Transformative innovation across food supply chains to improve decision-making

Global Food Security

Sustainable, healthy food for all

Contents

The report's findings originate from a high-level interdisciplinary and inter-sectoral meeting of academics, industry, non-government organisations, small and medium enterprises and policy makers, convened by the Global Food Security programme, in partnership with the Food and Drink Sector Council's Innovation Working Group, Sainsbury's, the Department for Environment, Food and Rural Affairs (Defra), and the Department for Business, Energy and Industrial Strategy (BEIS). The subsequent report has been developed by the Global Food Security programme.

The Global Food Security programme (GFS) is a multi-agency programme bringing together the main UK funders of research and training relating to food. GFS publications provide a balanced analysis of the evidence in a particular area, to provide recommendations to inform policy and practice, and therefore do not necessarily reflect the policy positions of individual partners.

This report was prepared by David O'Gorman on behalf of the Global Food Security programme.

Definitions

The Agriculture Bill – Developed by Defra in response to the future for food, farming and the environment consultation, the Agriculture Bill presents legislation to improve productivity, and develop a cleaner, healthier environment. It also outlines plans for future subsidy payments after leaving the EU[1].

Artificial intelligence (AI) – Technologies deploying vast datasets to identify better ways of performing complex tasks.

Big Data – Large volumes of data that can be structured or unstructured.

Biopesticides – Pest management solutions based on living micro-organisms, which include microbials (bacteria, algae, protozoa, viruses and fungi), macrobials (insects and nematodes), pheromones, semiochemicals and plant extracts.

The Clean Growth Strategy – UK government strategy led by the Department for Business, Energy and Industrial Strategy, which sets out proposals for decarbonising all sectors of the UK economy through the 2020s.

Childhood obesity: a plan for action – UK government strategy led by the Department of Health and Social Care, which outlines the actions government will take towards halving childhood obesity and reducing the gap in obesity between children from the most and least deprived areas by 2030.

Cloud computing – The delivery of computing services, such as servers, storage, databases, and networking over the Internet. There are different types of cloud, either public (owned and operated by a third-party cloud service provider), a private cloud (exclusively used by a single business), or a hybrid cloud[2].

The Courtauld Commitment 2025 – An agreement by government and industry to achieve a 20% reduction in food and drink waste arising in the UK, a 20% reduction in greenhouse gas intensity of food and drink consumed in the UK, and to reduce the impact associated with water use in supply chains.

Distributed ledger technology (DLT) and **blockchain –** An asset database that can be shared at different locations, eliminating the need for a central authority to keep a check against manipulation[3]. Blockchain is a decentralised transaction and data management technology developed first for Bitcoin cryptocurrency.

Glyphosate – A herbicide used primarily to control weeds and invasive species.

UK Industrial Strategy – UK government strategy to boost productivity by backing businesses to create good jobs and increase the earning power of people throughout the UK with investment in skills, industries and infrastructure.

Internet of Things (IOT) – Represents the interconnectedness of objects, places and things via the internet.

Integrated Pest Management (IPM) – A systems approach that combines different crop protection practices with monitoring of pests and their enemies, including biopesticides. Other techniques used in IPM include cultivation practices such as crop rotation and intercropping, physical methods such as mechanical weeders, using natural enemies of pests, and decision-support tools to inform farmers.

Neonicotinoids – A group of insecticides used for plant protection.

The Paris Agreement – An agreement of 197 parties to the United Nations Framework Convention on Climate Change (UNFCCC) pledge to avoid dangerous climate change by limiting global warming to "well below" 2°C and to "pursue efforts" towards 1.5°C[4].

Small and medium-sized enterprises (SME) – Businesses with fewer than 250 employees[5].

The Sustainable Development Goals (SDGs) – The 17 Sustainable Development Goals (SDGs), adopted by the UN in 2015, intend to build on the Millennium Development Goals (MDGs) and seek to achieve progress towards a new global Sustainable Development Agenda. The SDGs are universal and interconnected and there is an expectation that multiple stakeholders across nations will work together to implement them[6].

The UK Plastics Pact – Brings together businesses from across the entire plastics value chain with UK government and NGOs to eliminate single-use plastic by 2025.

Foreword

We are living in times of unprecedented change, whether that is the change that we plan for ourselves or the change that is driven by a world that is more uncertain and volatile than ever before. The Food and Drink Sector knows these symptoms well, we live with them every day, and often those disruptive challenges overwhelm our longer term strategies, but sometimes they can also be a catalyst for change and innovation.

Add to that an increasingly connected world where the interdependencies and risks are ever more complex and evolving and you have a series of challenges that require a completely new approach to resolve if we are to deliver a more secure, sustainable food system. No longer can we think and act within traditional silos nor can we work within the boundaries that have historically defined us. Value chains are becoming food systems, the science that we use will be interdisciplinary, and the data and technology multi layered, open and interoperable. This means a level of collaboration previously unseen.

Whilst we know we have to think and work differently, our biggest challenge is prioritisation, where, when, and how to focus our efforts for greatest impact. It is easy to be seduced by the art of the possible but our challenges require us to do more and at pace and drive results, and that means focus.

I was privileged to be part of a workshop that brought together individuals and organisations from across the sector to work on that prioritisation process.

The need to drive systemic change is indisputable. We can only be resilient to the "knocks" and "disruptions" and at the same time create value for all stakeholders if we deliver true structural change. That begins with thoughtful applied science and innovation that has the ability to transform the system both in its ambition, but also through implementation at scale and speed.

I look forward to working on the outputs of this work with the Food and Drink Sector Council, our partners, and thank GFS for facilitating this new way of working.

Judith Batchelar OBE
Director of Sainsbury's Brand

Executive summary

The food security challenge is evolving – globally there are now more people who are obese than underweight; the UN's Sustainable Development Goals (SDGs) have been published with a focus on sustainable production and consumption alongside ending poverty and hunger; and there was agreement at the Paris climate conference (COP21) aiming to limit global warming to 1.5˚C and to keep global temperatures well below 2˚C. It is clear that there are no silver bullets to solve the food security challenge and it will require a joined-up approach across the food system. Technology, as part of a broad set of solutions, will increasingly have an important role to play.

We may be on the cusp of a 4th industrial revolution, which will enable new and existing technologies to transform food systems. Data-driven supply chains guided by Artificial Intelligence (AI) - technologies with the ability to perform tasks that would otherwise require human intelligence; and Big Data – large data sets, and associated meta data, that reveal patterns and predict behaviour, could be used to improve resource efficiency, improve sustainability, and reduce levels of waste in food supply chains. Distributed ledger technologies have the potential to improve trust, traceability and provenance, improve connectedness and improve management of risks associated with food fraud incidences. Internet of Things (IOT) and cloud computing are expected to be embraced more widely, resulting in greater robotics and autonomy in agriculture, storage, distribution, logistics, retail and consumption, and providing virtual market places for buyers and sellers.

Technologies could lead to transformative innovation in the food system, creating a fundamental shift in the way food is grown and supplied to citizens. However there are challenges and trade-offs in adoption, which need to be managed, understood and researched to avoid unintended consequences and system volatility.

The Global Food Security programme (GFS) convened a high-level stakeholder meeting, in partnership with Defra, BEIS, and the Food and Drink Sector Council's Innovation Working Group, to investigate how transformative innovation can lead to 'business unusual' in food supply chains, bringing together academia, industry, small and medium enterprises (SMEs), non-government organisations (NGOs) and policy makers. The meeting examined the challenges to industry and business that technologies could address, and has provided future priorities for research, industry, and policy.

The major challenges for the food industry that would benefit from transformative innovation are:

- Traceability, transparency and disclosure
- Food safety, fraud, and security
- Efficiency, productivity, and sustainability
- Improving diets and health
- Reducing waste

To enable these challenges to be addressed, progress is needed on the following research, industry and policy priorities:

- A long-term, high-level UK food system innovation strategy and a joined-up systems approach to policy making
- Greater investment in AI and data technologies in the UK and globally - identifying UK centres of excellence, creating new centres of excellence and developing a supply of skilled people to enable transformative innovation in the food system
- A framework to enable an 'open data food system'
- Understanding trade-offs and unintended consequences of embracing AI and data technologies in the food system
- Understanding how social innovation can lead to transformational change
- Ensuring pre-competitive collaboration to develop and enable uptake of new and existing technologies

GFS will work with its programme partners and the Food and Drink Sector Council to develop a plan of action to address these priorities.

Introduction

The food and drink sector is important to the UK economy – the industry turns over £97.3bn, is the biggest manufacturing sector and employs over 400,000 people[7]. Currently, the UK produces just under half of the food it consumes and imports the rest, mainly from the EU[8]. Therefore, it is critical for government and industry to maintain a strong food and drink manufacturing sector after we exit the European Union, which has led to the formation of the Food and Drink Sector Council, announced in the Industrial Strategy White Paper[9]. The Food and Drink Sector Council is a formal industry partnership with government to creative a more productive and sustainable food and drink sector, covering production, manufacturing, retail, hospitality, logistics and consumers.

Since Alan Turing first devised the concept of machine-learning in 1950[10], the importance of **Artificial Intelligence (AI)** and data analytics has visibly increased, as organisations attempt to use the mass volume of data being produced to inform decision-making. There is no doubt that machine learning and AI is already improving peoples' lives, from intelligent personal assistants that can prepare us for changes in the weather, to systems that protect our money from criminals, or devices that offer medical advice from the comfort of our own home[11].

In a food security context, AI can be used in food production to reduce waste and improve productivity, efficiency, and costs of production; in smart food processing and manufacturing, using machines with embedded intelligence that communicate directly with other machines; and in broader supply chains, for example, using real-time optimisation to accurately estimate demand using market trend data, through real-time analysis to assess inventory levels, to identify mis-matches, and to optimise incoming delivery schedules.

Big Data and **Internet of Things (IOT)** technologies are also playing an essential role within agriculture and the wider food system, with machinery being equipped with sensors that measure soil, environmental conditions, and crop and livestock conditions. Food system actors integrate agronomic, environmental and operational data to ensure the correct supply of fresh produce to customers on a daily basis, and being able to use data to mitigate the risks of extreme weather and climate shocks to food production could also lead to reduced levels of waste throughout the supply chain. We are seeing growth in robotics and autonomous vehicle technologies, which may lead to reduction in pesticide use, improved weed control, and autonomous harvesting of crops[12].

Big data could also impact how we monitor fisheries. One third of fish consumed in the world is caught illegally and two thirds of fish species are overfished, which consequently is leaving stocks seriously depleted. A rapid collapse of fish stocks could lead to cascading failures across marine ecosystems, thus, it is anticipated that satellite data, remote sensing and ground truth observations could lead to better regulation of the marine economy[13], alongside improvements in agriculture. These technologies are already being used by the Satellite Applications Catapult in partnership with the government of Malaysia to monitor illegal logging[14].

Big data is also being used to improve health and diets. The growth of 'personalised nutrition' – an approach that uses information on individual characteristics to develop targeted nutritional advice, and wearable technologies, underpinned by data, could assist individuals in achieving a lasting dietary behaviour change that is beneficial for health.

Distributed ledger technologies (DLT) have the potential to be used in the food system to provide enhanced security, and data integrity without the need for a third party organisation, and therefore could become an important disruptive technology in the future. Blockchain, an example of DLT, can be used to reduce the risk of food contamination incidents, allowing citizens to trace a product throughout the supply chain. Furthermore, organisations such as Provenance[15] are working with local fishermen to help collect catch data and track fish through the supply chain using physical transactions and in the digital register using blockchain. Ownership is recognised and products are registered to the fisherman on the blockchain. This ownership cannot be altered, allowing transparency and verification across the supply chain. Blockchain could also benefit smallholders in Lower Middle Income Countries (LMICs), by reducing fees paid in each transaction, by removing barriers and freeing up financial systems.

Cloud computing allows users access to applications from anywhere, with connected devices, which can allow virtualisation of infrastructure and services, and increased availability and connectivity with end-users. Cloud computing is leading to changes in agricultural practice, with farming processes becoming more data-driven and data-enabled. This could lead to trading hubs which enable buyers and sellers to locate each other and transact business without the need for a third party.

These technologies are not mutually exclusive, and therefore combining technologies may lead to a smarter, data-driven food system, however we must understand how data-driven supply chains can work in principle, understand how we align all food system actors to embrace these technologies, and furthermore understand the costs of adoption.

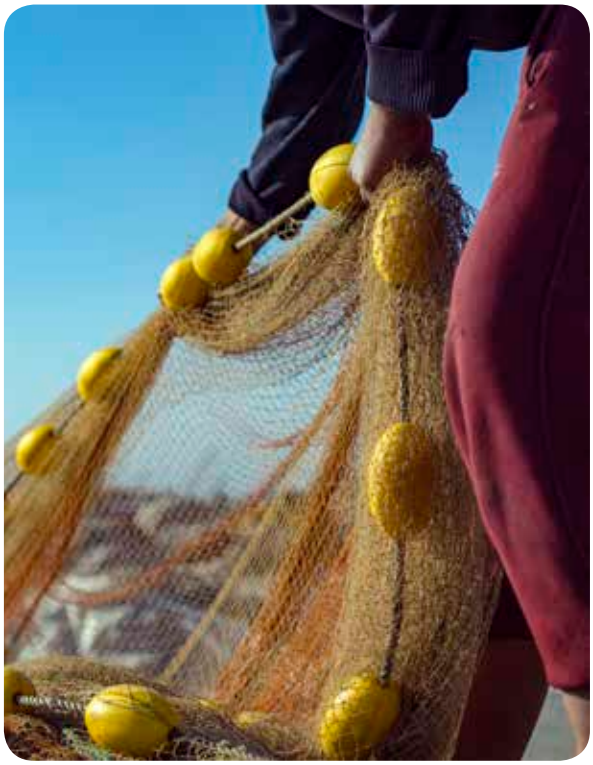
Government and industry are keen to harness the benefits of these technologies - the Industrial Strategy discusses the need to boost productivity and resource efficiency, to put the UK at the forefront of the Artificial Intelligence and data revolution; the Clean Growth Strategy highlights how technological innovation can reduce carbon emissions across sectors, including agriculture and food; the recently announced Agriculture Bill highlights the need to improve transparency across supply chains and embrace technological innovation, whilst investing in new technologies and methods that boost productivity; and the Childhood Obesity plan highlights opportunities for data and technology to be used to inform eating decisions[16].

Thus, it is imperative to understand how transformative innovation can lead to 'business unusual' in food supply chains, in order to meet food and drink sector challenges, and deliver against government and industry strategies.

What are the current and future challenges in the food system?

There are specific challenges that could be addressed by embracing disruptive technologies, which include the following:

Traceability, transparency and disclosure
Identifying where a product has come from, the farm where it was grown, the input materials, and the methods of production, are fundamental to improving traceability and transparency in the food system. Legislation requires that food is traceable to its origins of production[23], and furthermore citizens are demanding access to reliable and relevant information about origins and processes of food procurement, safety levels, production methods, pesticide use, and carbon footprint of food[24]. The food and drink industry therefore needs to ensure complete disclosure of products to ensure trust, but improved traceability may be costly and may lead to an increase in consumer prices. A lack of systems interoperability between organisations and lack of common definitions or standards creates barriers and hinders collaborative partnerships between stakeholders[25].



Case study: Abattoirs of the 21st Century

In 2016, former government chief scientist Sir Mark Walport called on government to investigate whether distributed ledger technology could improve public services and boost productivity[17]. A more recent speech by former Secretary of State for Culture, Media and Sport, Matt Hancock, announced that there is wide interest across government departments to deploy blockchain to tackle issues[18]. The Food Standards Agency (FSA), an independent government department trialled blockchain technology in cattle slaughterhouses – the first time it has been used as a regulatory tool to ensure compliance in the food sector, to understand whether it can be used to improve transparency and traceability in supply chains. In the pilot, the meat from the slaughterhouse was tracked on the blockchain, with the data accessible by both FSA and the slaughterhouse[19]. The use of blockchain may simplify auditing and inspections, which currently adds complexity to supply chains, and is resource-intensive. The success of this pilot demonstrates that blockchain could be implemented across the food system, in partnership with industry.

Safety, fraud and security

Experts agree that food safety requires a holistic, systemic, and verifiable approach to producing and moving food products through the supply chain safely[26]. The horse meat scandal in 2013 highlighted the prevalence of criminal networks in adulterating food products for profit, and raised concerns regarding safety of food supply chains. This led to a review into the integrity and assurance of food supply networks, which subsequently provided recommendations for government and industry, known as the Elliott Review. The formation of the National Food Crime Unit, a criminal intelligence function within the Food Standards Agency[27] has reduced food crime in the UK, however fraud and safety need to be tackled at industry and supply chain boundaries, and not simply national boundaries. Reflecting this dilemma for the food and drink sector, the Grocery Manufacturers Association estimates that fraud may cost the global food industry between $10 – $15 billion per year, affecting approximately 10 % of all commercially sold food products[28]. Food fraud scandals have become more frequent globally, and harm people's health, impede development of economies, and endanger the stability and security of society. The recent egg contamination scandal in Europe shows there is still a need to provide transparent, safe, traceable and secure food supply chains.

Climate change and extreme weather events may impact on food safety, by increasing flood risk and natural resource demand, which subsequently increases the risk of transporting pathogens and chemicals onto agricultural land[29]. Climate change may also lead to altered chemical and pathogenic inputs to food, therefore understanding stress tolerance responses of pathogens to temperature and pH, may help mitigate the risks of climate change to food safety[30].

Case study: Mobile food security

Diseases in plants cause major production shocks and economic losses in the agriculture sector, therefore monitoring health, and detecting crop diseases, is critical for sustainable agriculture and food security. Using advanced image processing, machine learning and cloud computing approaches, a BBSRC-GCRF Translation Award project has developed an innovative automated machine vision system for efficient crop disease diagnostics from imaging. The tool can be used on mobile devices and enables farmers to perform immediate potato disease diagnostics, giving growers more accurate information on which to base their disease control strategies and therefore improving crop yields. This technology can help make a significant impact on farmer incomes, and deliver highly cost-effective, long-term economic and social impact[20].

Efficiency, productivity and sustainability

We need to grow more food than we have ever grown in human history[31], and it will be impossible to meet the terms of the Paris Agreement without significant reductions in food-related greenhouse-gas emissions, as agri-food is predicted to take up nearly the entire annual carbon budget for a 2°C temperature rise by 2050, if current levels of growth continue[32]. For the UK to reach its ambition to be world leaders in terms of competitiveness, resource productivity and resource efficiency, it needs to understand how to sustainably manage natural capital, whilst also increasing biodiversity and optimising land use for food. There are also concerns about labour and skills shortages due to our evolving relationship with Europe and an ageing food and drink sector, so investing in the UK workforce is essential to meet the associated challenges.

The European Commission's ban on the use of neonicotinoids on all outdoor crops[33], public concern regarding the use of glyphosate in food production, and increased incidence of pest and weed resistance, has led to the development of new products and strategies using less conventional pesticides. However, solutions such as Integrated Pest Management (IPM) and biopesticides require time, monitoring and understanding of the pest, weed or disease. Data and technologies, including robotics, autonomous vehicles and drones can be used to reduce or eliminate conventional pesticide use, and therefore making technologies accessible and available for farmers and growers is essential to managing pests, weeds and diseases. A coordinated effort across government, industry and research is needed to develop the necessary skills and knowledge to implement future strategies which simultaneously improve productivity, efficiency and sustainability.

Improving diets and health

Globally, sufficient calories are produced to feed the population, but access to a safe, sufficient and nutritious diet is unequal around the world.

Around 821 million people globally do not have adequate food to meet their basic needs[34], and just under 2 billion people suffer from micronutrient deficiency[35]. Citizens and businesses feel emboldened to meet the Sustainable Development Goals (SDGs), including SDG 1 (no poverty) and SDG 3 (ensuring healthy lives and promote well-being for all at all ages), whilst simultaneously tackling the rise in obesity and non-communicable diseases, both globally and in the UK.

The overall cost of obesity to wider society in the UK has been estimated to be £27 billion, with the NHS spending an estimated £6.1 billion on overweight and obesity-related ill health in 2014/2015. The UK-wide NHS costs attributed to overweight and obesity are projected to reach £9.7 billion by 2050, with wider costs to society estimated to reach £49.9 billion a year[36].

Additionally, there are environmental impacts associated with food production, with inflated demand caused by overconsumption creating additional burden on planetary resources and adding to greenhouse gases. Understanding how we can we achieve win-wins and manage trade-offs, whilst improving diets and health (sustainable nutrition), is a fundamental question for government, industry and research.

Case study: From 'charms' to farms – bringing Science and Technology Facilities Council (STFC) experts to consider food system challenges

Formed in 2017, the STFC Food Network+ brings together STFC researchers and facilities with researchers and industry in the agri-food sector. The goal of the network is to build an interdisciplinary community working to provide a sustainable, secure supply of safe, nutritious, and affordable high-quality food. STFC provides access to the UK's biggest science facilities and supports UK research into particle, astro and nuclear physics, which are underpinned by powerful data science and technology. Scientific advances in the food system can stem from experts in other fields providing a unique perspective on challenges, and therefore STFC capabilities could provide innovative solutions to some major consumer-side food challenges. The network has funded over 20 scoping projects including projects examining how infra-red and pattern recognition can enhance pregnancy success in cattle, scoping feasibility of low cost gas-chromatography to assess quality of fresh fruit and vegetables throughout the supply chain, and using intergalactic cosmic rays to measure soil moisture levels to develop new drought indicators.

Case study: Providing common standards for suppliers and retailers

The barcode was first introduced in 1948, and since has been used to speed up point of sale transactions. Non-profit data standards organisation GS1 UK is providing a common platform for industry, and devised a single solution to managing and exchanging data[21]. The result was productDNA, which creates an industry data model for suppliers to share product data with retailers with standardised attributes. ProductDNA also provides a cloud-based catalogue and an independent physical product verification to ensure the accuracy of submitted product data[22]. Tesco and Ocado have signed up to productDNA, and the first SME, itsu, has also signed up to use this common standards for data. Ensuring buy-in from major retailers and SMEs is a step towards a unified data standards platform within food.

Reducing food losses and waste

Global food losses and waste is estimated at 1.3 billion tonnes annually, equalling one-third of global food production[37].

Food losses and waste is caused by a variety of factors, including severe weather events, pests and diseases, endemic and exotic diseases, storage and distribution losses, processing losses, supply chain inefficiencies and waste in retail and at household level. Climate change is expected to impact on frequency and intensity of extreme weather events including flooding, drought, and distribution of pests, weeds and diseases at particular latitudes, all of which will impact upon yields, affecting losses in agriculture[38]. Furthermore, overproduction due to contractual obligations in developed and developing countries provides excess yields and unnecessary waste.

The UK food and drink sector produces 10 million tonnes of waste a year[39], and avoidable food and drink waste costs manufacturers £1.9bn per year. However, industry has signed up to the Courtauld Commitment 2025[40], which aims to reduce food and drink waste in the UK by 20%, and will also attempt to meet SDG 12 – to reduce global food waste by 50% by 2030.

Case study: Creating homes of the future using Internet of Things

Receiving £1.14 million of funding from the Engineering and Physical Sciences Research Council (EPSRC), to improve the UK's food manufacturing digital economy, the Internet of Food Things (IoFT) Network Plus brings together data and computer scientists, chemists, and economists to investigate how AI, data analytics and emerging technologies can enhance the digitalisation of the UK food supply chain. The network is led by the University of Lincoln in partnership with the universities of Southampton, Surrey, University of East Anglia, and the Open University, in partnership with Siemens, Tesco, Food Standards Agency and GS1, to examine the application of the Internet of Things in connected homes of the future – for example, smart refrigerators which trigger grocery orders, or cooking devices which help us live healthier lives. The network will also examine how machine learning, and AI can be utilised to extract value from the vast amounts of data available across the supply chain, which could lead to improved efficiency and a reduction in waste.

What are the future priorities for research, industry and policy?

A long-term, high-level UK food system innovation strategy that encourages a joined-up and systemic approach to policy making

The food system is highly complex and diverse, constantly changing to known and unknown variables. Therefore, action should be taken to align all food system actors around a shared vision, ensuring all parts of the system have the tools, skills and knowledge to achieve this vision. Whilst a shared vision is essential, a joined-up, systemic approach is necessary to deliver it. A systems approach considers the activities, outcomes and actors involved in agriculture, storage, processing and manufacture, distribution, retail and consumption, alongside the various pressures and drivers, and recognises that the food system is highly interconnected. A systems approach avoids unintended consequences from interventions in one part of the system adversely affecting another[41].

A unified food system innovation strategy should clearly articulate key deliverables for, and enable protocols to facilitate, new and existing technologies.

The strategy should also clearly demonstrate how these technologies can help meet the targets of the Sustainable Development Goals, the UK's ambition to meet the Paris Agreement, and high-level government and industry strategies including the Courtauld Commitment agreement, the Childhood Obesity plan for action[42], the Agriculture Bill[43], the Industrial Strategy[44], and the Clean Growth Strategy[45].

The UK Plastics Pact[46] brought together industry, NGOs and governments, pledging to eliminate single-use packaging through redesign and innovation by 2025. This demonstrated how partnership between all actors can tackle the biggest challenges in the food system. An end-to-end data approach will help meet challenges around traceability, transparency, efficiency, food waste and health, thus, improving decision-making and future proofing the UK food system.

Encouraging greater investment in AI and other data technologies in the UK and globally

The AI Sector Deal[47] recognised the significance of investing in AI and machine learning, and how we produce, process and manage data is critical to innovation. Therefore, greater investment is needed in AI and data technologies within the food system, to meet the challenges outlined in this report. There should also be a greater focus on reducing the obstacles for food and drink sector SMEs to engage in innovation, as food sector SMEs account for 97% of businesses, 28% of employment and 19% of turnover[48].

In a continuously evolving landscape, venture capitalist firms are investing funds in technological solutions to solve key challenges, such as consumption of healthier food, shorter supply chains, personalised nutrition and alternative proteins[49]. Venture capitalists are therefore vitally important to the development of new business models.

Transformative innovation relies on collaboration between government and industry, however research and training is needed to develop the necessary capabilities in the UK to embrace transformative

innovation. UK Research and Innovation brings together the seven Research Councils, Innovate UK, and Research England, to support research an innovation in the UK, and develop leaders of tomorrow. The need to develop capabilities in the UK is critical, as the workforce in the food and drink manufacturing sector is ageing, and could face shortages after the UK leaves the European Union.

Therefore, it is critical that the UK develops the prerequisite skills, knowledge and capacity in areas including data sciences, biotechnology, food technology, food safety, food manufacturing, and agri- and environmental engineering. This also leads to commercially viable technological solutions to the problems addressed in this report. Part of skills development should be encouraging greater connectivity between education, businesses, and SMEs, and focusing on increasing knowledge exchange between researchers and end-users.

Whilst the UK has a centre of excellence in data sciences, the Alan Turing Institute, the UK needs to evaluate current infrastructure and ensure that there is safe space to foster creativity and develop novel and unique ideas to solve food system challenges. There are current initiatives that look to foster creativity, including Station F[50], created in Paris, and TechHub[51], in London. These initiatives are business incubators encouraging tech entrepreneurs and start-ups, and similar models could be used to focus on food system innovation. Utilising the current UK strengths, ensuring safe spaces to enable innovation, and encouraging collaboration between food system experts and technology experts could lead to food system transformation.

Understanding trade-offs and unintended consequences of embracing AI and data technologies in the food system

Whilst there are many benefits of embracing technologies in the food system, adopting them may lead to potential disruptions in the food system. Breakthroughs can often be polarising, as there are many benefits to productivity, resource efficiency, and for the economy, but a change in practice could be detrimental in terms of job losses, health and well-being, and impact on biodiversity. These disruptions can be minimised if a food systems approach is taken in technology development, identifying both the benefits and unintended consequences and mitigating the latter. More research and evidence is needed in order to understand the unintended consequences of embracing AI, Big Data, IOT, distributed ledger technologies and cloud computing in the food

system. We recommended an evidence-based review or assessment of the trade-offs and win-wins of embracing technologies in the food system, in order to future proof and minimise risks in adoption, which should include how 'low tech' and 'no tech' solutions could complement technological innovation.

Understanding how social innovation can lead to transformational change

Whilst top-down approaches providing technological solutions will be beneficial, we should not forget the value of social innovation – addressing individual and community needs, and improving human well-being. There has been a growth in new models of funding, including new ways to access capital, with the growth of crowdfunding projects in the UK and developing countries. Food has the ability to transform local communities and schools, therefore working with SMEs and Local Enterprise Partnerships to ensure market access to goods and services, coupled with an enabling policy and regulatory environment, can create conditions whereby social innovation thrives.

Ensuring pre-competitive collaboration to develop and enable uptake of new and existing technologies

Pre-competitive collaboration is critical, and requires a joined-up approach from industry. For example, all businesses produce huge levels of waste in the UK every year, and with a greater focus on clean growth[52], and the circular economy, governments and industry should undertake pre-competitive collaboration to provide 'collective intelligence', avoiding repetition and maximising the use of resources with open sharing of ideas.

Pre-competitive collaboration could lead to improved health outcomes – AI has the potential to improve health and well-being in the UK, by developing understanding of nutritional and dietary requirements, and tailoring products to individuals accordingly. This would take a coordinated approach across retail and industry to understand consumer purchasing behaviour, and subsequently could be used in production, agriculture and fisheries to better predict patterns.

Pre-competitive collaboration could improve food safety and traceability – including more rigorous monitoring processes, anticipating problems and reducing the risk to citizens of fraud and authenticity incidences, meeting plastic targets, and developing more robust biomarkers for traceability.

Developing a framework for an 'open data food system'

Pre-competitive collaboration requires trust and agreement between industries, and could enable greater sharing of data across the food system. However, there have been many high-profile examples of how data can be misused or shared unknowingly, which has resulted in low confidence of data sharing. Businesses have therefore worked in silos, to avoid data falling into the wrong hands[53]. Industry and government should work together to create safe and secure 'data platforms', establish data ownership requirements and work to sustainably integrate data, which could lead to data being used freely and willingly to improve supply chain productivity, transparency, safety and profitability. The use of open standards and royalty free licences alongside an open data framework should reduce barriers to entry in the food sector, which subsequently allows greater innovation and disruption.

Therefore, all food systems actors need to work together to develop global data standards that promote sharing of data.

Annex A – Workshop outputs

1.1. About the workshop

The report's findings originate from a high-level interdisciplinary and inter-sectoral meeting of academics, industry, non-government organisations, small and medium enterprises and policy makers, convened by the Global Food Security programme, in partnership with the Food and Drink Sector Council's Innovation Working Group, Sainsbury's, The Department for Environment, Food and Rural Affairs (Defra), and The Department for Business, Energy and Industrial Strategy (BEIS). The subsequent report has been developed by the Global Food Security programme.

Delegates at the workshop were spilt into groups in the following areas:

- Food safety, fraud and security
- Traceability, transparency and disclosure
- Efficiency, productivity and sustainability; clean growth and economic growth
- Value chain, logistics and risk, climate change
- Market, global commodities, finance and regulation
- Food diets, health and nutrition

Each group contained a mixture of policy makers, NGOs, researchers and industry to ensure a balance of expertise, and delegates were encouraged to change groups throughout the workshop.

1.2. Welcome and introductions

To set the scene, representatives from across the food system were invited to share their current and future challenges, which provided an opportunity to understand the issues from different perspectives. Groups were then formed, to build upon and discuss the challenges to business and industry. Some suggestions were captured by multiple tables due to overlapping remits, and thus may have been included more than once.

1.3. What are the challenges facing us now and in the future?

Table	Current challenges	Future challenges (10-20 years)
Food safety, fraud and security	• Global/UK food fraud and adulteration • Getting the right information to where it's needed at the right time • Complexity of supply chains • Ensuring trust and transparency in supply chains • Competitiveness leads to undermining of regulation • Border control (national and organisational boundaries) • Demand for low value food • Ensuring provenance • Ensuring adequate allergen information • Risks from pathogens, including E-coli, Salmonella, Campylobacter and mycotoxins	• Shortage of food due to natural resource depletion – subsequent impact on food safety and fraud • Increased stress in systems • Availability of markets • Increased demand could lead to increase in adulterated food • Data ownership and governance • Global drivers and impact upon pathogens (including E-coli, Salmonella, Campylobacter and mycotoxins)

Table	Current challenges	Future challenges (10-20 years)
Traceability, transparency and disclosure	• Open standards, adherence and agreement • Data integration and digitalisation • How can we trust the data that is being used? • Understanding how open data is managed • Provenance and traceability	• Understanding the risks and trade-offs in an open data food system • Managing data effectively • Ensuring win-wins in adoption of technologies • Enabling common open standards within the food system
Efficiency, productivity and sustainability; Clean growth and economic growth	• Understanding the best food policy – i.e maximise production or UK sourcing? • Labour and skills shortages • Pesticide restriction and regulation • Meeting the Paris Agreement • Involving all actors in decision-making • Managing natural capital (soil, nutrients, water, land) whilst remaining productive • Reducing plastic use	• UK competing with other countries • Labour and skills availability when adopting new technologies • Understanding best practice in agriculture • Developing other strategies to reduce pesticide use • Managing withdrawal of subsidies • Restructuring school and university curriculum to attract people into the food sector • Generating export value
Value chain, logistics and risk, climate change	• Siloed/linear supply chains • Reducing barriers for trade • Capturing value from innovation • Meeting the Paris Agreement/SDGs • Reducing GHG emissions in supply chains • Global homogenisation – risks of volatility and shocks	• Developing network/systemic supply chains • Real-time information supply chains • Ensuring a Green economy
Market, global commodities, finance and regulation	• Enabling market access • Maintaining access to suppliers and growers • Venture capital visibility • Impending financial crisis due to food systems complexity? • Ensuring UK regulation enables innovation	• Global policy making to achieve SDGs • Improving UK supply chain resilience – to protect from market shocks and volatility • How will AI and new technologies be regulated? • Metrics to achieve SDGs – currency? • Market exclusion

Table	Current challenges	Future challenges (10-20 years)
Food diets, health and nutrition	• Perceived trade-off between productivity and nutrition • Social inequality – social innovation • Joined-up policy making to reduce obesity, reduce incidences of non-communicable diseases and improve nutrition • Low value, cheap products • Obesogenic food environments	• Obesity epidemic • Encouraging an 'Eat less and better' mind-set • Enabling business models to achieve healthy and sustainable diets • Building an enabling environment that drives healthy choices • Achieving a lower price for healthier food • Adopting true cost accounting models in the food system

1.4. Developing a vision for 2030

In the next session, the groups considered what was already happening to meet the challenges outlined, and considered the best outcomes we could hope to achieve by 2030. It was crucial for the groups to consider enablers to achieve the perceived outcomes.

Table	What is the best outcome we can imagine by 2030?	How do we build an enabling environment?
Food safety, fraud, security	• Citizens have access to safe, affordable, secure, nutritious food • Food is valued (leading to reduced waste and better nutrition) • Rewarding responsible practice • Rewarding transparency leads to no fraud or adulteration • Global information architecture	• UK strategy for food • Global standards for food • Model for understanding true costs of food production • Stable, resilient supply chains • Strong regulation/enforcement
Transparency, traceability and disclosure	• Open data food system, with data integrated and shared widely • Digitalisation of supply chains • Personalised dietary requirements • Business models that enable transformative innovation	• Greater industry and government collaboration - pre-competitive research? • Citizen buy-in • Access to platforms • Recognising role of SMEs in food supply chains
Efficiency, productivity and sustainability; Clean growth and economic growth	• A Brexit-proof food system • Sustainable food systems – managing natural capital, environment, biodiversity and land • Climate change mitigation and adaptation • No waste - Circular economy supply chains • Data harmonisation	• Technological innovation • Enabling uptake of new technologies • Working with end-users • Environment that fosters creativity • Reducing labour gaps • Developing UK infrastructure. i.e. GPS and satellites

Table	What is the best outcome we can imagine by 2030?	How do we build an enabling environment?
Value chain, logistics and risk, climate change	• Ensuring systems are operating effectively • Respecting values • Open, shared assets – physical, knowledge, internet • Safe space to enact change • Brexit-proof UK supply chains • Eliminating barriers for adopting new AI and data technologies	• Data sharing agreements • Buy-in from key players in value chains • Cooperative systems • Standards and regulation that enable innovation in the UK • Pilot studies and worked examples to ensure viability • Government working closely with industry and business
Market, global commodities, finance and regulation	• Exporting UK expertise, technology and attracting inward investment • High quality produce • Agile policies and regulation – evidence based and constructed with a long-term view and a deep understanding of global agri-food systems • Understanding the unintended consequences of decisions • Diversification of global commodities and reduced reliance on particular crops • Free trade • Enabling financial environment	• Improving skills and training • Improving skills in production • Distance learning and on-the-job training • Joint ventures • Scenarios exercises
Food diets, health and nutrition	• Healthy and sustainable diets • All supply chain actors benefit from food supply • Infrastructure created to enable transformative innovation – i.e. Food Hub. • Eliminating childhood and adult obesity	• Changing business models • Joined-up approach by government and industry • Understanding best practice from other countries • Curriculum underpinned by food and nutrition • Publically funded, and pre-competitive research • Understanding current research and research gaps

1.5. Defining a vision

The delegates then discussed actions and areas to enable transformative innovation in the food system. The following themes arose, based on previous discussions at the workshop and discussions on tables during this session:

a) How do we align all food system actors around a shared vision?
b) Does alignment only occur after a crisis?
c) How do we future-proof UK capabilities?
d) Can we evaluate best practice that the UK could adopt?
e) How do we create business models to enable transformative innovation?
f) What does a food system innovation strategy look like?
g) How can we incentivise long-term thinking?
h) How can government and industry ensure a joined-up approach to policy making?
i) How can the UK encourage greater adoption of digital tools in agriculture and in the food system?
j) What does an open data food system look like?
k) How do we ensure data integration, shared ownership, and buy-in from government and industry?
l) How do we ensure the acceptance of new products and technologies, and demonstrate due diligence of risks associated with certain technologies?
m) How do we create a regulatory environment that enables transformative innovation?
n) How do we connect citizens to where their food comes from?
o) What are the protocols that enable distributed ledger technologies, blockchain and quantum technologies?
p) How do we mitigate risks of extreme weather and climate change on agriculture and the wider food system? What role does AI, data and technology play in climate change mitigation and adaptation?
q) How can the UK encourage societal change/social innovation?
r) How best can the UK manage reduction of pesticides and adoption of integrated pest management and biopesticide strategies?

Delegates finally collated the most important actions and outlined whether they were short-term or long-term targets.

	Short–term priorities **(2018-2024)**	Longer-term priorities **(2025-2030)**
Actions	• 'Brexit-proof' UK food supply chains • Understand needs of citizens • Understanding unintended consequences of adopting technologies • Build infrastructure to enable market access • Assessment and prioritisation of distortions which hinder supply chains • Mapping exercise to understand research landscape • UK defining international standards – creating Governing Standards Body similar to the Forest Stewardship Council (FSC) and the Marine Stewardship Council (MSC) • Cross-party coordination • Understanding current pre-competitive research landscape • Co-creation of policy • Creating a culture where food is considered valuable • Data-driven assessments to identify knowledge gaps • Agricultural reform – a new Common Agriculture Policy • Bridging labour gaps • Embed food and nutrition into current education curriculum • Connecting end-users and incentivising adoption of technologies • Creating a UK regulatory framework to enable innovation • Ensuring agri-food careers are seen to be desirable	• Food strategy defining food as a critical infrastructure • Meeting UK plastics pact • Meeting waste targets • Meeting the Paris Agreement and SDGs • Creating alternative business models that encourage healthy and sustainable diets • Building capacity – skills, knowledge and capabilities to enable transformative innovation • Food theatres – connecting citizens with food • Social innovation • Creating infrastructure that enables food security • Developing and utilising technologies to avoid borders and lags in trade • Delivering Courtauld Commitment • Delivering government strategies • Effectively managing natural capital

Acknowledgements

GFS would like to thank the following people for attending the meeting or assisting in the development of the report.

Dave Ross	Agri-Epi
Tom Hind	AHDB
Richard Steeves	Arc-net
Chris Brown	Asda
Yvette Sowerby	Bakkavor
Keston Williams	Barfoots
Andy Cureton	BBSRC
Jon Hoare	BEIS
Sue Armfield	BEIS
Ian Wheal	Breedr
Ian Ellison	Cambridge Institute for Sustainability Leadership
Richard Worrall	D2L2 Local Enterprise Partnership
Calum Fitzgerald	Daemon Solutions
Lucy Foster	Defra
Henry Leveson-Gower	Defra
Dan Haglund	DFID
Elizabeth Warham	DIT
Helen Munday	Food and Drink Federation
Riaz Bhunnoo	GFS
Martin Collison	Greater Lincolnshire Local Enterprise Partnership
Rachel Hackett	Greencore
Nancy Bailey	Go-Science
Blair Edwards	IBM
Kathryn Miller	Innovate UK
David Barclay	Innovent Technology
David Telford	Knowledge Transfer Network
Ian Noble	Mondelez
David Hix	Nestle
Jonathan Scurlock	NFU
Donna Champion	Nottingham Trent University
Paul Clarke	Ocado
Gwendolen Deboe	OECD
Jacob Beswick	Office of Artificial Intelligence
Lynne Davis	RSA
Mark Jarman	Satellite Applications Catapult Centre
James Leavesley	Stoke-on-Trent and Staffordshire Local Enterprise Partnership
Judith Batchelar	Sainsbury's
Sarah Blanford	Sainsbury's
Hilary Sutcliffe	Society Inside
Dave Hughes	Syngenta
Simon Pearson	University of Lincoln
Steve Brewer	University of Lincoln
Sue Davies	Which?

References

1 Agriculture Bill

2 Microsoft Azure – What is cloud computing

3 Distributed Ledger Technology: beyond block chain

4 The Paris Agreement

5 House of Commons Library – business statistics

6 UN Sustainable Development Goals

7 Food and Drink Federation - Stats at a glance

8 Defra Food statistics pocketbook 2017

9 Industrial Strategy: building a Britain fit for the future

10 Alan Turing and the development of Artificial Intelligence

11 Artificial Intelligence Sector Deal

12 Duckett et al, Agricultural robotics – the future of Robotic Agriculture

13 Future of the sea: final report

14 Satellite Applications catapult

15 Provenance

16 Childhood Obesity: a plan for action

17 Distributed ledger technology, beyond block chain

18 Digital transformation in government and blockchain technology

19 FSA trials first use of blockchain

20 BBSRC business magazine – Summer 2018

21 The barcode comes of age, New Food magazine, issue 4, Aug 2018

22 ProductDNA

23 Meat Industry Guide – Chapter 16

24 Systems for sustainability and transparency of food supply chains – Current status and challenges

25 Making Traceability Work across the Entire Food Supply Chain

26 Food safety behaviours in the home - Final Report for the Food Standards Agency

27 National Food Crime Unit

28 Food Fraud and "Economically Motivated Adulteration" of Food and Food Ingredients

29 Food and climate change: A review of the effects of climate change on food within the remit of the Food Standards Agency

30 Climate Change, Foodborne Pathogens and Illness in Higher-Income Countries

31 Dr Megan Clark, CSIRO

32 FAO - The State of Food Insecurity in the World

33 European Commission – Neonicotinoids

34 FAO - Food Security & Nutrition around the World

35 FAO, CABI - Combating Micronutrient Deficiencies: Food-based Approaches

36 PHE - Health matters: obesity and the food environment

37 Global Food: Waste not, want not

38 GFS Extreme weather and resilience of the global food system

39 WRAP - Food waste reduction

40 Courtauld commitment 2025

41 A food systems approach to policy for health and sustainability

42 Childhood Obesity: a plan for action

43 Landmark Agriculture Bill to deliver a Green Brexit

44 Industrial Strategy: building a Britain fit for the future

45 Clean Growth Strategy

46 WRAP – UK Plastics Pact

47 AI Sector Deal

48 Defra Food Statistics in your pocket 2017: Food Chain

49 Venture capitalists invest millions in food technology

50 Station F

51 Techhub

52 Clean Growth Strategy

53 Big Data in Smart Farming – A review

Partners

BBSRC bioscience for the future

EPSRC Engineering and Physical Sciences Research Council

E·S·R·C Economic & Social Research Council

Food Standards Agency food.gov.uk

Innovate UK

Llywodraeth Cymru Welsh Government

MRC Medical Research Council

NERC Science of the Environment

Department for Business, Energy & Industrial Strategy

Department for Environment Food & Rural Affairs

Department of Health & Social Care

Department for International Development

Public Health England

Government Office for Science

The Scottish Government

Affiliates

Science & Technology Facilities Council

wellcome trust

Met Office

Global Food Security
Sustainable, healthy food for all

Global Food Security (GFS) is a multi-agency programme, hosted by UK Research and Innovation, bringing together the main UK funders of research and training relating to food. GFS publications provide balanced analysis of food security issues on the basis of current evidence, for use by policy-makers and practitioners.

For further information please visit:
www.foodsecurity.ac.uk

Email: info@foodsecurity.ac.uk