has been identified, the degree and balance of known risks will change as actions to achieve net zero carbon are implemented. As the changes to practices become established, the existing systems in place (e.g., codes of agricultural practice, Hazard Analysis and Critical Control Point (HACCP) principles and the procurement requirements of major retailers and food service businesses) to mitigate risks are likely to evolve and the risk be managed accordingly. The awareness of new or evolving risks may be influenced by the nature of the innovation (e.g. breakthrough or incremental) and the maturity (e.g. established food business or start-up) and scale of enterprises.

5.1 Climate change and food safety risks

While it is not the purpose of this report to examine in detail the likely effects of climate change on food safety, some of the potential risks associated with measures to achieve net zero carbon, described below, will be similar to those associated with climate change. Unlike the food safety consequences arising from changes aimed at achieving net zero carbon, those arising from climate change are relatively well understood. Several studies on climate change and food safety have been published (e.g., EFSA, 2020; FAO, 2022; IPCC, 2022). These highlight the multiple pathways by which climate change may affect food safety including:

- Changes in temperature and precipitation
- Increased frequency and intensity of extreme weather events
- Ocean warming and acidification
- Changes in transport pathways of contaminants

Of particular concern are the possible effects on foodborne diseases including zoonoses, microbial agents especially mycotoxins and algal blooms, environmental contaminants and chemical residues (EFSA, 2020; FAO, 2022).

The IPCC (2022) concluded its global analysis with high confidence that, in addition to climate-related extremes affecting the productivity of all agricultural and fishery sectors with negative consequences for food security and livelihoods, climate-related food safety risks are increasing globally in agriculture and fisheries. Examples cited include:

- High temperatures and humidity increasing toxigenic fungi on many food crops (very high confidence).
- Algal blooms and water-borne diseases threaten food security of many coastal communities (high confidence).
- Increasing ocean warming and acidification are enhancing movement and bioaccumulation of toxins and contaminants into marine food webs (medium confidence).

The report found that ‘climate-related food safety risks have increased globally (high confidence)’ with particular concerns about increased:

- Salmonella, campylobacter and cryptosporidium infections (medium confidence).
- Mycotoxins associated with cancer and stunting in children (high confidence).
- Seafood contamination with marine toxins and pathogens (high confidence).

IPCC (2022) highlights that climate change will compromise food safety through multiple pathways (high confidence) and that the pressures on marine systems are complex.

Medina et al. (2017) drew particular attention to the food safety risks caused by mycotoxin contamination, especially aflatoxins, which disproportionately affect low- and medium-income countries. The projected impact of climate change on mycotoxin contamination is complex, with marked geographical differences probable. For example, northern Europe may be less affected than the Mediterranean region. Despite the uncertainty, there is currently a dearth of research data available to ensure the adequacy of current risk management measures in response to climate change.

The Working Group’s specific focus has been on the potential food and animal feed safety risks associated with changed systems of primary production in the UK which are intended to contribute to net zero carbon goals. These will be experienced in addition to those associated with climate change. The following hazards and potential food and feed safety risks associated with different production systems were identified and are described below.

5.2 Evolution of production systems for specific ends (and markets)

5.2.1 Crop and animal production

The wide range of farming objectives currently being pursued (e.g. sustainable intensification to rewilding and conventional to organic) mean that any food and animal feed safety risks are likely to be specific to particular production systems. Nevertheless, the general trend towards land being actively managed for multiple ecosystem services (food production, water filtration, biodiversity and carbon) is likely to increase. The current energy crisis is also likely to provoke reassessment of farm inputs with consequences for use of fossil-fuel based products (e.g., nitrogen (N) fertilisers). The innovations in production systems highlighted above (Section 4) will affect the following risk scenarios:

- The quantity of animal manures may decrease in line with changes in land use to meet net zero carbon targets (more forests and less meat consumption; UKCCC, 2020) but, conversely, more intensive systems may limit the area available for spreading and concentrate potential sources of pollution. It is also likely that there will be increased applications of domestic sewage, council green waste and industrial waste to farmland as landfill declines. Existing codes of practice and statutory controls protecting against the transmission of pathogenic organisms (such as *Escherichia coli* and *Clostridium botulinum*) and/or contamination with toxic elements should be validated against future changes in production systems.
- Recycled water and/or brown water use can increase the risk of transmission of many pathogens (e.g. *Cryptosporidium* spp.) especially to leafy vegetables.
- Wildlife contact with farm animals can increase the risk of exposure to zoonoses (e.g., avian flu).
- Modified crop rotations, coupled with climate change, may lead to new or increased levels of fungal diseases and mycotoxins (e.g., if growing wheat shortly after maize on the same land).
- There is a rapid pace of change in the development of novel animal feed formulations including the use of feed additives to inhibit methane production in ruminants (e.g., the potential inclusion of 3-Nitroxypropanol (3-NOP) in feed for dairy cows). Other approaches may entail changing feed composition and introduction of natural ingredients requiring case-by-case safety evaluation.
- Traditional plant breeding is being complemented with genetic modification and gene editing techniques. Each approach requires a tailored safety evaluation of any potential allergens, contaminants and toxicants in the crops produced.

- Changed land use (e.g., afforestation) and tillage practices may alter the amount and/or timing of runoff and leaching affecting the development of toxic algal blooms in watercourses. Upstream events in watercourses can affect risks for food produced downstream as well as the direct local effects on fish and other organisms used as food.

5.2.2 Aquaculture and ocean farming

The following changes have the potential to affect risks:

- Inclusion of more animal (including insect products that have regulatory approval) and plant by-products in fish feeds could reduce carbon footprints, although industry sources suggested that UK consumers might be averse to their use for farmed salmon. Such feeds are already being used for sea bass and bream farmed in the Mediterranean and imported into the UK. Reducing the fish oil component of feeds will also reduce exposure to persistent organic pollutants (POPs).
- Cultivation of seaweed and fish can support the goal of net zero carbon via multiple routes but contamination of sea water with heavy metals, algal and other biotoxins from runoff and dumping can result in poor quality fish, crustaceans and seaweed which pose food safety risks if consumed. Growing seaweed for food risks contamination with crustaceans or molluscs, for example, with the potential to provoke allergic reactions.
- Consumer behaviour which may be aligned with sustainability and net zero carbon goals, such as local harvesting of wild foods, may carry food safety risks. For example, serious water pollution incidents in England increased by 63% between 2017 and 2021 (OEP, 2023) with several documented warnings issued to the public not to harvest shellfish from estuaries or forage from the seashore. Similarly, seafood harvested from estuaries and close to shore may be at risk of contamination with chemical and biological hazards (Banach *et al*., 2020; EFSA, 2019; Mudadu *et al*., 2022).

5.2.3 Interactions of the circular economy with food production

A wide range of pressures including consumer environmental concerns, limiting disposal of wastes to landfill sites and the current energy crisis is fuelling the recycling and re-purposing of materials previously regarded as waste. The likely increased use of diverse nutrient sources, via wastes applied to land or through the introduction of food by-products into the food chain, raises the possibility of

increased risks to food and feed safety and the need to segregate food, feed and non-food crops:

- Recycling and waste product utilisation in food production systems will be increasingly necessary to minimise carbon costs. Such practices will require the development of validated safe practices, industry standards and guidelines, and regulatory instruments.
- Domestic and industrial wastes applied to a more limited area of agricultural land (see 5.2.1) requires vigilance to ensure that toxins and contaminants are controlled and do not enter food and feed chains. Because domestic sewage may contain pathogens, runoff and leaching can lead to polluted water being applied to crops downstream as irrigation, and also directly affect the food safety of fish and other aquatic organisms.
- Frass from insects (a mix of faeces, exoskeletons and uneaten feed) is currently treated as a manure. Insect farming is rapidly evolving and the use of sanitised frass as fertiliser is being investigated to ensure that no additional microbiological risks to food are involved (Smink and Huulgaard, 2022).
- Treated sewage is also applied to agricultural land posing potential risks to food from heavy metals, toxins and pharmaceuticals (especially antimicrobials). To address these hazards, standards for heavy metal concentrations and microbial content, coupled with a code of practice, have been introduced under the Biosolids Assurance Scheme launched by the UK Water Industry in 2021.
- Digestate from anaerobic digesters is spread on land but the regulatory regime is complex, with food and crop wastes treated differently. The quantity of digestate from food waste has declined as the food industry reduces its waste, but with domestic food waste to be collected separately in the next few years, this source may increase again. No specific food safety risks have been associated with digestate, but any pathogens shown to survive the digestion process could pose a risk if they were able to enter the food system (e.g. on salad crop leaves).
- Common to all of these ‘wastes’ is the inclusion of plastics from bags and microplastics. The fate of plastics entering soil and their possible entry into the food system is largely unknown. This is an area of considerable concern.
- Inclusion of food and other by-products into food packaging can increase potential food safety risks. For example, chitin derived from crustacean or insect exoskeletons needs to be processed into chitosan for commercial use. While there is currently no evidence that levels of allergenic proteins in biobased packaging materials would increase the risk of allergic reactions in

vulnerable individuals, the issue has still to be fully addressed for food contact materials (COT, 2021).

5.3 Novel or major changes to existing production systems

5.3.1 New technology farming

Controlled environments, of which vertical farms are the most recent innovation (see Box 1), have factory microbiomes which are different from conventional, outdoor, production facilities; this brings different food safety risks:

- The controlled environment system may help to prevent contamination with organisms associated with the complexity of conventional, outdoor production but will also generate unique hazards that will require targeted risk management measures using processes such as HACCP.
- Although the environment (temperature, nutrients, water and light) in a controlled system is optimised to promote crop growth, these same conditions might also accelerate the growth of pathogens.
- With more automation, recycling of nutrient solutions and substrates, and less human interaction with the crops, disease, moulds, or other unexpected events may not be noticed as quickly and could enter the food system. Vigilance and a HACCP is required for each facility with separate standards and food safety management plans (Lubna *et al*. 2022).
- So far there is limited experience of how the new systems will age, with dust or other matter such as biofilms accumulating over time. Many of the growing systems are made of plastics from which chemical migrants (e.g., endocrine-disrupting chemicals) may be released into foods. There are also concerns that products produced in this way may lack the microbial flora that play a role in the development of the human immune system and a healthy and robust gut flora.
- Some production systems are commercialised by new entrants to the food industry, with limited experience of food production, who may need additional support to identify and manage food safety risks. New, small-scale producers may require assistance to meet food safety and standard regulations.

5.3.2 Novel sources of protein

Novel protein sources are a subset of the alternative protein sources described in Box 3. For the UK they include non-traditional materials such as insects, seaweeds, microalgae, bacteria and jellyfish; cultured meat is both new and novel. Because they have not been widely consumed in the UK and cultured meat involves a novel process, they are regarded from a regulatory viewpoint as novel. Emerging concerns include the following:

- Insects can be produced in vertical factories on brown-field sites. Insect protein has implications for both human nutrition (macro- and micronutrient intake will change if existing meat sources are replaced) and health (because insect proteins have the potential to trigger food hypersensitivity). The long-term consequences for human health are little understood (Galecki and Sokól, 2019).
- Novel sources of proteins from plants and microalgae have the potential to cause allergic reactions in sensitive individuals.
- Production of cultured meat in bioreactors is still mainly at pre-production scale with beef, chicken, fish and milk being actively researched. There are some concerns that the risk of contamination of cell cultures, growth media and final products at industrial scale without antimicrobials is high. Interactions of growth-promoting chemicals and hormones used to facilitate cell growth is not well understood and plastic surfaces on which the cells are grown may release harmful contaminants (FSA, 2022a).
- Labelling of the food products from these new processes needs to include both safety (e.g., allergy) and consumer interest statements (e.g. composition, source of cultured cells, origin declarations).

5.3.3 Changes to livestock and fish feeds

There are several new developments in animal and fish feeds which aim to reduce carbon footprints. These include replacement of soya bean in feeds with other protein sources, using food by-products in feed, and employing supplements to reduce methane from ruminants (see sections 5.2.1 and 5.2.2). Issues noted in the current work are:

- Alternative proteins used to replace soya bean may affect animal health and ultimately the nutritional profile of meat produced. For example, lupin meal containing high levels of alkaloids has produced toxic effects in poultry and poor performance due to anti-nutritional non-starch polysaccharides. However, other protein sources could benefit the nutritional profile.

- The use of food waste as animal feed has a history of animal health problems such as BSE, Foot and Mouth and African Swine Fever.
- Given the speed of change for new animal feeds and supplements, all stakeholders will need to ensure that systems of scientific evaluation of evidence, risk assessment, policy development and functioning of the regulatory framework are sufficiently agile.

5.4 New products developed in anticipation of consumer/market demands

Although the focus of the present study is on changes to activities associated with primary food production, consumer choice and satisfying the expectation of consumer trends is a strong driver of change in the production system. The FSA's Advisory Committee on Social Science (ACSS) report (2022b) on the Impact of Climate Change on Consumer Food Behaviours drew attention to four behavioural trends namely: avoidance of food waste, increased use of alternative packaging such as biopolymers to reduce fossil fuel based plastic use, increased use of reusable containers to purchase food and drink, and the increased consumption of novel proteins. This section summarises the potential food safety issues arising from changes led by consumer choices.

5.4.1 Changes to the human diet

Plant-based and novel proteins produced to respond to trends for sustainable 'healthier' plant-based diets may introduce allergen and toxin-related hazards, as well as possible nutritional deficits, for example:

- Consumers may lack awareness of the nutritional choices being made, when, for example, plant-based protein is substituted for animal meat in the diet. Typically, plant-based meat substitutes are highly processed foods that are nutrient deficient (except for high levels of sodium) unless fortified with nutrient additives (FSA, 2022a) so may not have nutritional equivalence to foods they are replacing.
- Proteins in plant-based meat alternatives consumed instead of meat or dairy present additional complexity in terms of their nutritional profile and digestibility, and the need for appropriate processing technologies and formulation (Sridhar *et al*., 2022)

- Plant proteins and some sources of insect protein may pose allergenicity risks. Most plant-based meat substitutes contain the known allergens found in soya bean and/or wheat. Although rare at present, allergic reactions due to chitin contamination of insect protein and potential cross-reactivity with allergens in house dust mites or crustaceans, might become more common if more chitin is consumed.

5.4.2 Demand for changes to packaging and labelling

Some consumers and the food industry are looking to move away from single use plastics in favour of alternative packaging solutions, and progress towards net zero carbon is likely to add to this trend. The FSA has already considered the food safety issues associated with alternatives to plastic food packaging (FSA, 2019, 2020) so these will not be repeated here. However, information about sustainability and allergenicity of novel proteins may require new labelling to inform consumers about:

- Risks from allergens in foods that are reformulated to reduce or remove animal products as part of net zero carbon strategies, for example, use of legumes/concentrated pea protein due to their allergenic potential.
- Allergen (and possibly toxin) risks from new proteins such as insect protein, which may be not obvious to consumers if used as an ingredient in powdered form, to boost the protein content of a product.
- The potential for misleading claims about the net zero carbon or sustainability credentials of foods; currently there is no consistent standard for sustainability claims or labelling for foods.

6. Appraisal of food and feed safety risks

In this guide

This is a time of rapid alterations to primary production systems, so the present situation is very fluid. Food businesses and retailers are pressing ahead with their plans to contribute to net zero carbon targets while governments at national, regional and local levels are still determining their detailed policies.

Against this mixed and rapidly evolving background, the relative food safety risks associated with the production systems described above have been appraised. The evidence available to make this assessment was largely obtained from published reports, 'grey' literature and interviews with informed people in the relevant businesses and areas of production. Although not exhaustive, the following key potential food safety risks have been identified and are summarised in Table 2.

6.1 Areas where new risks might emerge

Although no new food safety risks arising from transition to net zero carbon have been specifically identified, there are changes to production practices that are big enough to have the potential to produce new risks in future. The areas for particular vigilance are:

6.1.1 Animal and fish feeds

The introduction of new plant components into animal and fish feeds is unlikely to cause food safety risks but the use of animal products and food by-products in feed has a long history of problems. The use of animal products from ‘waste’ streams to augment feeds can lead to zoonoses and microbiological and prion contamination of animal foods. However, there is now tight regulatory oversight of animal feed manufacture with the benefits of a highly standardized animal feed industry in the UK.

6.1.2 Vertical farms

These recently introduced production systems are potentially ‘clean’ and with minimal food safety risks. However, because the systems are novel, there is little experience of what will happen as the systems age. Microbiological safety risks could arise from the establishment of biofilms in plastic tubing and filters and from dirt and dust on surfaces. The recycling of water might also provide a source of contaminants to plant products especially leaf crops. New entrants may have little previous experience of food production so there is a risk that aspects of good hygiene standards are unintentionally overlooked and may not be built into business practices. This is more important for small businesses selling into local markets because any producer supplying large retailers will be subject, additionally, to assurance schemes.

6.1.3 Alternative protein sources

Legumes (peas and beans) are traditional sources of protein (so strictly neither new nor novel) but increasingly promoted as sustainable replacements for animal protein in human diets. Food safety issues are generally well understood. For example, the pyrimidine glycosides vicine and convicine present in faba beans can lead to life-threatening favism in individuals with G6PD deficiency but these have been substantially reduced by conventional breeding. The presence of raffinose series oligosaccharides in most peas and beans (needed for seed germination) produces flatulence in humans – not a safety issue but a limiter of consumption. Legumes present a risk of cross-reactive allergy,` although processing (hydrolysing) the protein can reduce pea allergy substantially.

Insect farming is developing rapidly with the main market currently expected to be pet food. Future market growth is likely to be for the aquaculture sector and then for the production of pigs and chickens; the trajectory for human consumption is uncertain. Insects typically consist of 60% protein with 20-30% fat and efficiently concentrate the protein in their feeds, although the choice of insect

substrate has a major influence on this. Insects vary in their food sources and metabolism, so that different food safety concerns may arise for specific insects. For example, heavy metals in feed will accumulate in black soldier fly larvae but be excreted by mealworm. Similarly, house fly larvae can break down *E.coli* in feed while mealworm can break down mycotoxins. To date, no pathogens have been found in black soldier fly production facilities. The main human food safety concerns that can arise are allergenicity (to both ingested proteins and chitin; those with allergies to crustaceans can produce an allergic reaction), chemical contamination with heavy metals (from the insect feed), carry over of any pathogens from any manures used in the feed and potential accumulation of nanoplastics. The widespread pathogen *Bacillus cytotoxicus* (causing diarrhoea) has been found in foods containing an unnamed insect flour (Cairo *et al*., 2022).

Red seaweeds can contain up to 45% protein although this varies seasonally. Human food safety issues are largely centred around heavy metal accumulation because they can rapidly accumulate elevated concentrations of metals such as arsenic, cadmium and copper when grown in contaminated coastal waters. Brown and red seaweed production for ruminant animal feed is increasing because it has been shown to reduce methane emissions, although carcinogenic bromoforms in red seaweed are a safety concern in feed.

6.1.4 Cellular agriculture

Two types of products are produced through cellular agriculture. The first are cellular products (usually proteins) made naturally by unicellular organisms or plant and animal cells, and the second are acellular products such as milk and egg proteins, plant proteins, food enzymes and food additives. Acellular products are normally the result of genetic modification of a bacterium or yeast from which the desired molecule is extracted and purified. This is standard practice in the development of lab-produced enzymes for yoghurt and cheese making (e.g., recombinant chymosin) and the food safety issues are well known and managed.

Animal muscle cells, cultured by adding hormones and growth factors to promote cell growth, are used to produce cultured meat (now also being referred to as ‘cultivated meat’) and there are some food safety concerns about them (FSA, 2022a). Although the products are generally grown in sterile conditions without the use of antimicrobials, the latter may be used when cleaning equipment between batches. If the meat is grown on plastic surfaces, then plastics containing endocrine disrupting chemicals should be avoided. The source of animal cell lines raises ethical issues for some religious groups.

6.1.5 Packaging

Food packaging is a major means of reducing food waste and thus can contribute towards achieving net zero carbon. However, the desire to reduce consumption of fossil fuels and production of food waste simultaneously is leading to the development of new packaging approaches including bio-based packaging, active and intelligent packaging, nanotechnology packaging films, and reusable and zero packaging.

Business operators have the responsibility to ensure that no food safety issues arise as a result of the packaging approach that they adopt. There are potential safety concerns arising from the use of some nanomaterials (especially metals) and the migration of nanoparticles into food and thence into the human bloodstream. There are food safety risks, too, in replacing plastics with biopolymers because they typically have reduced barrier or mechanical properties. This may increase the risk of contamination and reduce food shelf life. Some processed biopolymers could also retain original proteins leading to potential allergenicity concerns due to incomplete purification.

Increased use of re-useable containers and minimal/zero packaging on food products can lead to inadvertent cross-contamination by consumers, as well as the absence of safe ‘use by’ dates on products in the home.

6.1.6 Use of food by-products (wastes)

Processing of waste materials via composting and anaerobic digesters is already well regulated and food safety risks are understood. However, as collection of domestic food waste is introduced in parts of the UK, there is a possibility of pathogens (known or unknown) surviving thermal processing. Processing conditions should therefore be validated against the likely pathogens present.

As pressure to increase the recycling of all materials increases, the complexity of waste and compost regulations and associated codes of practice may inadvertently compromise food safety if producers do not comply with them. Moves to change the regulatory framework for wastes from process-based to product-based may assist in reducing the complexity, but in the short-term, vigilance for new pathogens and sources of chemical contamination is required.

6.2 Known food safety risks in new backgrounds

6.2.1 Regenerative/mixed/rewilded farming

Farming systems in which the production of crops and animals are closely integrated on the same farm are fundamental to mixed farming and are especially favoured by regenerative farming approaches. The food safety risks arising from animal wastes in close proximity to food crops (e.g., *E. coli* and other microorganisms such as *Listeria monocytogenes*, salmonella, clostridia and cryptosporidia) are well known but may be amplified by an increase in regenerative farming practices, particularly when adopted by new entrants. Similarly, crop diversification to produce maize silage for animal feed can increase levels of *Aspergillus flavus* in soil increasing the risk of aflatoxin production in subsequent wheat crops.

6.2.2 Agroforestry

Agroforestry has the prospect of being a major contributor to achieving net zero carbon in the UK. The choice of agroforestry system has a big effect on whether food safety risks are likely. Orchards combining fruit trees, pasture and sheep were common in the recent past but have largely disappeared. A return to grazed orchard means that fruit must be protected from faecal contamination, with windfalls eliminated from the fruit intended for human consumption. Planting trees in alleys between crops could result in more tree pollen allergenicity if the pollen is deposited, for example, on grains. Similarly, trees producing nuts (e.g., hazel and walnut) could contaminate harvested crops if they were broken or crushed and therefore not removed by usual sifting procedures. Fortunately, both of these occurrences are likely to be low risk because the timing of tree flowering and nut maturity does not generally coincide with cycles of crop development. Nevertheless, producers should be made aware of the risks.

6.2.3 Aquaculture

Harvested seaweed can be contaminated with crustaceans raising allergenicity concerns in some humans.

Development of large-scale recirculation systems, aquaponics and integrated multi-trophic aquaculture (IMTA) is occurring internationally but has not yet been adopted in the UK. The food safety risks in open net pens are well understood, but these newer systems may give rise to greater opportunities for incidents of contamination. For example, IMTA uses waste from fish to feed shellfish so that chemicals used to treat the fish might be transferred to other trophic levels (i.e.

shellfish).

6.3 Known risks for which guidance exists

6.3.1 Water

Water is ubiquitous in primary production both as a component of the food produced and as a cleaning agent for surfaces and equipment used during the production process. Changes to land and energy use to move towards net zero carbon may affect the amount of water available for primary production and as competition for fresh water increases, there may be pressures for agriculture to use more ‘brown water’ especially in peri-urban areas. Clean water is an essential component of a safe food system, with water contaminated with heavy metals and/or sewage posing numerous food safety risks requiring meticulous management. For example, the on-farm washing of salad products has previously led to outbreaks of cryptosporidiosis in humans; these risks may increase if pressure to conserve water use increases as a response to net zero carbon measures. Current regulations are intended to minimise safety risks, but incidents of pollution of river and coastal waters have resulted in documented cases of food contamination.

6.3.2 Manure, sludge and compost

Good manure management is key to the effective operation of many agricultural systems and the delivery of safe food. Farm manure contains many microorganisms that pose a risk to food safety and these need to be managed by, for example, allowing a minimum of six months between manure application and seed drilling (FSA, 2009). Similarly, guidance exists for the application of sewage sludge and compost. If farmers do not apply these organic fertilisers according to the guidance, then this could lead to an increased risk of contaminated food. Ready to eat crops (e.g., baby leaf spinach, salads, some fruits) provide the highest potential food safety risk because contaminated irrigation water downstream of the site of organic fertiliser application may be used unknowingly. Similarly, water polluted with slurry and solid manure poses food safety risks for fish, shellfish and seaweed via multiple pathways. Active pharmaceutical ingredients originating from human and animal waste have been detected in the environment, water and edible plants (Cunningham *et al*., 2009; Hafner *et al*., 2023). While such reports have resulted in media attention, there is no evidence of direct risks to human health (Cunningham *et al*., 2009). Research publications are available on the behaviour of microplastics in sludge and compost (Mahon *et*

al., 2023). However, there is a scarcity of data on appropriate treatment options to protect agricultural systems.

It should be noted that processes to remove residues also have a carbon footprint and, therefore, a risk-based approach is essential.

Table 2. Key food safety risks arising from net zero carbon changes to food and feed production practices;

Recognised risk	RR
Potential risk	PR
No identified risk	NIR

Risk category	Production system or input to system	**Food safety risk**: Allergenicity	**Food safety risk**: Chemical contamination	**Food safety risk**: Biological contamination
Areas where new risks might emerge	Animal and fish feeds	NIR	PR	RR
Areas where new risks might emerge	Vertical farms	NIR	RR	RR
Areas where new risks might emerge	New protein sources	RR	PR	NIR
Areas where new risks might emerge	Cellular agriculture	NIR	PR	PR
Areas where new risks might emerge	Packaging	PR	RR	RR
Areas where new risks might emerge	Use of wastes	NIR	PR	RR

Known food safety risks in new backgrounds	Regenerative/mixed/rewilded farming	NIR	NIR	RR
Known food safety risks in new backgrounds	Agroforestry	PR	NIR	PR
Known food safety risks in new backgrounds	Aquaculture	PR	RR	NIR
Known risks for which guidance exists	Water	NIR	RR	RR
Known risks for which guidance exists	Manure, sludge and compost	NIR	PR	RR

7. Risk profile, conclusions and recommendations

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7.1 Risk profile

The primary responsibility for assessing, quantifying and managing hazards and risks through mitigation measures resides with individual food producers supported by the regulatory and enforcement activities of governments. Because this project has essentially been an exercise in looking ahead to potential food safety risks, there is, as already mentioned, almost no published quantitative

information available on the likely size, impact and range of such risks with respect to their interaction with measures to move towards net zero carbon. Several potential hazards and the risks associated with different elements of primary food and feed production have been assessed.

Table 3 takes the key potential food safety risks identified in **Table 2**, identifies factors contributing to the risk, and ranks the relative level of concern before any mitigation has occurred. This ranking was based on the degree of concern expressed in expert interviews and reading of literature. Mitigation and current controls, either via the use of existing regulations and codes of practice or the extrapolation of existing good practice to new production practices, are identified. **Table 3** is for production practices and **Table 4** is for the major inputs of water and nutrients into field-based systems of primary crop production.

Three features stand out from this exercise:

1. The rigorous employment of current regulations and codes of practice should be sufficient to reduce most potential food and feed safety concerns associated with practices to move towards net zero carbon to low risks.
2. Priority needs to be given to increased emphasis and capacity to enforce the current guidelines and regulations to meet amplifications of existing risks.
3. Much ownership of the regulations and codes of practice falls outside the FSA so that the food and feed safety responsibility of the FSA can only be achieved through active cross-departmental cooperation, especially with Defra.

Table 3: Risk profile, risk management and recommended assurance mechanisms in changed production systems that may contribute to moving towards net zero carbon. Food safety risks are allergenicity (Aller), chemical (Chem), and biological (Biol). Levels of concern are **High**, medium (**Med**) and requires further understanding (**RFU**). The leading owner of the recommended assurance mechanism is shown as (L).

Production system	Food safety risk	Factors contributing to risk	Level of concern	Mitigation and current controls	Owner	Rec ass me

Animal and fish feeds	Biol	Introduction of animal products directly or via waste streams.	**High**	Feed regulations	FSA(L) Defra	Dev Adv Con Ani (AC
Vertical farms	Chem	Dirt and dust accreting with age.	**High**	Good practice and retailer assurance.	Defra(L) FSA	Rec prac to b dev
	Biol	Biofilms in pipes and media.	**High**	Good practice and retailer assurance.		
Novel protein sources	Aller	Plants and insects are potential allergens.	**High**	Product monitoring and public awareness. Selection of insect feed.	FSA(L) DoH Defra	Alle labe
	Chem	Some insects and seaweed accumulate heavy metals.	**Med**	Moving seaweed production offshore.	FSA(L) Defra	Mor whe con in fo

	Chem	Migration of chemicals from plastics.	**RFU**	Use of more inert materials.	FSA	Res requ
Cultured meat	Biol	Use of antimicrobials.	**RFU**	Some antimicrobial use necessary to avoid microbial contamination.	VMD(L) FSA	Res requ
Packaging	Chem	Nanomaterials.	**High**	Minimise metal use. Packaging regulations.	FSA	Pac regu Reu pac requ guic
	Biol	Biopolymers may allow microbial incursion.	**High**	Monitor and improve polymers.	FSA	
Regenerative/mixed/rewilded farming	Biol	Proximity of animals and crops. Interaction of wild and domestic animals. Changed cropping may increase incidence of mycotoxins.	**High**	Strict separation of manure and edible parts of crops. Monitoring of aflatoxins.	Defra(L) FSA	Upd imp of e guic

Agroforestry	Aller & Biol	Specific concerns depending on tree/crop combination.	**Med**	Separation of edible crop parts (e.g. nuts and grains).	Defra(L) FSA	Upd imp of e guic
Aquaculture	Aller	Cross contamination of products.	**Med**	Quality control processes.	Defra(L) FSA	Reg goo prac
	Chem	Contamination of sea with heavy metals and chemicals used to treat fish.	**High**	Monitoring water quality and moving production pens offshore.	Defra(L) FSA	Enfo curr regu

Table 4: Risk profile, risk management and recommended assurance mechanisms for common inputs into field-based primary crop production systems that may contribute to moving towards net zero carbon. Food safety risks are allergenicity (Aller), chemical (Chem), and biological (Biol). Levels of concern are **High** and medium (**Med**) and requires further understanding (**RFU**). The leading owner of the recommended assurance mechanism is shown as (L).

Input	**Food safety risk**	**Factors contributing to risk**	**Level of concern**	**Mitigation and current controls**	**Owner**	**Recommended assurance mechanism**

Water	Chem	Increased use of grey water with heavy metals in crop production.	**Med**	Enforcement of current manure, sewage and water regulations.	Defra(L) FSA	Current regulations need to be rigorously enforced.
	Biol	Contamination with nitrate and phosphorus promoting algal and microbial growth.	**High**	Enforcement of current manure, sewage and water regulations.	Defra(L) FSA	
Manure, sludge and compost	Chem	Sludge may contain chemical contaminants.	**Med**	Monitoring and compliance with good practice .	Defra(L) FSA	Ensuring existing guidance is known to the farming community and rigorously enforced.
	Biol	Microbes in manure and slurry can contaminate water and crops.	**High**	Compliance with good practice guidelines.	Defra(L) FSA	
Use of food by-products	Chem	Chemical contamination.	**Med**	Monitoring and codes of practice.	Defra(L) FSA	Codes of practice updated to incorporate current waste materials.
	Biol	Survival of pathogens.	**High**	Monitoring and codes of practice.	Defra(L) FSA	

7.2 Conclusions

This report was limited to considering changes occurring in the next decade. In the longer term the UK's contribution to achieving net zero carbon globally will be very dependent on the UK's carbon footprint in primary production not being moved offshore (i.e. carbon leakage; see for example, UKCCC, 2022). The balance between UK production and imports of food is also an important driver of food safety risks and requires constant monitoring. The longer-term view on food safety will need to take account of the rapid developments in novel proteins and associated allergens, novel packaging materials and crop breeding technologies.

To respond effectively to potential food safety risks and consumer interests arising from activities to deliver net-zero carbon policies, support and research will be required from multiple government departments (see Tables 3 and 4). Some of the current Areas of Research Interest (ARIs) of the FSA (e.g. Adapting to the food and feed system of the future; Addressing Global Grand Challenges) and Defra (e.g. Climate Change and Net Zero, Land Use, Nature-Based Solutions, One Health) are relevant to a better understanding of the impact of net zero carbon policies. These ARIs provide an opportunity for cooperation, co-funding and visibility of key areas in need of more scientific data. Although it was not an objective of this report to produce a list of research needs, some obvious examples have been highlighted (e.g. mycotoxins; new food production systems such as cultured meat; impact of microplastics and other materials in waste streams and in soil). A systematic analysis of research gaps is needed to identify where further scientific evidence is required to inform policy developments. While there is some synergy between the FSA and Defra ARIs, as primary production practices change, effective horizon scanning, joint research and analysis will be needed to underpin the FSA's ability to meet the associated challenges.

We have reached the following conclusions:

- Overall, discussions with academic and business experts indicate that changes to primary food production practices to accommodate the move towards net zero carbon are likely to be largely positive for society and provide good business opportunities to develop a competitive agriculture and food production sector that delivers safe foods.
- Moves towards net zero carbon may change the degree and balance of known existing risks where novel technologies are employed.
- Known safety risks will also reappear in production systems which are based on earlier production systems for which traditional good practice-based

knowledge has been lost or is limited.

- New high-protein foods from plant, insect and animal cell cultivation raise particular issues about allergenicity and other legitimate factors such as ethical considerations.
- New entrants to novel technologies for food production may be unfamiliar with the food safety and other regulations which already exist. While new ideas and sources of funding are welcome, inexperience with practical risk assessment and management protocols is a concern.
- Existing regulations, codes of practice and guidelines should be sufficient, if fully implemented, to reduce to acceptable levels the food safety risks identified in this report which are associated with the move towards net zero carbon. However, there is evidence (e.g. for water) that these frameworks are neither followed in practice nor rigorously enforced. This should be a matter of concern for the FSA.
- The involvement of multiple government departments in the regulation of the UK food system increases the likelihood that some food safety issues associated with moves to net zero carbon may be overlooked or fall between departmental remits.
- Several sections of this report point to the increasing complexity and pace of developments. Changes to production practices are occurring quickly so agility and vigilance will be needed to ensure a speed of response that keeps ahead of these developments. This will require regular, collaborative horizon scanning and data gathering in collaboration between government departments and agencies.

7.3 Recommendations

Throughout this report and especially in Tables 3 and 4, it is clear that the mitigation of many food safety issues stems in whole or part from policies or regulations overseen by government departments other than the FSA. For example, water and manure regulations are the responsibility of Defra in the UK Government while any changes envisaged in the land use, land use change and forestry sector to move towards net zero carbon will also involve the devolved administrations. The Science Council is constituted to make recommendations to the FSA alone, but in several places the recommendations will require the FSA to facilitate discussions with other government departments and investigate these multifaceted problems collaboratively.

We have grouped our recommendations for food and animal feed safety into three major themes: i) surveillance of emerging technologies and engagement with producers and consumers; ii) inter-departmental cooperation and regulatory review; and iii) research and horizon scanning:

7.3.1 Surveillance of emerging technologies and engagement with producers and consumers

We recommend that the FSA:

1. Maintains active surveillance of likely areas of production changes in response to net zero carbon policies and encourages food and feed businesses to embed responsibility for food safety into their innovative practices following PAS 440 principles (from the BSI).
2. Develops guidance that will ensure safe food at the site of production through active engagement with new food-producing technologies (e.g. vertical farming, novel proteins such as insect rearing and cultured meat).
3. Develops and communicates advice for primary producers and consumers on how to minimise food safety risks when producing or consuming foods that they perceive as contributing towards net zero carbon or sustainability agendas (e.g. recycling of food by-products, reuse of packaging, foraging).

7.3.2 Inter-departmental cooperation and regulatory review

We recommend that the FSA:

4. Engages with other government departments to assess the effectiveness of current regulation, enforcement, codes of practice and guidance in assuring future food and feed safety and, given the changes to primary production practices described in this report, whether the balance and scope of these assurance mechanisms is appropriate.
5. Ensures that the regulatory framework for animal feed is sufficiently agile to cope with fast-moving changes and any accompanying risks arising from the many innovative net zero carbon developments including new and novel protein sources, food waste recycling, by-product/co-product use and new supplements.
6. Rapidly establishes whether the current risk analysis and regulatory frameworks in place are able to cope with the novel technologies, ingredients and products which might be used in food.

7. Reviews the potential impacts on food safety arising from the use of manure, compost, slurry, sewage sludge and food by-products applied to land to determine whether current regulatory frameworks are fit for purpose as companies and consumers move towards net zero carbon.

7.3.3 Research and horizon scanning

We recommend that the FSA:

8. Undertakes a systematic analysis of research gaps to identify where scientific evidence is needed to understand the risks and benefits associated with production and consumption of food and feed in a low carbon economy. The added challenge of a food supply that provides sustainable healthy diets should not be underestimated in the context of the above recommendations and necessitates a strong programme of horizon scanning and analysis to stay ahead of technological, commercial and social developments.

Work is already underway in the FSA and Defra to mitigate several of the potential food safety risks identified in this report. **Annex 3** outlines some of the current work to mitigate some of the risks identified and to improve regulatory frameworks which deliver safe food and feed from primary producers.

8. Acknowledgements

In this guide

We are especially grateful for comments received on an earlier draft of this report from staff in the FSA and Defra, and for the external reviews of Prof. Bob Doherty (University of York) and Prof. Bridget Emmett (Centre for Ecology and Hydrology, Bangor). These inputs have substantially improved this final version.

Annex 1: Methodology employed in the collation of evidence for this report

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8. Acknowledgements
9. Annex 1: Methodology employed in the collation of evidence for this report
10. Annex 2: Government policies and technological changes affecting primary production
11. Annex 3: Current FSA and Defra activities highlighted during WG6's work that aim to address potential food and feed safety issues raised in the

This project was undertaken in four phases using the following methodology:

Phase 1

The early scoping Phase 1 (interviews and survey) sought expert input on activities over the next decade to achieve net zero carbon which are being made to primary production practices and technologies and which may, in turn, affect the whole food system. For example, possible changes to animal feed, changes/innovations in soil management for carbon capture, changes to crop growing practices, and restoration of wetlands.

Five experts were interviewed about the broad landscape of carbon emissions reduction for the food system in July and August 2021:

• **Prof Tim Benton** (Chatham House): Director, Environment and Society Programme and is an IPCC and CCRA author.

• **Prof Jonathan Scurlock** (NFU) who has over 30 years' experience as a specialist in environmental science and energy policy, with particular expertise in bioenergy and other renewable energy technologies, climate change and the global carbon cycle.

• **Prof/Dr Emma Piercy** (FDF): Head of Climate Change and Energy Policy at the Food and Drink Federation (FDF), which recently announced their roadmap to net zero by 2040.

• **Prof Bob Doherty** (University of York): Professor of Marketing and Chair in Agrifood at the University of York Management School.

• **Pete Smith** (University of Aberdeen): Science Director of Scotland's Climate Change Centre of Expertise.

The WG6 Chair (Mrs Claire Nicholson) and deputy Chair (Prof Jonathan Wastling) interviewed these experts with assistance from the Science Council Chair (Prof Sandy Thomas) and a Science Council Member with expertise in agronomy, Prof Peter Gregory. These interviews helped frame the questions used in the follow-up survey.

A **targeted survey of a diverse range of experts** was then carried out across a range of disciplines relevant to sustainability, carbon reduction and the food

system. This survey asked the participants to identify specific changes that will be happening to (or affecting) the food system over the next decade in the move towards net zero carbon.

The survey was sent to nearly 90 individuals and organisations and was also forwarded to other experts by respondents. There were 31 responses which were summarised by means of categorisation (incl. occupation, sector etc) in the Ipsos/MORI report attached as Annex B of the interim report (https://science-council.food.gov.uk/Online%20Survey%20Responses; FSA 2022c). Note that the comments in this annex are those of the participants and not necessarily those of the Science Council.

Phase 2

Phase 2 consisted of an in-person workshop that took place on 18 November 2021 and focused on mapping out the food safety implications of activities in primary food production over the next decade to help achieve net zero carbon. Thirty-one participants took part in the workshop; this included thirteen participants from the FSA and the Science Council, and 18 external experts comprising academics as well as practitioners from agriculture and industry.

The event brought together wide-ranging expertise in food science, allergy and immunology, human and animal infectious diseases, zoonoses, food safety and nutrition, food sustainability, environmental impact of livestock and livestock management, veterinary and livestock industry, meat and seafood industry, land use systems, soil and crops, agriculture and horticulture development.

The Ipsos/MORI written record of the workshop was provided as Annex C in the Interim Report. Again, the views expressed are those of the participants and not necessarily those of the Science Council.

Phase 3

This phase had two main elements:

1. Further engagement with experts to both confirm understanding of outcomes, due to particular activities, and to build up knowledge about activities that had not been fully addressed by Phase 2.
2. A workshop with representatives from other UK Government Departments whose remit means they have joint policy responsibility with the FSA on some decarbonisation activities that had been highlighted in Phase 2.

1. The following experts were interviewed:

- Angela Booth (AG Agri) – Livestock feed
- Cath Lehane (Red Tractor) – Wider view of farming developments
- Simon Thorpe (Red Tractor) - Wider view of farming developments
- Prof Ilias Kyriazakis (Queens University Belfast) – Livestock feed
- Nigel Edwards (Hilton Food PLC) – Farmed Fish
- Dave Robb (Cargill) – Farmed Fish
- Paul Morris (Mowi Feed) – Farmed Fish
- Nina Sweet (Consultant and formerly technical advisor at the Waste and Resources Action Programme (WRAP)) – Waste to land and anaerobic digestion
- Prof Louise Heathwaite (Chair of the Defra Science Advisory Council) – Science and policy in sustainable agriculture
- Tim Ellis (CEFAS) – Farmed fish and aquaculture
- Eliza Capuzzo (CEFAS) – Farmed fish and aquaculture
- Keith Jeffery (CEFAS) – Farmed fish and aquaculture
- Tom Jenkins (Innovate UK) – Innovative agriculture technology
- Andrew McLay (Innovate UK) – Innovative agriculture technology

2. On 20 June 2022 FSA held a workshop to engage with other Government Departments with an aim to establish where cooperation is needed, as many of the activities to help decarbonise food production with a food safety aspect straddle the divides between departmental remits and necessitate joint investigation. Representatives from the following Departments were invited.

- Department for Environment, Food and Rural Affairs (Defra)
- Department for Business, Energy and Industrial Strategy (BEIS)
- Health and Safety Executive (HSE)
- Government Office of Science (GO-Science)
- Department for Transport (DfT)

The Chair of the FSA Advisory Committee on Social Science (ACSS) also participated. The Department for Health and Social Care (DHSC) were unable to attend but were consulted on the outcomes from the workshop afterwards.

Phase 4

This phase involved additional reading by Peter Gregory of some refereed papers and a wide range of grey literature (particularly reports from international and UK agencies) recommended by survey respondents and the experts interviewed. As writing of the final report progressed, sections were commented on and revised by member of the working group. Members of the Science Council had five formal opportunities to comment on drafts before the final report was approved.

Annex 2: Government policies and technological changes affecting primary production

In this guide

Policy context

A key policy of the UK government is its Food Strategy (Defra, 2022) designed to deliver the following objectives:

- ‘a prosperous agri-food and seafood sector that ensures a secure food supply in an unpredictable world and contributes to the levelling up agenda through good quality jobs around the country
- a sustainable, nature positive, affordable food system that provides choice and access to high quality products that support healthier and home-grown diets for all
- trade that provides export opportunities and consumer choice through imports, without compromising our regulatory standards for food, whether produced domestically or imported.’

It is proposed to achieve these objectives through multiple activities, among which is the reduction of GHG emissions in line with net zero commitments, namely:

1. ‘Broadly maintain the current level of food produced domestically, including sustainably boosting production in sectors where there are post-Brexit opportunities including horticulture and seafood.
2. Ensure that by 2030, pay, employment and productivity, as well as completion of high-quality skills training will have risen in the agri-food industry in every area of the UK, to support our production and levelling up objectives.
3. Halve childhood obesity by 2030, reducing the healthy life expectancy (HLE) gap between local areas where it is highest and lowest by 2030, adding 5 years to HLE by 2035 and reducing the proportion of the population living with diet-related illnesses; and to support this, increasing the proportion of healthier food sold.
4. Reduce GHG emissions and the environmental impacts of the food system in line with our net zero commitments and biodiversity targets and preparing for the risks from a changing climate.
5. Contribute to our export strategy goal to reach £1 trillion of exports annually by 2030 and supporting more UK food and drink businesses, particularly small and medium sized enterprises (SMEs), to take advantage of new market access and free trade agreements (FTAs) post-Brexit.
6. Maintain high standards for food consumed in the UK, wherever it is produced.’

These objectives and associated activities demonstrate the multi-dimensional nature of the UK food system and its policy environment and the close alignment of climate change, GHG emission and net zero considerations.

The UK Committee for Climate Change examined the changes required to UK land use to achieve net zero (UKCCC, 2020). Their report starts from a premiss that ‘ *the current approach to land use is unsustainable if the UK is to maintain a strong agriculture sector that also delivers climate mitigation, adaptation and wider environmental objectives*’. The current rate of decline of GHG emissions across the food system is insufficient to meet net zero by 2050, so the report makes the case for climate mitigation to be at the heart of a new land use strategy.

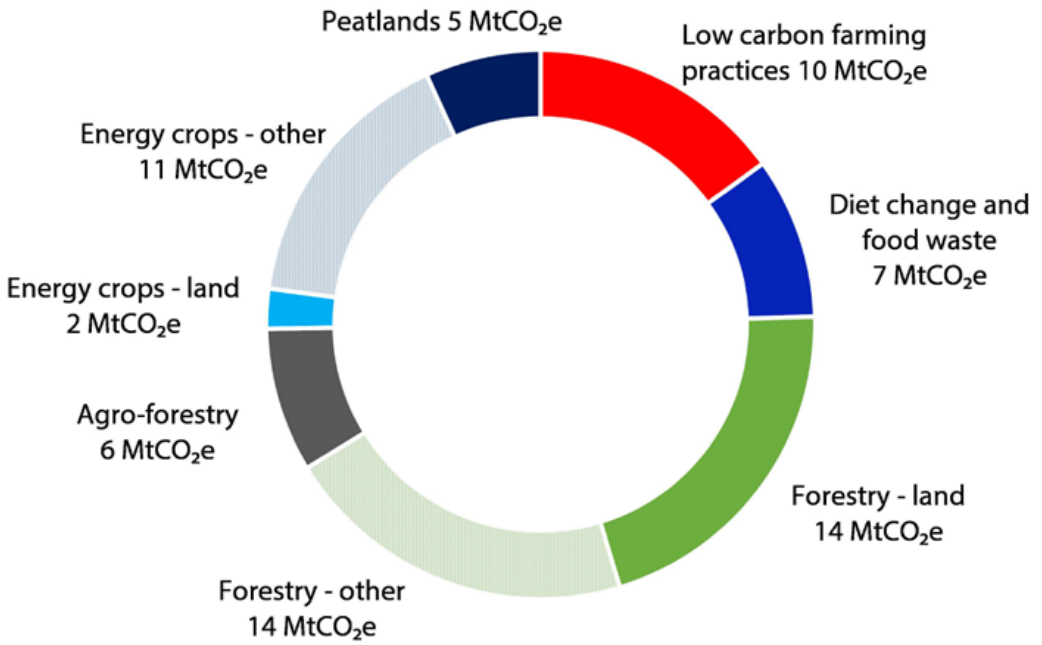
The report proposes that about 9% of agricultural land will be required for actions to reduce GHG emissions and sequester carbon by 2035 and 21% by 2050; this would reduce emissions by 67% from the LULUC (and forestry) sector by 2050. The corollary is that the UK’s domestically produced food will have to come from about 25% less land by 2050.

A wide range of actions is proposed to deliver reduced emissions (Annex 2, figure 1) with about half of the reduction coming from afforestation with agroforestry and energy crops contributing a further third. The key actions envisaged are:

1. Low carbon farming practices to reduce GHG emissions from soil, livestock and manure – includes controlled release fertilisers, improved livestock health, slurry acidification.
2. Afforestation and agro-forestry – increase forest cover from 13% to 17% by 2050 at a rate of 30,000 ha per year.
3. Restoration of peatlands – restore at least 50% of upland peat and 25% of lowland peat.
4. Bioenergy crops – expand the growing of energy crops by 23,000 ha per year.
5. Reduce consumption of carbon-intensive foods – consumption of beef, lamb and dairy products reduced by at least 20% per person and food waste by 20%. This equates to a 10% reduction in sheep and cattle numbers by 2050 compared with 2017.

In essence the proposals fall into two groups: first, delivery of reductions in land-based emissions and increased carbon sequestration; and second, reduced demand through dietary change and reductions in food waste. Given the extensive nature of changes proposed, the report acknowledges ‘there is inevitable uncertainty around the precise levels of ambition that can be achieved

in practice’. However, a critical component of the UKCCC report is that the emission reductions delivered should not be at the expense of food imports that result in ‘carbon leakage’ to other countries. A mix of regulation, financial incentives and enabling policies is required to deliver the actions envisaged.



Source: CCC analysis.
Notes: Based on the CCC ‘Further Ambition’ scenario in *Net Zero - The UK's contribution to stopping global warming*. These are savings compared with business as usual GHG emissions in 2050.
'Energy crops - other' and 'Forestry - other' refer to GHG savings from the use of harvested products in other sectors of the economy (e.g. with CCS).
Savings from diet change and waste reduction are from direct agricultural emissions reduction only.

Annex 2 Figure 1: GHG savings from measures proposed to reduce UK agriculture and land use emissions (UKCCC, 2020).

While there is strong consensus among organisations and institutions representing primary producers that an integrated approach to reducing GHG emissions is required that also embraces food production, biodiversity, water quality and other environmental factors, there is much less agreement on the actions to be taken (Ward, 2023).

Both the National Farmers Union (NFU, 2019) and the Food, Farming and Countryside Commission (FFCC, 2019) have developed alternative suggestions for how producers might contribute to net zero, with the NFU focussed on food

production and modest carbon reductions and the FFCC on farmland biodiversity through agroecological interventions that promote both production and nature conservation, but very little about carbon. Together, these three reports highlight a set of emerging tensions that will require resolution including (Ward, 2023):

1. The relative balance of effort and potential between supply-side and demand-side measures to reduce emissions.
2. Contrasting visions of farming's role in food production and environmental management.
3. Different implicit models of behaviour change among farmers and landowners and of the relationship between the state and the individual.
4. The techniques and technologies for measuring and monitoring progress in emissions' reductions.

How these tensions are resolved in practice have several consequences for food safety considerations. For example, demand-side changes to diets (e.g. reduced ruminant meat and dairy and increased plant protein consumption) and reduced food waste have potential allergen and microbiological implications. Similarly, the juxtapositioning of wildlife and animal production to combine nature and production objectives risks harming farm animal health with knock-on consequences for meat composition and quality.

Technological innovation

Technological innovations are already underway in nearly all areas of primary production and throughout the food system. The FSA's Rapid Evidence Assessment of emerging technologies impacting the UK food system identified six important technology fields (FSA, 2021):

1. Food production and processing (indoor farming, 3D food printing, food side- and by-product use, novel non-thermal processing, novel pesticides).
2. Novel sources of protein (such as insects for human food and animal feed).
3. Synthetic biology (cultivated meat and proteins).
4. Genomic applications along the food chain (for food safety applications and personal 'nutrigenomics').
5. Novel packaging (active, smart, biodegradable, edible and reusable).
6. Digital technologies in the food sector (supporting analysis, decision making and traceability).

The Assessment examined some of the food safety risks (allergen, contamination/toxicity and fraud) associated with each of the technological

innovations identified within each technology field. Annex 2 Table 1 details the level of various food safety risks associated with those technologies that affect primary production, although it is not clear from the report how the assessments of high, medium and low categories were derived. The report concluded that the widespread nature of change means that the FSA should ‘adopt a complex systems perspective to future food safety regulation’ (FSA, 2021).

Innovate UK provides funding to de-risk the translation of innovation from research to exploitation and is supporting work in three key areas of primary production:

1. Precision agriculture (including biosensors, drones, imagery, spectral cameras, calving interventions etc with smart phones often as the end point and agronomists and vets as the delivery points to farmers).
2. Alternative proteins (including non-traditional crops, insects (black soldier fly), microalgae and bacterial fermentation – aquaculture and monogastric animals are often the target markets for these products.
3. Controlled ‘farming’ (including vertical farming, growing cultivated meats, developing production systems as an optimised factory).

The development of alternative proteins is supported by private equity investment and is currently the fastest growing area globally because consumer demand makes it attractive from an investor perspective.

Annex 2 Table 1. Abbreviated table from the FSA Rapid Evidence Appraisal of Emerging Technologies that will impact the Food System

Emerging technology	**Food safety risk:** Allergens	**Food safety risk:** Con/Tox	**Food safety risk:** Fraud	**Enhanced food safety:** Allergens	**Enhanced food safety:** Con/Tox	**Enhanced food safety:** Fraud
Food production and processing						
Indoor farming	No	Medium	No	Medium	Medium	Low

Food side/by products	Medium	High	High	No	No	No
Novel pesticides	Low	Low	No	No	Medium	No
Novel proteins						
Alternative proteins	Medium	High	High	No	No	No
Novel feedstocks	Low	Medium	Medium	No	No	No
Synthetic biology						
GM/GE organisms	Medium	Medium	No	Medium	Medium	No
Lab-based products	Medium	High	High	No	Medium	Medium
Genomic applications						
Genomes for food safety	No	No	No	Low	High	High
Genomes for personalised medicine	No	No	No	High	High	No
Novel food packaging						
Active packs	Low	Low	No	Low	Medium	Medium
Nanotech/biodegradable	Medium	Medium	No	Low	Medium	No
Reusable	High	High	High	No	No	No

No = no anticipated impact

Annex 3: Current FSA and Defra activities highlighted during WG6’s work that aim to address potential food and feed safety issues raised in the report.

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Recommendation	FSA/Defra activity
1. Maintains active surveillance of likely areas of production changes in response to net zero carbon policies and encourages food and feed businesses to embed responsibility for food safety into their innovative practices following PAS 440 principles.	**FSA** - Our Food 2021: An annual review of food standards across the UK also includes an assessment of compliance against food law requirements.

2. Develops guidance which will ensure safe food at the site of production through active engagement with new food-producing technologies (e.g. vertical farming, novel proteins such as insect rearing and cultured meat.)	**FSA** - Novel foods and processes (including novel proteins such as insect) will need to be assessed as novel foods before being placed on the market. Novel foods need to pass a safety assessment before going on sale in the UK and that includes considering the allergenic potential of that food. The FSA has commissioned a wholesale review of the Novel Foods Regulatory Framework, identifying and critically evaluating a range of potential regulatory models, taking into account the UK regulatory landscape and drawing on international best practice and stakeholder views. The review is due to be completed by spring 2023 which will help inform guidance for novel food applications and stakeholders, later in 2023. The FSA is currently expanding its stakeholder engagement function to maintain ongoing dialogue with the industry. This includes dedicated Account Managers and our plans for a single point of contact under the new Case Management System (CMS) which is due to go live in spring 2023. CMS will also provide applicants more support at the front end of the service and there will be a number of steps prior to applicants submitting a new application to help them establish what information is essential for their application to progress.

3. Develops and communicates advice for primary producers and consumers on how to minimise food safety risks when producing or consuming foods that they perceive as contributing towards net zero carbon or sustainability agendas (e.g. recycling of food by-products, reuse of packaging, foraging).	**FSA** - Containers for re-use must be designed for repeated use and are subject to food Contact Materials legislation. Testing based on expected use of the final article must be carried out on plastic food contact materials. FSA has prepared consumer guidance for foraging that was published in January.

4. Engages with other government departments to assess the effectiveness of current regulation, enforcement, codes of practice and guidance in assuring future food safety and, given the changes to primary production practices described in this report, whether the balance of these assurance mechanisms is appropriate.	**Defra** - As part of the Government's Food Strategy, Defra will work with the FSA to develop dedicated guidance materials for approval of alternative protein products as part of the review of novel food regulations. The Environment Agency's sludge strategy is available at https://www.gov.uk/government/publications/environment-agency-strategy-for-safe-and-sustainable-sludge-use

5. Ensures that the regulatory framework for animal feed is sufficiently agile to cope with fast-moving changes and accompanying risks arising from the many innovative net zero carbon developments including new and novel protein sources, food waste recycling, by-product/co-product use and new supplements.	**FSA** - The FSA Advisory Committee on Animal Feed (ACAF) assesses any new feed or ingredients in feed. Recycled food (not of animal origin) falls under FSA animal feed legislation, but recognised Animal By-product and Transmissible Spongiform Encephalopathies (TSE) legislation means Defra lead where products of animal origin (POAO) are included.

6. Rapidly establishes whether the current risk analysis and regulatory frameworks in place are able to cope with the novel proteins and cultured meats that might find their way into food and feed.	**FSA** - Novel foods and processes (including novel proteins such as insect) will need to be assessed as novel foods before being placed on the market. Novel foods need to pass a safety assessment before going on sale in the UK and that includes considering the allergenic potential of that food and the risk of contaminant transfer from feed substrates. The current regulatory framework inherited from the EU considers the safety assessment of new products. ACNFP independently reviews safety assessments. The authorisation process also has a requirement to publicly consult on the risk management opinions prior to the FSA making recommendations on authorisations. A limited number of insect species are currently permitted on the market under transitional measures but applications for authorisation, including evidence on safety, will need to be submitted by 31 December 2023 for these insect species to remain on the market.

7. Reviews the potential impacts on food safety arising from the use of organic wastes and food by-products applied to land to determine whether current regulatory frameworks are fit for purpose as companies and consumers move towards net zero carbon.	**Defra** – The existing regulatory regime for the manufacture and placing of fertilisers on the market in the UK is fragmented and does not cover organic or recycled nutrients and newer types of fertilisers that are used in combination with traditional fertilisers to improve nutrient use efficiency. A new framework is under development to streamline statutes and smooth the route to market of new and innovative products that are less polluting to the environment or are less resource intensive in their manufacture. Consultation on the new framework is planned in 2023. Current research under Defra's agri-food evidence portfolio aims to establish baseline data on levels of potentially toxic elements (PTEs) in mineral fertilizer products sold in England and to appraise the domestic implications of setting or reducing thresholds of PTEs across the EU and within the UK. It will also explore the presence of a broader range of contaminants in inorganic and organic fertilisers including waste-derived products. The Environment Act 2021 requires local authorities in England to arrange weekly collection of food waste for recycling or composting. Anaerobic digestion is the government's preferred route for treating food waste. Defra is working with stakeholders, including industry and local authorities, to expand the capacity for food waste treatment in England. It is also working closely with the BEIS who lead the Green Gas Support Scheme (GGSS), which is incentivising the building of new anaerobic digestion facilities. **FSA** - Hygiene and contamination team continue to work with Defra where any changes they propose could have food safety implications.

8. Undertakes a systematic analysis of research gaps to identify where scientific evidence is needed to understand the risks and benefits associated with production and consumption of food and feed in a low carbon economy. The added challenge of a food supply “that is healthier and more sustainable” should not be underestimated in the context of the above recommendations and necessitates a strong programme of horizon scanning and analysis to stay ahead of technological, commercial and social developments	**FSA** - Recently published a piece on the future of animal feed that is focused on sustainability impacts The Future of Animal Feed: Acknowledgements | Food Standards Agency

Annex 4: References

In this guide

Banach, J.L., Hoek-van den Hil, E.F., van der Fels-Klerx, H.J. 2020. Food safety hazards in the European seaweed chain, Comprehensive Reviews in Food Science and Food Safety 19, 332-364.

Business, Energy and Industrial Strategy (BEIS). 2021. Net Zero Strategy: Build Back Greener. HM Government, London. October 2021.

Cairo, J., Gherman, I., Day, A. and Cook, P.E. 2022. *Bacillus cytotoxicus* – a potentially virulent food-associated microbe. Journal of Applied Microbiology, 132, 31-40.

Chiaranunt, P. and White, J.F. 2023. Plant beneficial bacteria and their potential applications in vertical farming systems. Plants, 12, 400.

Committee on Toxicology (COT). 2021. Annual report for 2020. FSA, London.

Cunningham, V., Binks, S.P. and Olson, M.J. 2009. Human health risk assessment from the presence of human pharmaceuticals in the aquatic environment, Regulatory Toxicology and Pharmacology 53, 39-45.

Department for Environment Food and Rural Affairs (Defra). 2022. Government Food Strategy. HM Government, London. June 2022.

European Food Safety Authority (EFSA). 2011. Scientific Colloquium on Emerging Risks in Food: from Identification to Communication, EFSA Scientific Colloquium. Summary Report 15.

European Food Safety Authority (EFSA). 2019. Scientific report on analysis of the European baseline survey of norovirus in oysters. EFSA Journal 17(7):5762, 86 pp. https://doi.org/ 10.2903/j.efsa.2019.5762

European Food Safety Authority (EFSA). 2020. Climate change as a driver of emerging risks for food and feed safety, plant, animal health and nutritional quality. EFSA supporting publication 2020:EN-1881.

Fiorella, K.J., Okronipa, H., Baker, K. and Heilpern, S. 2021. Contemporary aquaculture: implications for human nutrition. Current Opinion in Biotechnology, 70, 83-90.

Food and Agriculture Organisation of the United Nations (FAO). 2022. Climate change: implications for food safety. FAO, Rome.

Food, Farming and Countryside Commission (FFCC). 2019. Our Future in the Land. Royal Society for the Arts, London.

Food Standards Agency (FSA). 2009. Managing farm manures for food safety. London, FSA.

Food Standards Agency (FSA). 2019. Review of bio-based food contact materials. London, FSA. June 2019.

Food Standards Agency (FSA). 2020. Market and safety analysis of alternatives to plastic food packaging. London, FSA. October 2020.

Food Standards Agency (FSA). 2021. Rapid Evidence Review. Emerging technologies that will impact on the UK food system. London, FSA.

Food Standards Agency (FSA). 2022a. Alternative proteins for human consumption. London, FSA.

Food Standards Agency (FSA). 2022b. FSA Advisory Committee for Social Science. Impact of climate change on consumer food behaviours. London, FSA.

Food Standards Agency (FSA). 2022c. FSA Science Council Working Group 6. Food safety and net zero carbon. Interim Report. London, FSA. July 2022.

Galecki, R. and Sokól, R. 2019. A parasitological evaluation of edible insects and their role in the transmission of parasitic diseases to humans and animals. PLoS ONE, 14, e0219303.

Häfner F, Monzon Diaz OR, Tietjen S, Schröder C and Krause A. 2023. Recycling fertilizers from human excreta exhibit high nitrogen fertilizer value and result in low uptake of pharmaceutical compounds, Frontiers of Environmental Science, 10, 1038175.

doi: 10.3389/fenvs.2022.1038175

Intergovernmental Panel on Climate Change (IPCC). 2022. Working Group II Report. Impacts, adaptation and vulnerability. Technical Summary. IPCC, Geneva.

Lubna, F.A., Lewus, D.C., Shelford, T.J. and Both, A-J. 2022. What you may not realize about vertical farming, Horticulture 8, 322.

Mahon, A.M., O'Connell, B., Healy, M.G., O'Connor, I. Officer, R., Nash, R. and Morrison, L. 2023. Microplastics in Sewage Sludge: Effects of Treatment, Environmental Science and Technology, 51, 810-818.

Medina, A., Akbar, A., Baazeem, A., Rodriguez, A. and Magan, N. 2017. Climate change, food security and mycotoxins: do we know enough? Fungal Biology Review, 31, 143-154.

Mudadu, A.G., Spanu, C., Pantoja, J.C.F., Dos Santos, M.C., De Oliveira, C.D., Salza, S., Piras, G., Uda, M.T., Virgilio, S., Giagnoni, L., Pereira, J.G. and Tedde, T. 2022. Association between *Escherichia coli* and *Salmonella* spp. food safety criteria in live bivalve molluscs from wholesale and retail markets. Food Control, 137, 108942.

National Farmers' Union (NFU). 2019. Achieving Net Zero: Farming's 2040 Goal. London, NFU.

Office for Environmental Protection (OEP). 2023. Progress in improving the natural environment in England, 2021/2022. London, OEP.

Organisation for Economic Development and Cooperation (OECD). 2019. Enhancing the mitigation of climate change through agriculture. OECD, Paris.

Rossi, L., Bibbiani, C., Fierro-Sañudo, J.F., Maibam, C., Incrocci, L., Pardossi, A. and Fronte B. 2021. Selection of fish for integrated multi-trophic aquaponic production in the Mediterranean area using DEXi multi-criteria analysis. Aquaculture, 535, 736402.

Skiftesvik, A.B., Blom, G., Agnalt, A.-L., Durif, C.M.F., Brownan, H.I., Bjelland, R.M., Harkestad, L.S., Farestveit, E., Paulsen, O.I., Fauske, M., Havelin, T., Johnson, K and Mortensen, S. 2014. Wrasse (Labridae) as a cleaner fish in salmonid aquaculture – The Hardangerfjord as a case study. Marine Biology Research, 10, 289-300.

Smink, C.K. and Huulgaard, R.D. 2022. Waste not, want not: the regulatory barriers of upcycling frass. Pp. 271-279 In *Circular Economy Supply Chains: From Chains to Systems* (eds Bals, L., Tate, W.L. and Ellram, L.M.). Emerald Publishing Ltd, Bingley.

Sridhar, K., Bouhallab, S., Croguennec, T., Renard, D. and Lechevalier, V. 2022. Recent trends in design of healthier plant-based alternatives: nutritional profile, gastrointestinal digestion, and consumer perception, Critical Reviews in Food Science and Nutrition, DOI: 10.1080/10408398.2022.2081666.

UK Climate Change Committee (UKCCC). 2020. Land Use: Policies for a Net Zero UK. London, Climate Change Committee.

UK Climate Change Committee (UKCCC). 2022. Trade Policies and Emissions Reduction: Establishing and Assessing Options. Agriculture and deforestation. Progress Report.

van Gerrewey, T., Boon, N. and Geelan, D. 2022. Vertical farming: the only way is up. Agronomy, 12, 2.

Ward, N. 2023. Net Zero, Food and Farming – Climate Change and the UK Agri-Food System. Earthscan, Routledge, Abingdon, UK.

Wilkinson, J.M. and Young, R.H. 2020. Strategies to reduce reliance on soya bean and palm kernel meal in livestock nutrition. Journal of Applied Animal Nutrition, 8, 75-82.