Institute of Food Science + Technology

Food System Framework

A Focus on Food Sustainability







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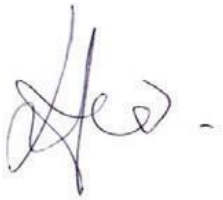
Foreword

“The imperative to overhaul our food system to prioritise environmental and social sustainability cannot be overstated. The food system interacts with a multiplicity of other systems; health, the economy, and the earth system itself. Understanding our place within these systems means that we understand how directly the food system impacts every inhabitant of our planet. Since the inception of our framework report in 2017, we've borne witness to the escalating repercussions of human-induced climate change, compounded by the disruptive forces of the COVID-19 pandemic as well as geopolitical turmoil around the world. These events have rippled across the food system, exacerbating resource constraints, intensifying extreme weather events, and catalysing socio-economic upheavals.

Yet, amidst these challenges, there is cause for hope and optimism. We are witnessing commendable efforts and the emergence of transformative technologies aimed at addressing this series of crises. IFST remains resolute in its commitment to collaborate with passionate partners, accelerating progress in critical areas and shedding light on overlooked necessities. This updated report marks a pivotal continuation of the groundwork laid out in our 2017 publication, serving as a beacon guiding our path forward.

This report is organised by areas of direct importance to our members and relevant stakeholders, empowering them to actively engage with sustainability as a daily imperative. Moreover, it provides a strategic roadmap, identifying where IFST can strategically intervene to maximise our impact as an institution in this vital endeavour.

As we propel our advocacy and expand our initiatives, your feedback and engagement are invaluable. Together, let's amplify our collective voice and chart a course towards a more resilient and fair food system.”



Sterling Crew
President, Institute of Food Science and Technology

Executive Summary

This updated document addresses considerations within the **global agri-food system** in a format intended to be accessible to individual IFST members to enable them to understand the **sustainability considerations** which impact the organisations within which they work, and to support focused engagement by the Institute in the interests of members and the broader industry alike. The key themes identified in the original 2017 report remain valid and are reflected here. In many cases IFST's role is not to develop new resources for members, but to direct them to existing relevant and trustworthy authorities.

Resource risks and pressures. The global agri-food system is fundamentally dependent on the natural environment whilst also causing significant environmental impacts. IFST has a role to play in UK and global efforts to increase **agri-food system resilience** through:

- Guidance for agri-food professionals.
- Promoting targeted research.
- Supply chain risk management.
- Using its voice with policymakers.

Healthy sustainable diets. There is a need to deliver good human and environmental health outcomes from the agri-food system. In partnership with appropriate technical colleagues, IFST supports through:

- Guidance on incorporating sustainability into the assessment of new processes and products.
- Contributing to the development of solutions to the global challenge of food and nutritional waste.

Circular economy and sustainable manufacturing. The current economic model of 'take-make-consume-discard' is unsustainable, and alternative models are beginning to emerge across the economy. IFST can support adoption of updated business models through:

- Addressing the food safety and regulatory challenges to arising from the increased use by-products as inputs.
- Supporting industry efforts to increase resource efficiency in the food sector.
- Facilitating creation of new practical standards for smaller organisations.
- Supporting optimisation of the usability of foods through improved labelling.

Executive Summary

Novel production systems and ingredients. New farming and processing technologies are beginning to emerge and there are opportunities for further innovation and for the optimisation of existing approaches to delivering **sustainable nutrition**. To maximise the impact of emergent foodstuffs and technologies, IFST can:

- Contribute to addressing the multiple challenges of novel protein technologies.
- Promote increased automation in those areas where labour shortages are impacting the agri-food system.
- Support research into the appropriate increased use of data-enabled and machine-learning technologies.

Decent work and equitable trade. The livelihoods and working conditions of many of the billion-plus people who work in the agri-food system need to be improved. With many supply chains dependent on **smallholder farmers** in developing economies, IFST can:

- Explore the opportunities for improved education and training provide by digital systems.
- Support research into a fuller understanding of the impacts of automation in the agri-food system.

Transparency, traceability and trust. Linked to the capacity to demonstrate provenance to sustainability as well as food safety standards, new software and data management systems can help drive improvements in agri-food system sustainability and strengthen **consumer trust.** IFST can:

- Increase industry knowledge of emerging traceability and transparency technologies.
- Support development and uptake of innovative approaches to assurance.

Food System Framework

A Focus on Food Sustainability

2nd Edition, April 2024

Introduction The Purpose of This Document

This document builds on the “Food System Framework – A Focus on Food Sustainability” report published in 2017. We have seen many changes affect the global agri-food system in that time, including the COVID-19 pandemic, the UK’s exit from the European Union (EU), the Russian invasion of Ukraine and many examples of extreme weather at home and abroad. In 2021 the UK hosted the 26th annual Conference of the Parties, or COP26, on climate change.

Sustainability can be a difficult concept to pin down, with definitions often adopting terminology from “our Common Future”, published in 1987 by the Brundtland Commission. Also known as the Brundtland Report, this document defined sustainable development and, by extension, sustainability. “Meeting the needs of the present without compromising the ability of future generations to meet their own needs” is the core concept at the heart of engagement on the topic.

Introduction The Global Agri-Food System

The United Nations Environment Programme (UNEP) defines the agri-food system as "the complete set of people, institutions, activities, processes, and infrastructure involved in producing and consuming food for a given population". This covers all stages of the value chain - from growing and harvesting agricultural products through to processing, packaging, transporting, selling, cooking, consuming, and the disposal of waste food and packaging.

A key characteristic of the agri-food system is the extensive linkages, interdependencies and feedback loops between value chain stages and the wider environment, society and economy. The agri-food system is both dependent on natural resources and significantly impacts the global environment. The agri-food system also has a major influence on human health and is an important global source of employment and economic value. It also has significant cultural significance in many societies.

Growing environmental pressures, including climate change, soil degradation, disruption of water cycles, expanding pathogen ranges and the increasing frequency of extreme weather events, coupled with population growth and migration, all impact on and will continue to affect the agri-food system. The complexity of the agri-food system means that it needs to be addressed as a system in its entirety if effective policy responses are to be developed by business and government.

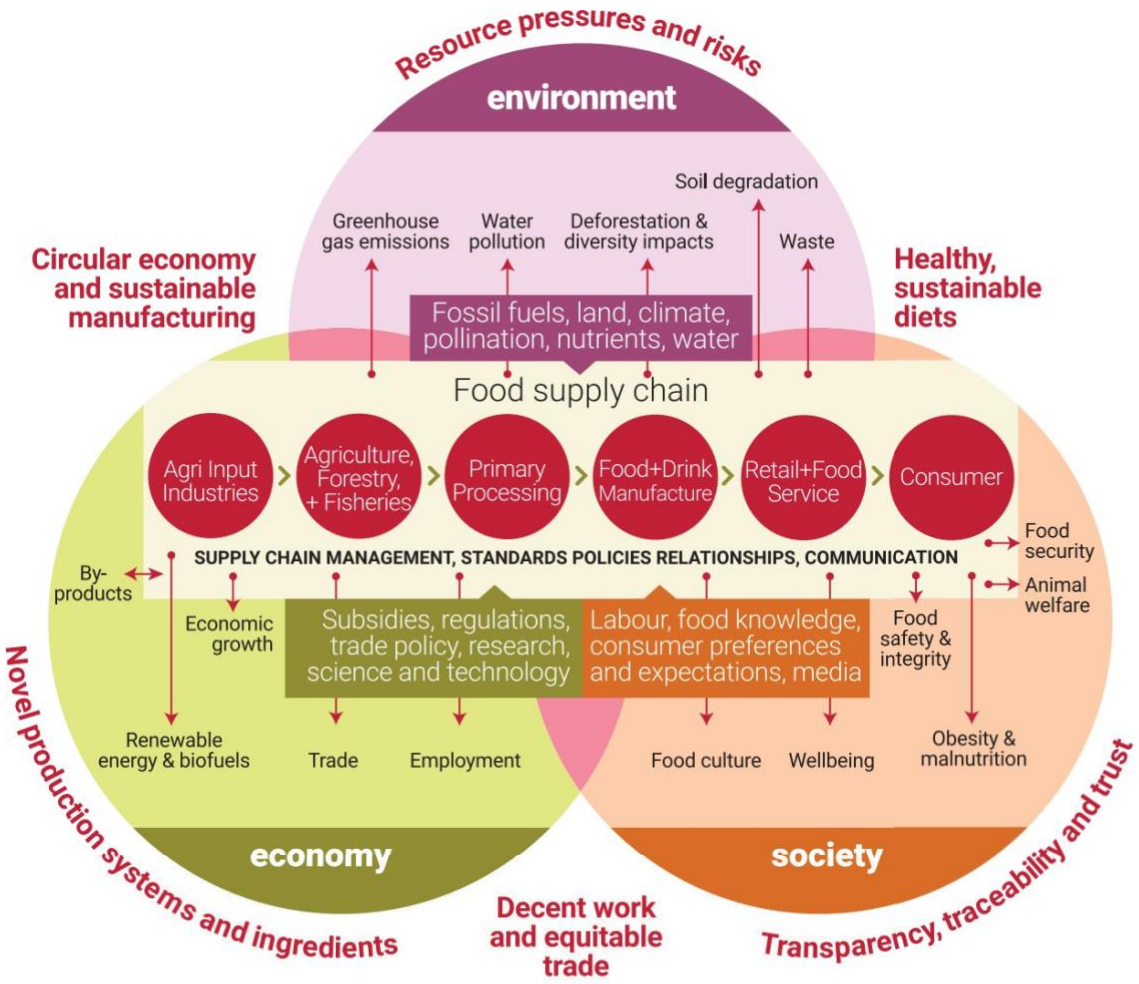
Land availability and quality is a key constraint on agricultural production. Globally, land is used not only to produce human-edible food - but also biofuels, fibre and livestock feed. Overall, around 12% of the world's land is cultivated and a further 25% is used as pasture. The expansion of cropland and pastures is the leading cause of ecosystem degradation and biodiversity loss and contributes 11% of global greenhouse gas emissions. Balancing these competing demands for land in a sustainable way is a fundamental challenge facing the agri-food system in the rest of the century.

There is a significant variation in the proportion of land used to feed humans directly versus being used for feed or other uses. A study published in Environmental Research Letters in 2013 found that, from the 41 crops analysed, overall 59% of the total produced calories are delivered to the world's agri-food system, with the rest lost in the transition from animal feed to human consumption or used industrially or as biofuels. 89% of the calories used in animal feed are lost to the agri-food system through inefficiencies of the feed-to-edible food conversion.

The majority of calories produced in the major croplands of Europe, US and China are not used for human consumption but other uses - particularly feed and biofuels to meet growing meat, dairy and energy demands. Crop requirements needed for livestock have caused major livestock-producing countries to become net importers of grain. Protein and soya specifically are a significant environemntal issue as countries which are net importers of nitrogen and phosphorous can suffer significant diffuse or point source pollution.

In the interests of thematic clarity, this report is presented in a linear fashion but with frequent internal referencing to related topics to reflect their inter-dependencies.

Figure 1: The food system - and key IFST food system themes outlined in the executive summary. Source: IFST Food Systems Framework: A Focus on Sustainability 2017.



In 2015 the **United Nations** (UN) launched the **Sustainable Development Goals** (SDGs), a set of 17 high-level ambitions to address the social, environmental and governance issues facing the global economy. Sitting beneath the 17 Goals are 169 targets, typically positioned in a way suggesting relevance primarily to national governments but with many also having direct significance to businesses and other organisations outside government.

Since their launch, the SDGs have increasingly become adopted by organisations of all types as a common framework for discussion and reporting of action, primarily, around environmental and social progress. Throughout this report, the content is indexed with SDGs with direct and indirect relevance to the topics discussed at a thematic level. The full set of SDGs can be seen in the figure below.

All UN member states have signed up to the SDGs, making it unlikely that businesses in major agri-food systems are not covered either morally or legally by their aims. The specifics of what the UNSDGs mean by 'no poverty', for instance, sits in the next level of granularity beneath the goals and will (or not) be reflected in national laws in ways that suit individual legislatures.

Figure 2: United Nations Sustainable Development Goals. Source: UN SDG Communications Materials. https://www.un.org/sustainabledevelopment/news/communications-material/

Characteristics of the Agri-Food System

The global agri-food system consumes a significant proportion of the world's resources and is set to consume more with the birth of the eight billionth global citizen marked in 2022. Resource consumption includes not only land and water, but also the use of inputs such as nitrogen fertilisers. Associated impacts include the emissions associated in the production of input materials and the downstream environmental consequences of their escape into the broader environment. Supply chains are long and inter-linked and have typically built up over time as a consequence of multiple independent decisions, usually taken on an isolated economic basis. Consumption and impacts vary globally, according to degree of industrialisation, level of economic development, prevailing climatic conditions and other factors.

The agri-food system is the biggest user of key natural resources, such as terrestrial and marine biodiversity, soils, freshwater, minerals and fossil fuels. The United Nations Environment Programme (UNEP) estimates 60% of global terrestrial biodiversity loss is related to food production. As such, the agri-food system has significant influence over critical global and local biophysical processes such as the water cycle, climate, nitrogen cycle. The status of many of these sub-systems is declining and has the potential to impact upon the future production capacity. Water, in particular, has been identified as a critical agri-food system resource that is under threat and has the potential to impact upon yields, quality and safety of food. Agriculture uses 70% of all fresh water withdrawn from rivers, lakes, and aquifers, which can lead to depletion of water resources when more water is extracted than can be replenished. Loss of wider ecosystem services such as pollination, also threaten future production.

The annual global risk report published by the World Economic Forum (WEF) has shown a distinct transition from economic to environmental risk drivers since it was first published in 2007. Key amongst the environmental risks identified by the WEF are extreme weather events and the chronic impacts of climate change. Water stress is now characterised in their reporting as a societal issue, but it is one with clear implications for agriculture (early editions of the report classified water as a primarily environmental issue). The COVID-19 pandemic exposed the lack of resilience to extreme shock of many global supply chains, including agri-food, and led to a change in the approach to risk taken by many organisations. Changes in sourcing result in an additional assurance burden which may need to be repeated as a consequence of future shocks.

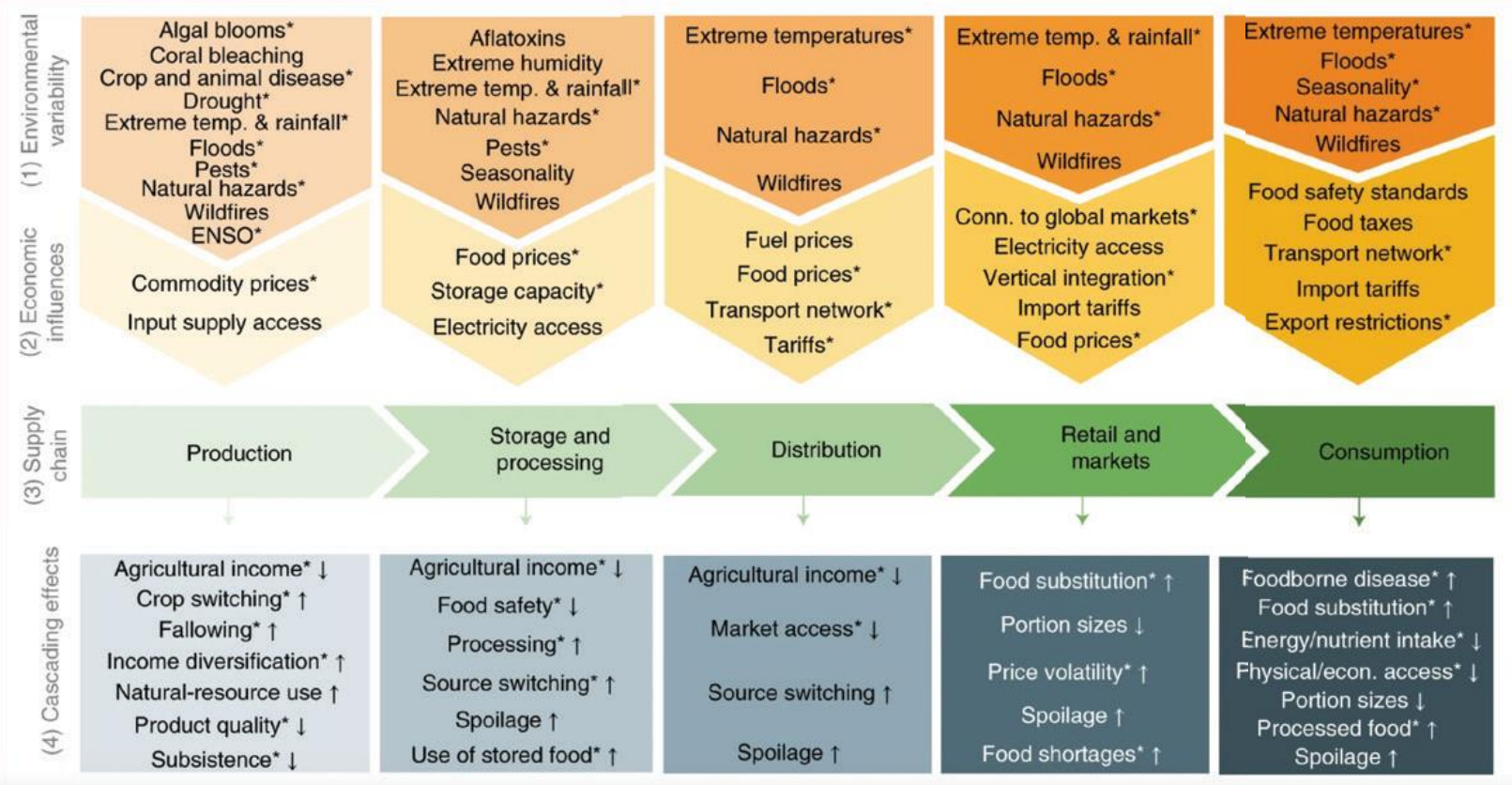


Figure 3: Entry points for environmental variability in food supply chains. Source: Davis, K.F., Downs, S. & Gephart, J.A. Towards food supply chain resilience to environmental shocks. Nat Food 2, 54–65 (2021). https://doi.org/10.1038/s43016-020-00196-3

Several trends and high-profile events are increasing citizen/consumer, policy maker and investor interest in ethical and environmental management of food supply chains. In particular, the rise of social media, the work of campaigning Non-Governmental Organisations (NGOs), and changing consumer expectations mean that there is growing scrutiny on practices from farm to point of sale. Improving practices and building trust is likely to mean greater transparency, an evolution of the use of standards and better use of food chain data.

Disclosure mechanisms, both statutory and voluntary, continue to increase in importance, reflecting citizen/consumer interest in assurances that the food they consume has been produced in ways which are both environmentally and socially responsible. In some cases, statutory obligations on organisations extend along their supply chains back to source, placing more complex responsibilities on larger businesses. Reporting is a mixture of qualitative and quantitative data and applies at both enterprise and product level. After a flurry of interest in the 2000s, Life Cycle Assessments (LCAs) and the subset of LCAs relating to emissions (carbon foot-printing) are returning to products.

Transparency can increase consumer confidence in products and companies and allow them to make more informed decisions. For companies, it can reduce the ethical, financial, and supply risks that can result from a lack of transparency in their supply chain. Many companies, aware of these benefits, are now beginning to put serious effort towards improving the transparency and traceability of their supply chains.

Retail and environmental standards are being brought up to date with this trend towards increasing transparency. Common voluntary standards such as the British Retail Consortium Global Standard (BRCGS) Food Safety, the 9th edition of which was published in 2022, is becoming progressively broader in scope, and the ISO14001 environmental management standard encourages a whole supply chain perspective including a de facto materiality assessment. Other organisations are also creating important new initiatives to incentivise transparency and disclosures. For example, the Task Force on Nature-Related Financial Disclosures (TNFD) is currently developing a voluntary biodiversity climate-related financial risk disclosure for companies to use to provide information to investors and other stakeholders, following from the climate equivalent (TCFD) which became a requirement for large UK businesses in 2022. It is important that actions taken to improve the sustainability of agri-food products are taken on the basis of robust evidence and consistent approaches to avoid inappropriate or unsupportable claims (often known as 'greenwash'). The UK's Competition and Markets Authority (CMA) has produced guidance on making environmental (and other) claims, and has powers to impose direct civil penalties on companies.

Common Voluntary Standards	Aims
BRCGS	Provides a framework to manage product safety, integrity, legality and quality, protecting the consumer across a wide range of food industries.
ISO14001	The internationally recognised standard for environmental management systems (EMS). Gives a framework for organisations to design, implement, and improve their environmental performance.
TNFD	Guidance and recomendations for organisations to report and act on evolving nature-related dependencies, impacts, risks and opportunities.
TCFD	Created to improve and increase reporting of climate-related financial information. It was disbanded in 2023 and is no longer active.
CMA	A body helping the UK economy, businesses and individuals by promoting competitive markets and tackling unfair behaviour in a number of ways.

The treatment of people within supply chains and the fair sharing of benefits is extending from conditions in developing countries into industrialised economies. The development of public and private money for ecosystem services is impacting on the land available to produce food in the UK and the content and context of emerging trade deals has ethical implications where standards are divergent. Long-standing issues of animal welfare are expanded by lengthening supply chains, new agricultural practices and the tensions between environmental and husbandry benefits of particular approaches. A driver for some behind the move to novel proteins, the ethical impact of agri-food extends to the nutritional profile of ‘plant-based’ products for human consumption and the bioavailability of the nutrients they contain.

The capacity to generate and process data relating to the global agri-food system continues to evolve with the development of more powerful computing systems and the demand from stakeholders for visibility. Inevitably, this capacity varies along supply chains with greater adoption of traceability management systems associated with wealthier economies. Inconsistent information requirements from different actors in the system further exacerbates the complexity in ensuring the sufficiency and appropriateness of data provision. Technologies such as blockchain are in the early stages of implementation but do not immediately solve issues with access to comprehensive and reliable primary data. The use of large muti-source data sets ('big data'), remote sensing and web-connected technology (the 'Internet of Things' or IoT) has the potential to revolutionise food supply chains among other sectors.

Benefits and concerns include:

- Optimising agricultural and manufacturing systems - including better demand and supply management using real-time data
- Increasing supply chain traceability and risk management - including the identification of current and future risks to supply risks from disruptions such as climate change.
- Enabling faster product development and innovation.
- Creating smarter logistical chains.
- Transparency between actors in food supply chains.
- The potential for greater vulnerability to cyber crime.

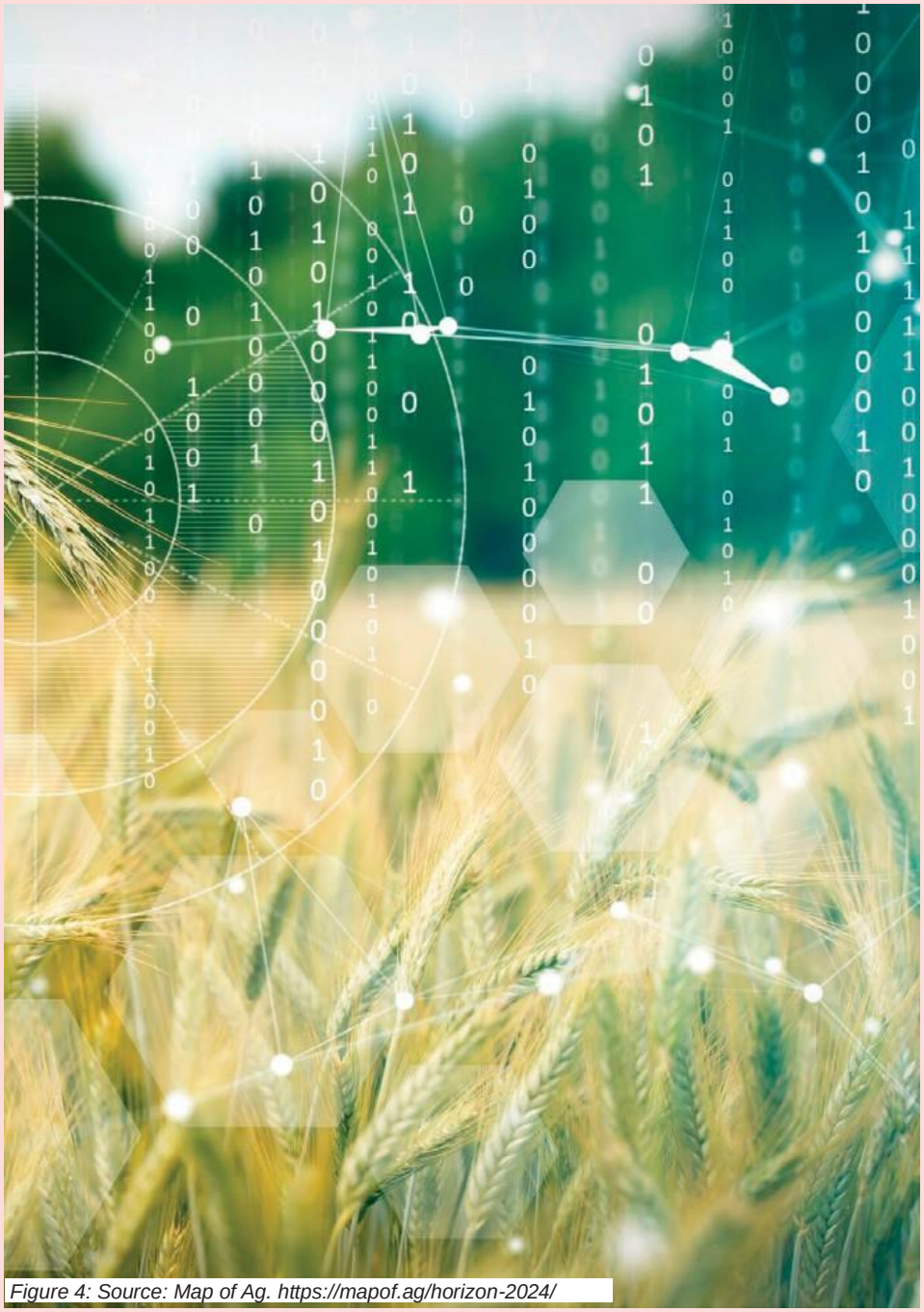
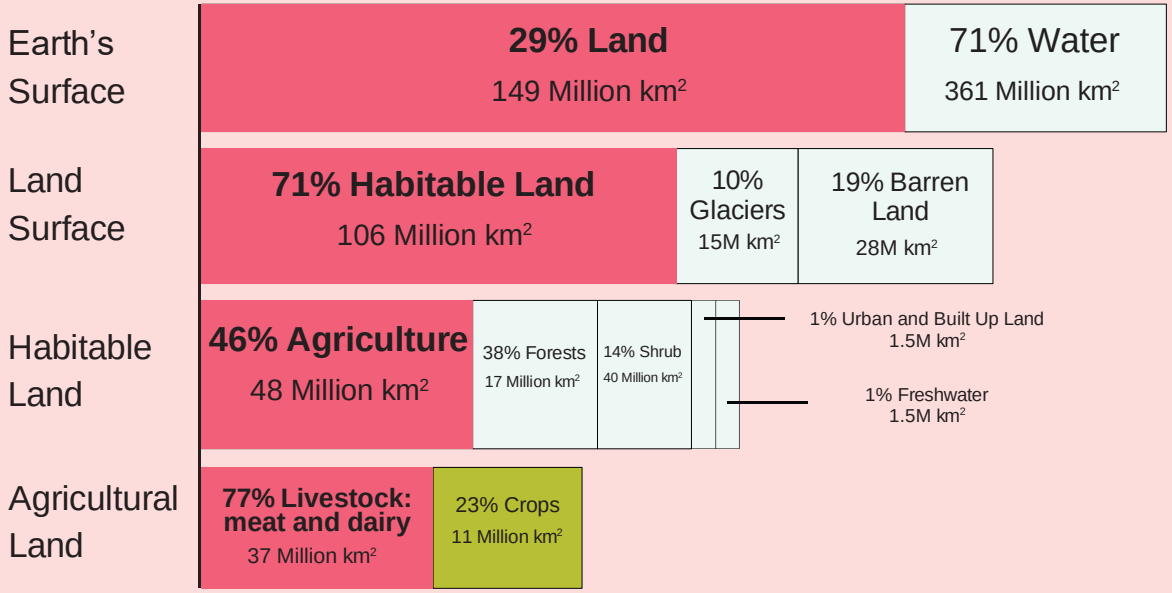


Figure 4: Source: Map of Ag. https://mapof.ag/horizon-2024/

Agriculture is a major user of key natural resources, already occupying nearly 40% of total land area and accounting for over 70% of global water withdrawals. A forecast 90% increase in global crop production needed to feed the future population will require improved use of inputs, technologies and practices to increase production output per input of unit (agricultural intensification) such as that achieved in Brazil. Intensification can also offer environmental benefits - most notably sparing non-agricultural land from conversion, a major driver in GHG emissions.

However, if not properly regulated, it can have significant environmental adverse consequences such as soil degradation, increasing water pollution and contamination from agri-chemical run-off. Many agricultural production systems are now centred on a very narrow range of crop and livestock species (two thirds of human calorie requirements are provided by four crops: rice, wheat, maize, and potatoes) leading to greater exposure to disease risks and are dependent on a range of 'artificial' inputs such as pesticides, inorganic fertilizers, antibiotics and irrigation. Intensification is also reflected economically, with four agribusinesses controlling 90% of the global grain trade.

Figure 5: Global Land Use for Food Production. Source: UN Food and Agriculture Organisation (FAO) 2019. Via Our World in Data



Smallholders are a key part of the global agri-food system - managing more than 80% of the world's 500 million small farms. Smallholders produce many of the major globally traded crops such as cocoa, coffee, tea and cotton, as well as vegetables, fruits and flowers. Smallholders in developing and emerging economies face many challenges such as climate change, poor infrastructure, rising input prices and lack of agricultural extension services, which can result in smallholders being subject to unfair trading. Cooperative groups and growers' associations aim to ensure fairer conditions for smallholders.

The role of women and children in global food production are of particular note. Women small holders and subsistence farmers produce half of the world's food, with women accounting for around 43% of the global agricultural labour force but are often unpaid and offered less support than men. Various initiatives aim to empower women farmers including the Fairtrade Foundation and the Ethical Trading Initiative. It is also estimated by the UN International Labour Organisation (ILO) that 60% of all children globally are engaged in labour work in agriculture.

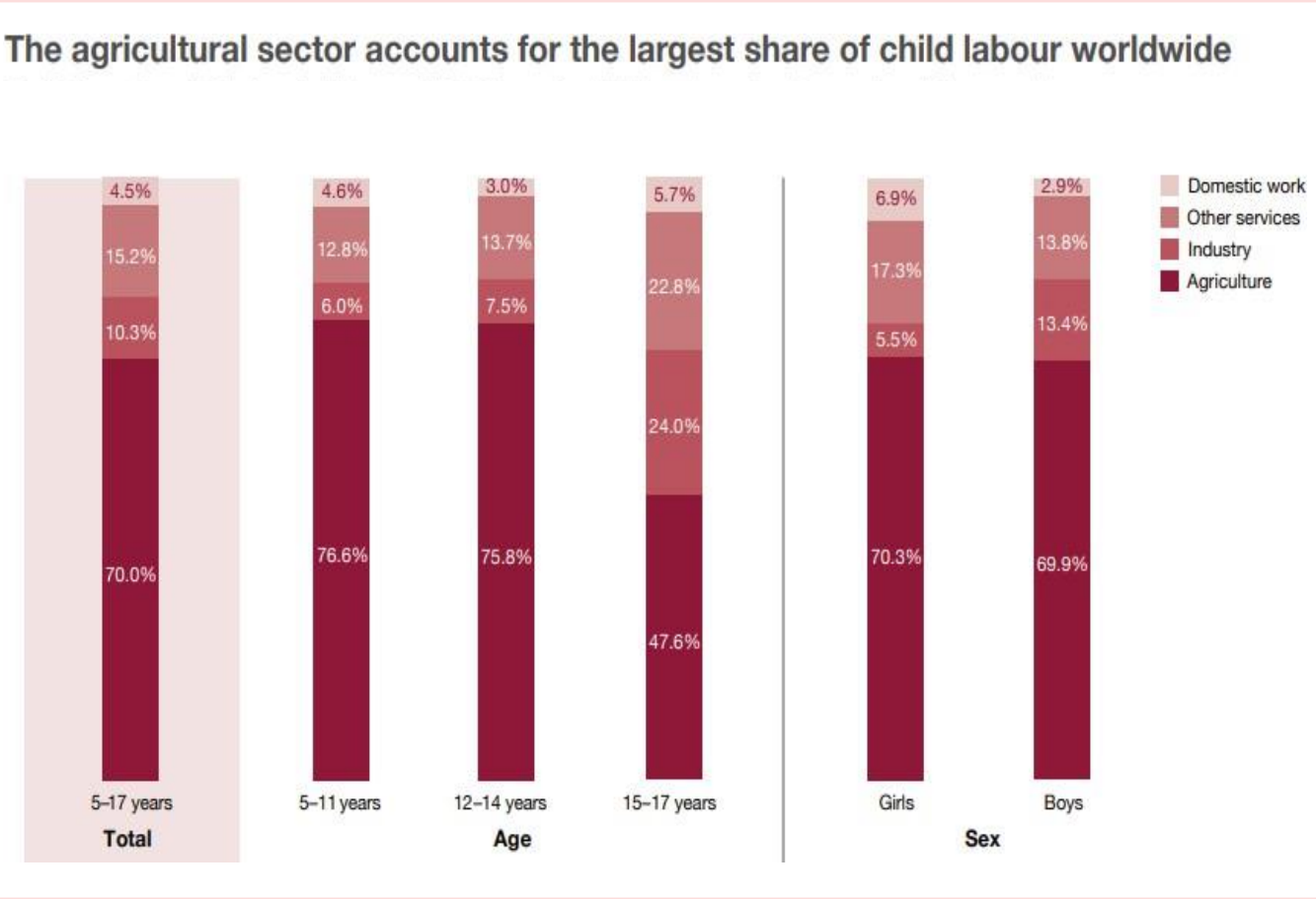
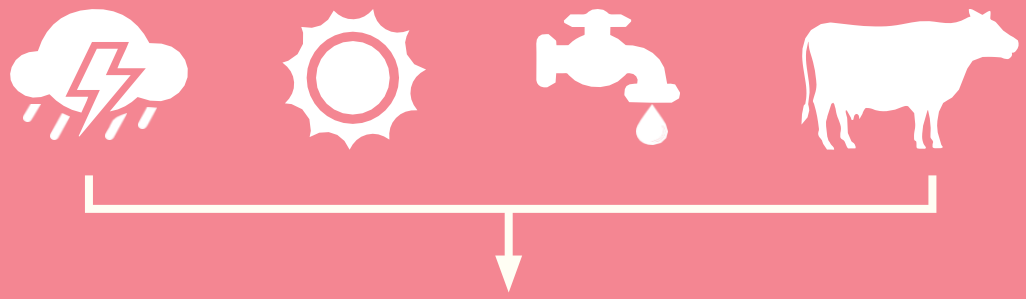


Figure 6: Percentage distribution of children aged 5 to 17 years in child labour, by sector of economic activity, afe and sex. Source: ILO and UNICEF: Global estimates 2020, trends and the road forward (New York, 2021)

Acute instances of extreme weather are increasing globally and when they occur have dramatic impacts on agriculture and the natural environment more broadly. Instances of flood, drought and late frosts all have the potential to directly and dramatically affect both yields and productivity. Secondary effects include disruption to fossil-fuel based power generation, which is reliant on adequate supplies of cooling water, hydro-power generation, and logistics as road and rail links are cut. The human impact can be significant, such as the flooding in Pakistan in 2022 which covered more than one tenth of the land area of the country. Even in less extreme circumstances, disruptions to transport systems impact the movement of people as well as the movement of goods.

The food sector is also severely exposed to the chronic effects of climate change, themselves the cause of extreme weather events, which will impact on crop productivity, animal health and trade patterns both directly and indirectly through its effects on water, land, and populations. The viability of existing plant and animal species in a warming environment is uncertain, with studies suggesting that higher temperatures will more than offset the growth gains for plants from higher levels of carbon dioxide. The distribution of wild species is already changing in response to the changes in climate. As temperature and rainfall patterns continue to become less predictable, the reliability of established planting and cultivation reduces, something which is already beginning to be felt by the farming sector.



Extreme weather events as a result of climate change have exposed the food system to heavy impacts - including on crop productivity, animal health and trade patterns.

Soil health is vital for agricultural production. The first global soil assessment took place in 2015, revealing that a third of land is moderately to highly degraded as a result of soil erosion, compaction, salinisation acidification and pollution. Moreover, it is estimated that 12 million hectares of topsoil are lost every year to soil degradation, and agricultural practices can contribute to this significantly. Soil management strategies will be key to ensure the future health of this resource for direct use in agriculture and horticulture and soil is also a valuable carbon sink. In July 2023 the European Commission proposed legislation to revive degraded soils, mitigating the impacts of some intensive farming practices and contributing to the sequestration of atmospheric carbon.

In-setting is the practice of running climate protection projects along a company's own value chain that demonstrably reduce or sequester emissions and thereby achieve a positive impact on the communities, landscapes and ecosystems associated with the value chain. Off-setting, which is an acknowledged interim-only measure, effectively pays another entity to take action on an organisation’s behalf without any fundamental changes to its own conduct. Afforestation (tree-planting) has become a common off-setting approach but is fraught with complexity and credibility issues.

In its sixth carbon budget, the UK’s Climate Change Committee (CCC) noted three key land-use changes with the potential to make significant contributions towards the UK achieving a net-zero emissions profile by 2050. Two of these, the restoration of peatland, and the reforestation of parts of the UK’s farmland (presumed to be possible in line with a parallel recommendation for a 20% reduction in the consumption of meat and dairy products) are covered by existing codes of practice. The third, using soils to sequester atmospheric carbon dioxide, was framed less quantitatively in the absence of an agreed standard.

Such a standard is currently under development, however, and the concept of using carbon sequestration as an income stream for farmers is gaining traction. Large-scale trials conducted in Australia using seaweed as part of modified feed to reduce enteric emissions of methane from cattle have not delivered the anticipated benefits.

Inevitably this, and other uses of land in the carbon economy such as solar farms and growing energy crops, has the potential to change the use of land away from food production. In a survey of Scottish livestock farmers conducted in 2022 64% of respondents with rough grazing and permanent pasture said they would consider transitioning out of livestock farming entirely and into 'farming carbon capture' by helping the land return to a semi-natural state (often referred to as rewilding), providing financial support is in place.

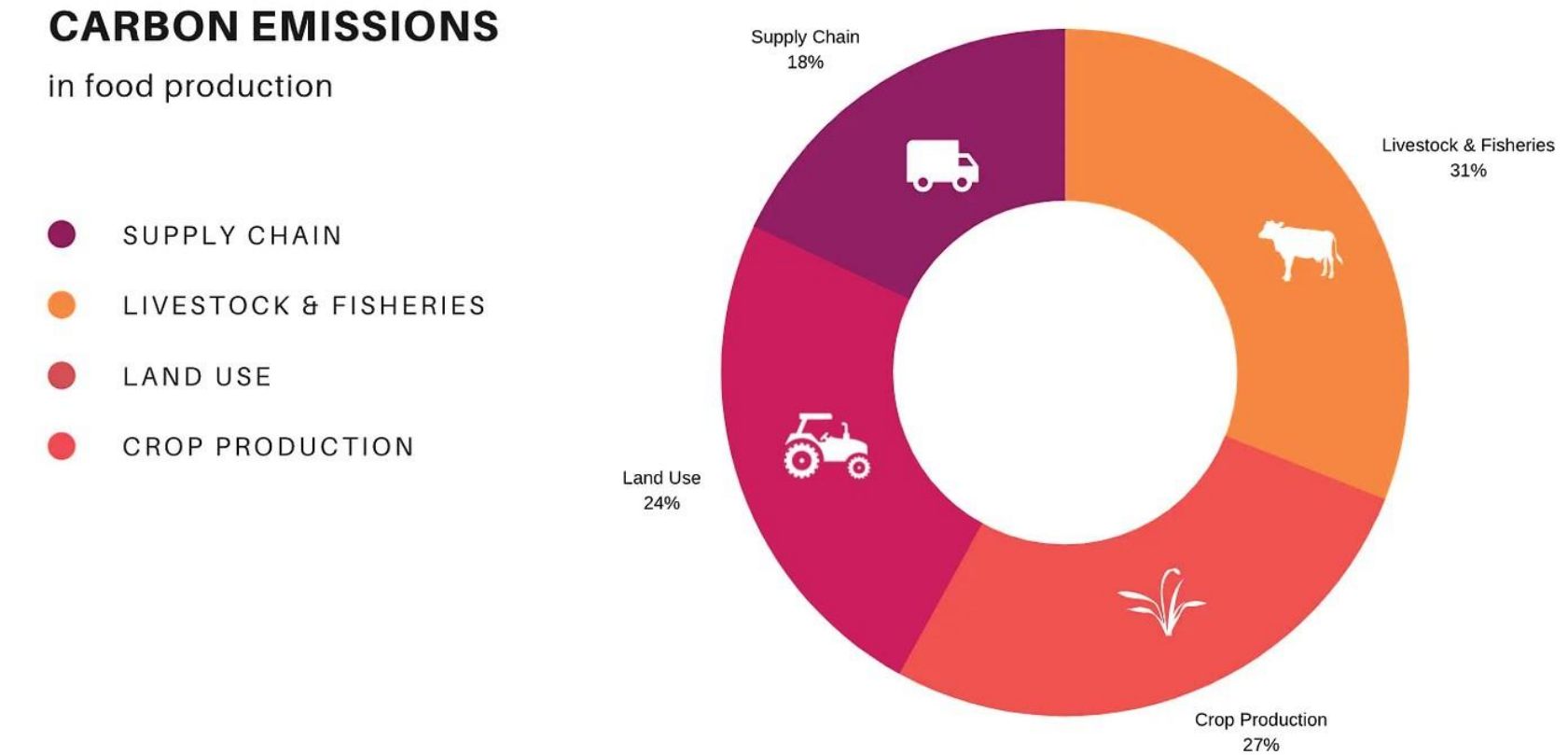


Figure 7: Carbon Emissions in Food Production. Source: https://medium.com/carbonbase/watch-your-carbon-footprint-food-38aec5ab9c12.

Original Data Source: Our World in Data

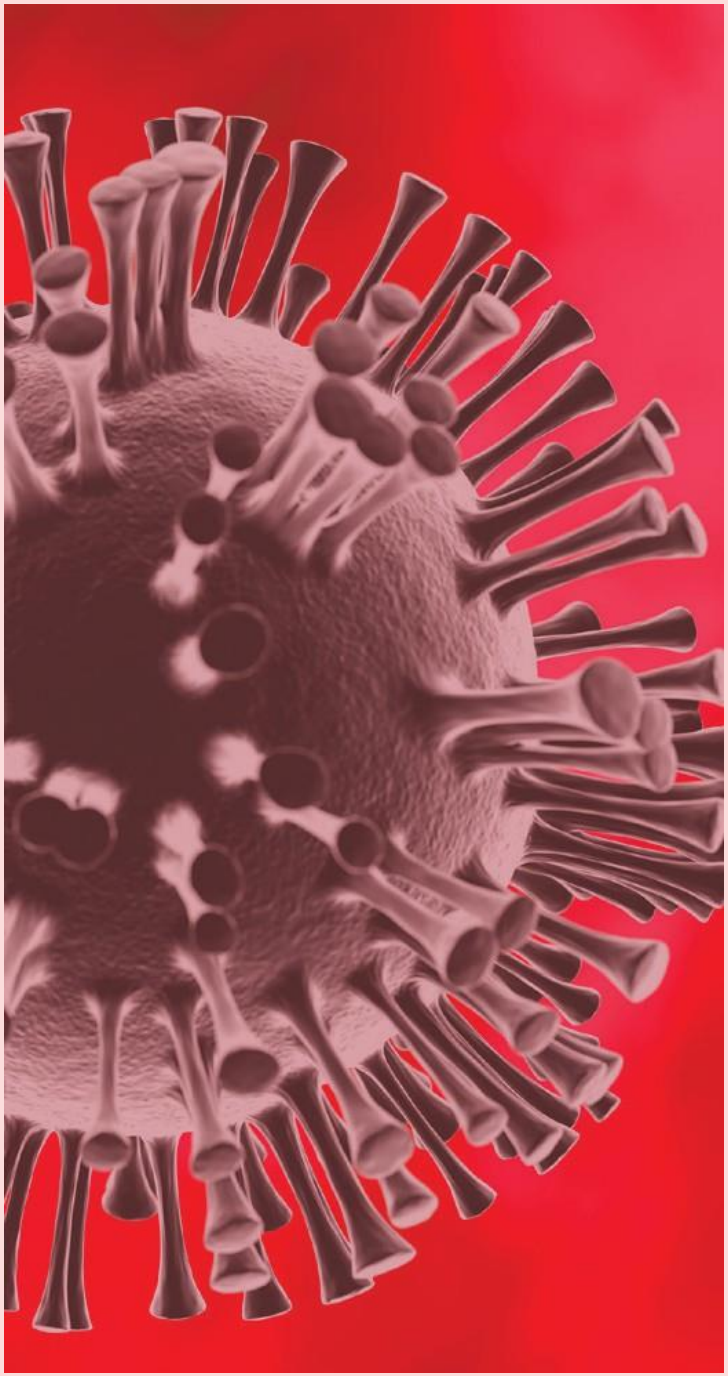
The welfare of animals in the agri-food system is subject to regulatory control to varying degrees around the world. The UK Government receives advice from the Animal Welfare Council (AWC), an expert body advising the Department for Environment, Food and Rural Affairs (Defra) and the Scottish and Welsh Governments on the welfare of animals. This includes farmed, companion and wild animals kept by people. The AWC provides opinions and letters of advice to ministers, which can have a rapid impact on regulation. UK animal welfare regulations dating back to 2006, for instance, were amended during the heatwave in summer 2022 to reflect the impact of extreme weather on humane transport. Broader developments in regulation include the UK Animal Sentience Act, a Bill to make provision for an Animal Sentience Committee with functions relating to the effect of government policy on the welfare of animals as sentient beings, including crustaceans and decapods following submission of the findings of an academic research report. The Bill received Royal Assent and became law in April 2022.

A similar system exists in the EU, and humane practices are widely supported throughout the Western world and beyond. In a referendum held in Switzerland in 2022 37% of the turnout voted to ban intensive livestock farming and the proposal achieved a majority in one of the major urban areas. As biologists understand more about animal intelligence, and as ‘cultured’ meat and further acceptable plant-based alternatives reach market, it is likely that more states will respond with public consultation and possible regulation.

The COVID-19 pandemic has served to illustrate the vulnerability of international trade to systemic shocks. The upsurge in cases in China in December 2022 as movement restrictions were lifted three years on from the initial outbreak is a reminder, if one were needed, that something similar is likely to happen again. The impact is not limited to direct effects on the transport of foodstuffs but extends to supply of consumable products required by agri-food businesses. Combined with international commerce and travel, as global consumption has converged on progressively more similar diets, the risk of disease outbreaks having the scale and duration of the COVID-19 pandemic increases.

The swine flu outbreak of 2009-2010 was less significant than initially feared, but the disease remains present in the global pig population, and the risk of more readily human-transmissible variants remains and current disease outbreaks impact a range of regionally and globally important agricultural products. Avian influenza has seen repeated outbreaks of varying virulence in the UK and elsewhere, most recently leading to mandatory housing measures being introduced for all poultry and captive birds across all areas of England in November 2022.

Spread by insects, the Xylella fastidiosa bacterium has killed trees across large parts of Italy and now poses a potential threat to olive plantations in Spain and Greece. Global banana production is seriously threatened by a strain of the soil-borne fungus Fusarium oxysporum f. sp cubense Tropical race 4, commonly referred to as TR4. Although there are hundreds of banana varieties, global trade is dominated by the Cavendish variety, which is made more vulnerable by the practice of vegetative propagation. Large-scale work is underway to find a solution. This repeats work undertaken following an outbreak of TR4 in the 1950s, which lead to the Cavendish variety replacing the previously dominant Gros Michel variety".



More generally, in a warming world the spread of existing human diseases such as malaria will increase. The impacts of such increased diseases are not unique to the agri-food sector but will place increasing operational pressures on organisations in affected areas and increasing expectations on supply chains.

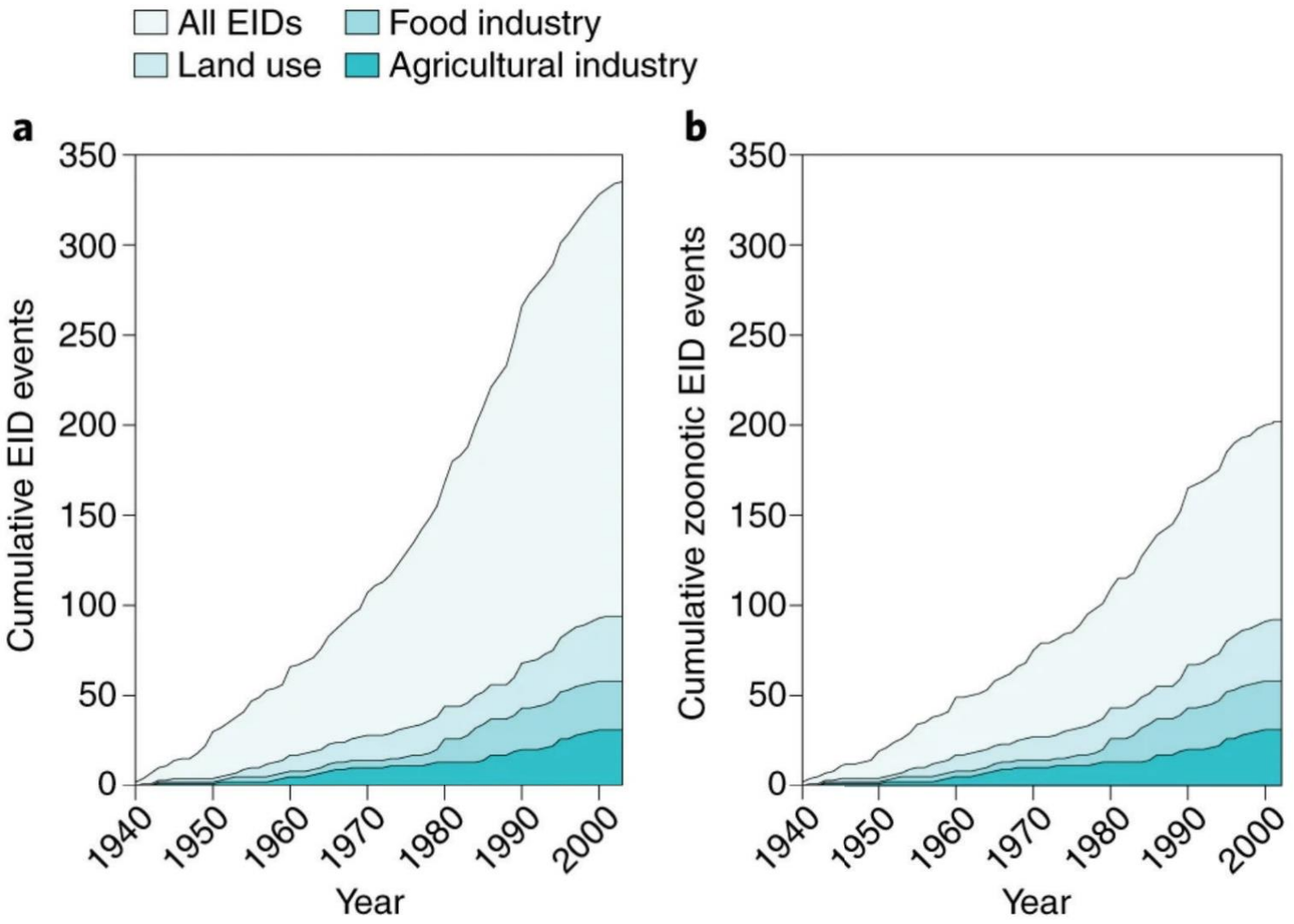


Figure 8: Effects of agricultural drivers on emerging infectious diseases (EIDs) and zoonotic EIDs of humans since 1940. Agricultural drivers were associated with 25% of all (a) and nearly 50% of zoonotic (b) diseases that emerged in humans. For these figures, we use the definition of a zoonotic EID provided by Jones et al.1, which is a disease that emerged via non-human to human transmission, not including vectors. Source: Rohr, J.R., Barrett, C.B., Civitello, D.J. et al. Emerging human infectious diseases and the links to global food production. Nat Sustain 2, 445–456 (2019). https://doi.org/10.1038/s41893-019-0293-3

The use of antibiotics as growth promoters in agricultural livestock has been common practice in parts of the world for decades, and as recently as 2019 was used in 70% of global production despite their precise mechanisms being poorly understood. A parallel concern in the field of human health has been the rise of resistance of common infectious diseases to medicinal antimicrobials leading to progressively more stringent guidance for the medical sector as a consequence of increasing public and political attention, with the World Health Organisation publishing a global action plan on antimicrobial resistance in 2015.

Organisations such as the Responsible Use of Medicines in Agriculture (RUMA) in the UK are pivotal in advocating for high standards of animal health and welfare within the food system. RUMA focusses on promoting responsible medication practices, aiming to minimise the need for antibiotics and antimicrobials in livestock farming. Through collaboration with actors at all stages from farm to fork, including industry stakeholders, veterinarians, and policymakers, the UK has a robust framework to ensure medicines are used sparingly and animal welfare is safeguarded. The Agriculture and Horticulture Development Board (AHDB), which represents farmers, growers, and others in the supply chain, has developed resources such as the Medicine+ Hub, an online tool to help dairy, beef, and sheep producers monitor and compare medicine use and tackle the threat of antimicrobial resistance. As a result, UK sales of antibiotics to treat farm animals has decreased by 55% since 2014, and HP-CIA sales have fallen by 83% in the same timeframe.

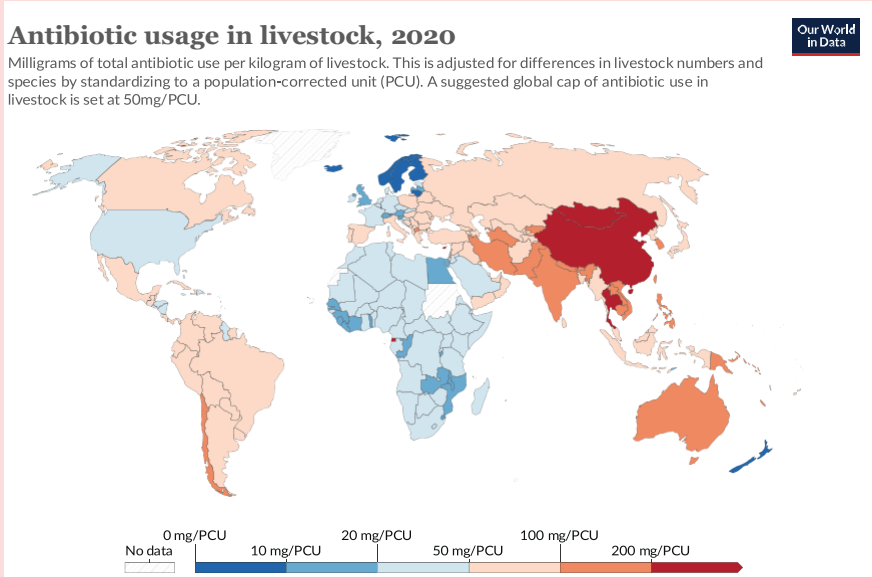


Figure 9: Antibiotic usage in livestock, 2020. Source: Our World in Data, Mulchandani et al. (2023)

Almost nothing is consumed in industrial economies without some form of processing having taken place, even if that is simply washing and packing of fresh produce. Even at such a basic level, however, processing can be controversial. The public distaste for single-use plastics, albeit tempered during the COVID-19 pandemic, has led to legislation in countries around the world. Even the concept of the processing of ingredients into food can be controversial, as illustrated by the rise of the term ‘ultra-processed’. Reductions in levels of processing or the use of preservatives, especially in combination with lower levels of packaging, have clear implications for public health. As the protection provided by these measures is reduced, the risk of food spoilage potentially increases.

The concept of the ‘circular economy’ is receiving growing attention, including in UK government policy. Treating secondary system outputs as raw materials for other processes rather than wastes is appealing both economically and environmentally. The ‘circles’ of the circular economy can involve multiple stages, and the return of treated municipal effluent to the land is a long-established practice. More recently, refinements to this approach have included recovery of specific resources from both process (including fibre and protein) and post-consumer waste streams, the latter including phosphorus and, more commonly, energy in the form of combusted methane from anaerobic digestion (AD). Such innovation brings with it the risk of unintended consequences such as changed fertility arising from the loss of carbon from digestate returned to agricultural soils.

Figure 10: The circular economy model. Source: European Parliment Research Service.

Food waste occurs across the whole agri-food system with the most significant source in developed economies being otherwise edible food thrown away by consumers at home. As well as the over-arching Goal of “Zero Hunger”, which is framed more around market measure and fair access, the UN SDGs include a target under the Goal of “Responsible Consumption and Production” of halving food waste by 2030. The Waste Resources Action Programme (WRAP) runs a number of voluntary reporting schemes for businesses in the UK and reports on national performance. Reduced food waste features in scenarios presented by the UK’s Committee on Climate Change (CCC) in the sixth carbon budget and is reflected in UK legislation. Mandatory separate domestic food waste collection is spreading across the UK and Defra have run a consultation in England on the possibility of future mandatory reporting of food waste by businesses.

An internationally agreed protocol, the Food Loss and Waste Accounting and Reporting Standard (FLAWRS), recognises three legitimate routes for re-direction of material intended for human consumption which would otherwise have gone uneaten; re-distribution to human use via charities or similar channels, use in animal feed, including non-agricultural animals, and bio-based materials. The latter are characterised as industrially viable non-food products, although there are some grey areas around energy recovery.

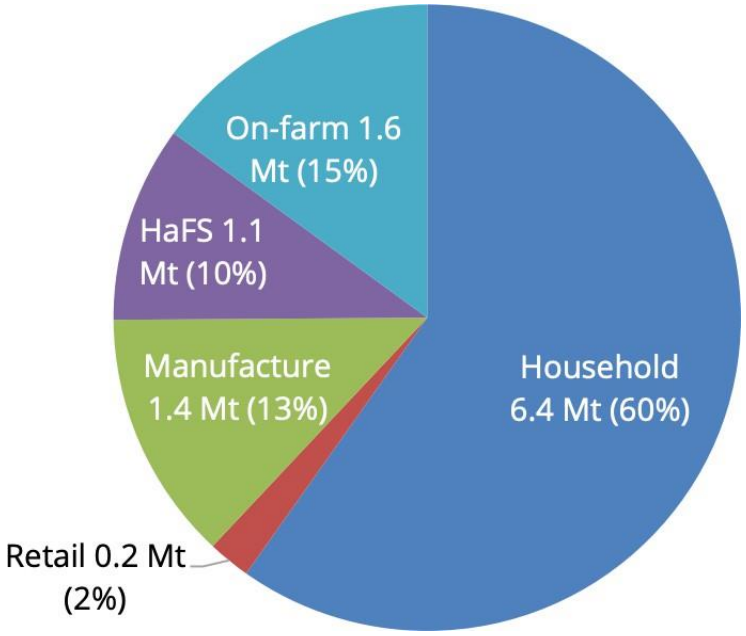
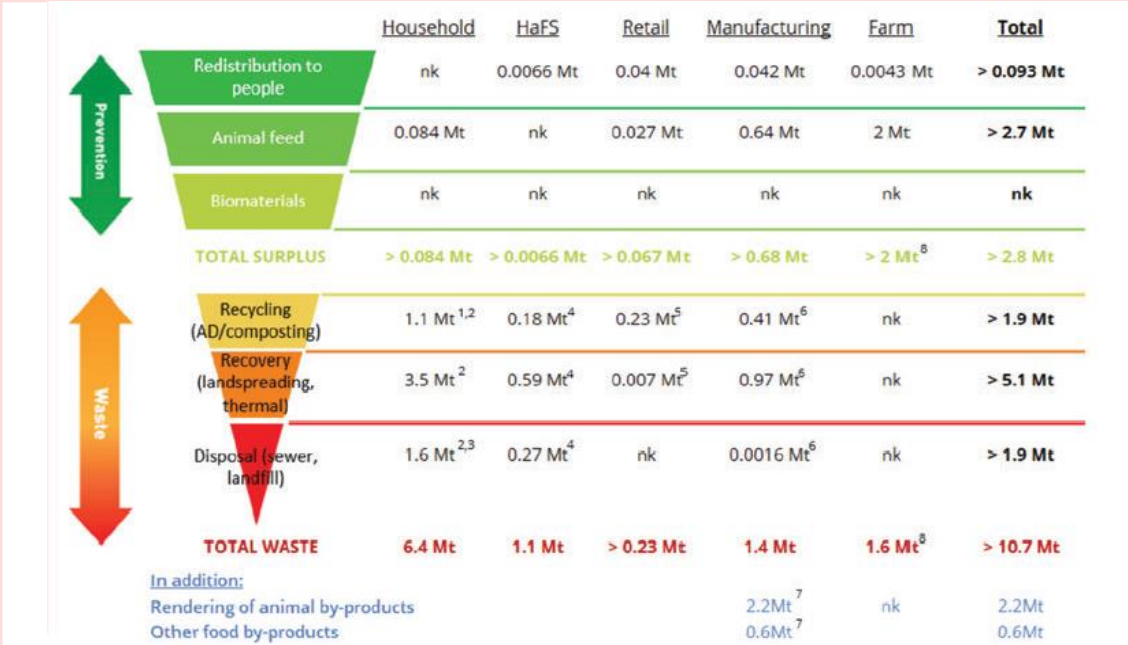


Figure 11: Total food waste arising in the UK, by sector, Source: WRAP Food Surplus and Waste in the UK Key Facts 2023.



	Household	HaFS	Retail	Manufacturing	Farm	Total
Prevention: Redistribution to people	nk	0.0066 Mt	0.04 Mt	0.042 Mt	0.0043 Mt	> 0.093 Mt
Prevention: Animal feed	0.084 Mt	nk	0.027 Mt	0.64 Mt	2 Mt	> 2.7 Mt
Prevention: Biomaterials	nk	nk	nk	nk	nk	nk
TOTAL SURPLUS	> 0.084 Mt	> 0.0066 Mt	> 0.067 Mt	> 0.68 Mt	> 2 Mt[8]	> 2.8 Mt
Waste: Recycling (AD/composting)	1.1 Mt[1,2]	0.18 Mt[4]	0.23 Mt[5]	0.41 Mt[6]	nk	> 1.9 Mt
Waste: Recovery (landspreading, thermal)	3.5 Mt[2]	0.59 Mt[4]	0.007 Mt[5]	0.97 Mt[6]	nk	> 5.1 Mt
Waste: Disposal (sewer, landfill)	1.6 Mt[2,3]	0.27 Mt[4]	nk	0.0016 Mt[6]	nk	> 1.9 Mt
TOTAL WASTE	6.4 Mt	1.1 Mt	> 0.23 Mt	1.4 Mt	1.6 Mt[8]	> 10.7 Mt
In addition:						
Rendering of animal by-products				2.2Mt[7]	nk	2.2Mt
Other food by-products				0.6Mt[7]		0.6Mt

Figure 12: Summary of food surplus, waste and related material arisings in the UK, and their respective treatment/ disposal routes. WRAP Food Surplus and Waste in the UK Key Facts 2023.

All other routes remain defined as waste. Material which is inedible, such as nut shells, is reported but not subject to reduction targets. Municipal authorities in the UK routinely use collected domestic food waste to produce energy through anaerobic digestion (AD), or compost. Business models are starting to emerge using low-grade mixed waste such as domestic food waste, as the basis of novel routes back into the human agri-food system via insect proteins. Otherwise, human-edible product which is produced for other uses, including feed, fibre and energy crops, are not within the scope of the FLWARS (subject to local extension).

The environmental significance of food waste reduction along with societal and economic benefits, is clear. Although wastage is not evenly spread across all categories, approximately 30% of all the resources currently used in the agri-food system, including land, could be spared and the current level of human nutrition maintained, even without productivity gains. Strategies for reducing consumer food waste include packaging innovation, more effective use of information along value chains, consumer education and sharing apps.

£14 billion worth of food is thrown away each year in the UK.

CO_2 25 million tonnes of greenhouse gasses are released each year in the UK.

6.4 million tonnes of UK wasted food could have been eaten.

Packaging plays an important role in reducing food waste by protecting products in handling and transit, giving portion guidance and extending shelf life. This is a particular area for focus as a significant proportion of household food waste arises from products 'not used in time' - including products that have spoiled (mouldy, mushy or rotten) as well as those that have passed a date label. Improved shelf-life through technological innovation and increased understanding of storage through improved consumer education both have a part to play in how shelf life is set.

Some innovations, such as re-sealable packs and the use of in-pack modified atmosphere, have become widespread. Others, including portion control through multi-pack formats, can have an impact on unit cost and relative packaging levels, both of which are undesirable to consumers. Consumer understanding of best practice in in-home storage is inconsistent and is a necessary enabler for improved outcomes from packaging innovation. On-pack communication, such as the freezer 'snowflake' symbol, is not sufficient in itself. Research by WRAP shows continuing misunderstanding of how food can be frozen or defrosted, pointing to a need for consistent parallel messaging beyond the packs themselves.

Innovation in packaging materials is also significant in product protection or other characteristics, often supporting underlying objectives such as automation or broader operational efficiency as well as reduced material and energy usage. New materials, characteristics such as self-healing packaging or materials, new production methods such as 3D printing and additive manufacture are all reaching market. Design innovation is seeing existing materials used in new ways. Examples of this include the introduction by some beverage manufacturers of paper-based bottles in place of energy-intensive materials such as glass, whilst others are using tethered caps to reduce pollution risk linked ultimately to micro-plastics entering the environment.

The agri-food system reflects broader societal issues and is impacted by change in the economy at large. As a consequence of the severity of the climate crisis, civil society expectations of governments and businesses have become progressively greater, and the widespread use of social media amplifies the voice of the citizen. The desire to 'Build Back Better' from the COVID-19 pandemic may not have led to meaningful change but reflects a general desire for environmental and societal improvement. The concept of a 'just transition' features in policy as well as the public discourse and is most obviously reflected in the debate at COP27 and other UN meetings around where the cost of climate mitigation should be borne, leading to the launch of a Loss and Damage fund for vulnerable nations.

Economic and political issues also underlie other considerations in the capacity of the agri-food system. Lack of sufficient labour to harvest some crops, exacerbated by unpredictable weather patterns, results in on-farm wastage. The UK National Farmers' Union (NFU) reported in summer 2022 that £60m worth of food had gone unharvested. The sharp increase in energy prices driven by the Russian invasion of Ukraine has contributed to a squeeze on household finances resulting in changes in consumption patterns.

Issues around individual and public health have continued to garner attention, with an ongoing focus on moderating the consumption of livestock products and products high in fat, sugar and salt. This has extended to include processed and 'ultra-processed' foods, which have been proposed to be linked to various negative health outcomes. As the market for plant-based products grows, and the cost of food and cooking affects both diets and, potentially, the safety of some in-home kitchen practices, these new realities will drive the need for increased attention on product safety.

Figure 13: Image source: https://www.asiapathways-adbi.org/2023/03/managing-water-resources-in-agriculture-can-ensure-food-and-water-security/

The idea of a “sustainable diet”, healthy for both people and planet, has become fairly mainstream although this has yet to be reflected in broader consumption habits. Defined by the UN FAO as “those diets with low environmental impacts which contribute to food and nutrition security and to healthy life for present and future generations”, sustainable diets are protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy; while optimizing natural and human resources. Evidence shows that shifting dietary patterns to more plant-based diets can significantly reduce greenhouse gas (GHG) emissions and land and water use, as well as decreasing the risk of all-cause mortality in humans. The promotion of sustainable diets is increasingly important in a world dealing with shifting dietary preferences and expected global meat consumption increase of 76% by 2050.

Government policy does not necessarily reflect the linkages between human health, nutrition and dietary requirements and environmental impacts in the way implied by the concept of sustainable diets. An emerging message is that healthier foods and diets also tend to have lower environmental impact. The Eatwell Guide released by Public Health England to provide dietary advice and the Livewell Plate released by WWF (formerly known as the Worldwide Fund for Nature) to provide information on sustainable diets both recommend reducing meat consumption by cutting non-dairy protein to 12%. This is incidentally reflected in guidance from the UK CCC, which recommends an overall reduction in meat and dairy consumption for environmental reasons, allowing a reduction in methane emissions from cattle and conversion of pasture to woodland.

Figure 14: Food systems for healthy diets and the SDGs. All of the SDGs are directly or indirectly relevant to food systems. FAO (2025) SDG Wheel. Source: https://www.fao.org/fileadmin/user_upload/codexalimentarius/photo-archive/Infographics/SDG-Wheel.jpg

As global diets transition and meat intake increases, the prevalence of non-communicable diseases is expected to rise. Whilst hunger and under-nutrition remain endemic, more people are now obese than underweight globally and obesity is projected to affect over one third of men and women in the UK by 2030, compared with current rates of around 25%. In the UK, diet-related chronic diseases account for 9% of all NHS spending and 25% of all cancers are attributable to dietary factors. It is projected that by 2050 the cost to the NHS will approach £10bn per annum, with a further £50bn to wider society.

In addition to their effect on public health, these non-communicable diseases represent a serious financial burden for governments and taxpayers. Obesity alone has a $2.0 trillion impact on global gross domestic product (GDP). Many countries are looking at regulations as a way to combat these emerging diet related threats to health, such as taxes on specific foods or ingredients to reduce consumption. These approaches are controversial and still relatively new, and so it is uncertain whether they will encourage the development and consumption of healthy foods. Regulation to date has focused on specific ingredients and categories, and implementation has been patchy. Although some success has been claimed for fiscal approaches such as sugar taxes, the controversy over 'ultra processed foods' (UPF) has yet to fully play out.

Figure 15: Global Alliance for the Future of Food and IPES-Food, 2017

The global agri-food system is highly dependent on labour: approximately 1.2 billion people work in agriculture, about 31% of the global workforce. Many of these workers are in low- and lower middle-income economies such as sub-Saharan Africa where population is forecast to increase most significantly in the coming decades. The nature of the agri-food labour market - which relies heavily on migrant, subcontracted labour in unregulated regions of the world - increases the risk of labour rights abuses. Business focuses on addressing fundamental labour issues, as set out by the International Labour Organisation (ILO): forced labour (modern slavery); freedom of association and rights to organise; equal remuneration; and child labour.

In developed economies the picture is different as a consequence of different mixes of economic activity and greater capital investment in agriculture. In the UK, approximately 0.5 million people are employed in the agriculture and fisheries sectors, only 2% of total UK employment, with some 3.9 million, or 14%, employed in the agri-food sector from farm to retail. The bulk of these are in retail and foodservice jobs, which have historically seen a high level of labour from nations within the European Union. The departure of the UK from the EU and its impact on availability of harvest workers, and the impact of many UK workers not returning to economic activity after the COVID-19 pandemic are contributing to the labour impacts noted above.

Improving the working conditions and economic status of these workers is a key agri-food system challenge. Mechanisation and automation will continue to impact upon employment at all stages of the food value chain, albeit for a range of reasons. Work within the agri-food system is often dirty, dangerous, and/or difficult. Figures from the ILO show that agriculture accounts for approximately half of all fatal workplace accidents globally. Removing physical risk, adapting to environments where human labour is in short supply and economic cost drivers all contribute towards a drive to automation.

The link between citizens' expectations on social and environmental action and statutory responses is complex, often mediated by media coverage. Citizens may expect action without understanding the options and their implications, and regulators may take action in a similar vein. The response to single-use plastic in the agri-food system and elsewhere, linked in the UK to Sir David Attenborough's documentary series Blue Planet II, has led the policy response, where policy in other areas can precede public opinion. Often, the complexity of arguments can be lost in the debate. In the UK the situation is further complicated by the responsibility for environmental regulation lying with the devolved administrations of the four constituent nations. Legislative programmes such as the Good Food Nation (Scotland) Act 2022 which sets out to achieve a system "where people from every walk of life take pride and pleasure in, and benefit from, the food they produce, buy, cook, serve, and eat each day", and the Wellbeing of Future Generations (Wales) Act 2015 which "requires public bodies in Wales to think about the long-term impact of their decisions, to work better with people, communities and each other and to prevent persistent problems such as poverty, health inequalities and climate change". The UK Environment Act 2021 has a wide range of top-level provisions which will permit added future targets (so-called 'secondary legislation') and is intended, amongst other considerations, to uphold in full the 'polluter pays' guiding principle whereby organisations responsible for causing environmental damage are also responsible for its mitigation.

Citizens respond to issues in the agri-food system. An example being increased awareness of plastics linked to the BBC documentary series Blue Planet II.

This can lead to changes in policy and legislative programmes.

Such as the Good Food Nation Act 2022 in Scotland and the Well-being of Future Generations Act 2015 in Wales.

Regulation impacts at multiple levels, including nationally (such as the Climate Change Act), large companies (such as implementing the recommendation of the TCFD), small and medium enterprises (SME)s (such as the Packaging Waste Regulations) and within specific sectors. Some regulation imposes complex duties on organisations to consider not just the impact of their own direct activities, but also their broader supply chains. This applies to the Modern Slavery Act 2015 and the Timber and Timber Products Placing on the Market Regulations (UKTR) and UK Forest Law Enforcement, Governance and Trade (FLEGT) Regulations. Other global legislatures have equivalent requirements, and consumer research has shown a widespread expectation that businesses take responsibility for the conduct of their supply chains more generally. The Environment Act introduces the concept of extended producer responsibility, already present in the automotive sector, whereby organisations placing products on the market bear responsibility for end-of-life environmental burdens. In summer 2022 Defra held a consultation on possible future mandatory reporting of food waste by businesses.

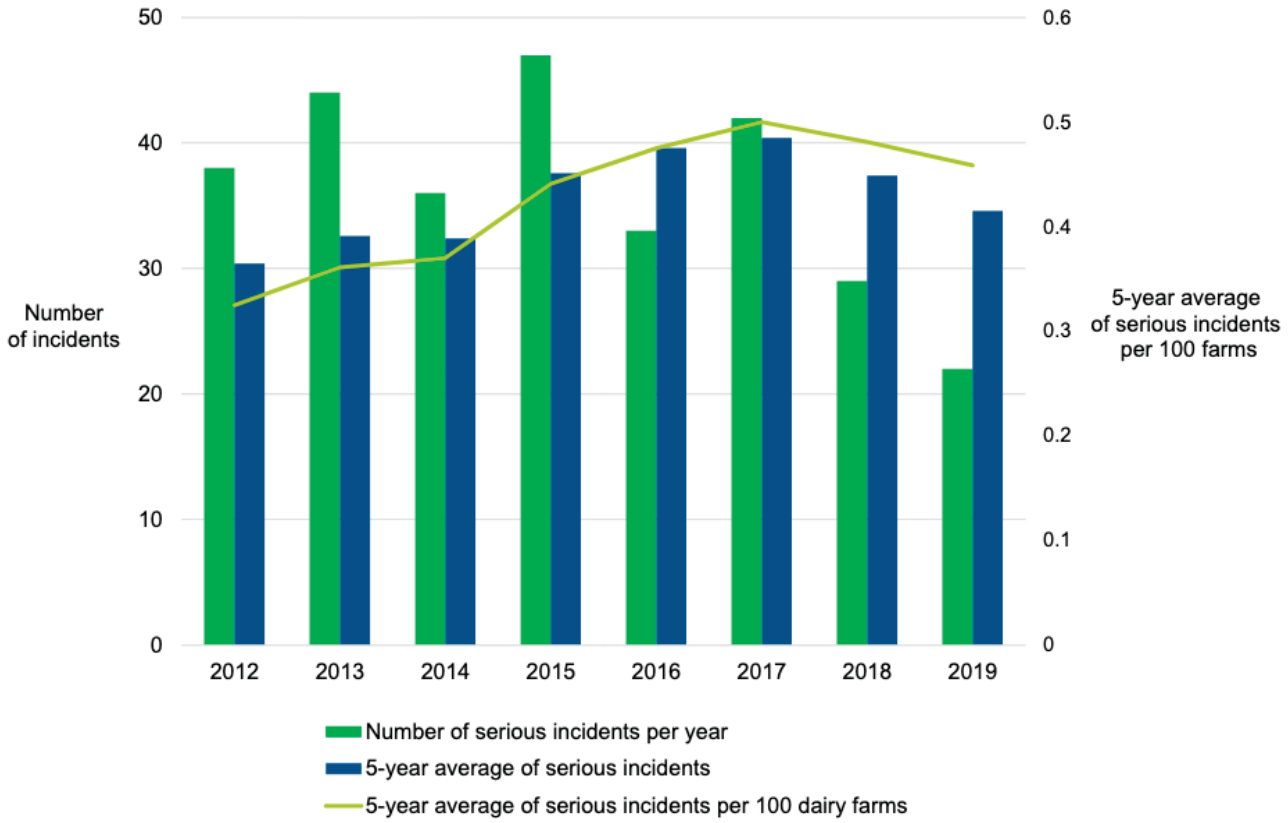


Figure 16: An example of environmental compliance in the food system. Data collected on serious pollution incidents caused by dairy farming (England) 2012 to 2019. Source: Environment Agency report. Regulating for people, the environment and growth, 2019. Updated 22 February 2021.

UK regulation is potentially subject to change following the exit from the EU with the Retained EU Law (Revocation and Reform) Bill 2022 bringing a renewed status, including possible revocation, of regulations adopted from EU law. The impact of any such changes is subject to continued political debate and remains unclear at the time of writing. Regulatory approval is necessary for the introduction of novel foods, with actions taken in other legislatures a possible guide to future direction in the UK. In November 2022, for example, the US Food and Drug Administration (FDA) approved a California company called Upside Foods to take living cells from chickens and then grow them in a controlled laboratory environment to produce a meat product, having deemed it safe for human consumption. On the opposite side of the argument, in spring 2023, the Italian Government approved a ban on cultivated meat framed around protecting the national food culture. With increasing meat consumption strongly linked to the improving economic circumstances of consumers, the potential for novel foods to address a forecast 78% growth in global demand for meat products is clear.

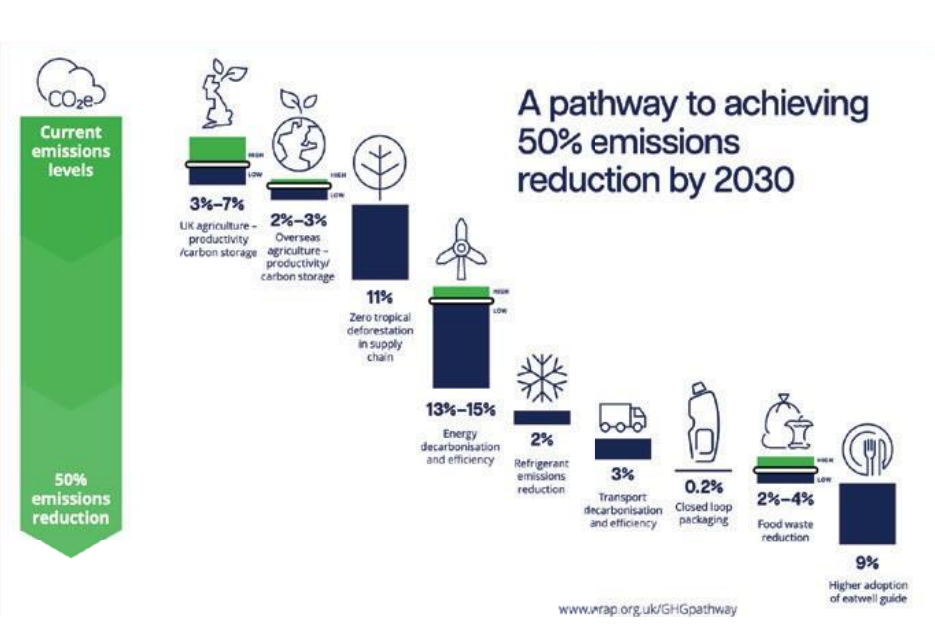
Much of the environmental framework around corporate action, however, is characterised by voluntary rather than binding agreements. The Paris Climate Agreement, the aim of which was to keep global average temperature increase to no more than 1.5°C above pre-industrial levels, is voluntary even at a national scale. Even where there are legal frameworks in place, such as the UK's Climate Change Act which makes it a duty of the Secretary of State to achieve net-zero on recognised greenhouse gases by 2050, implications for the conduct of businesses and their employees is not necessarily clear. Whilst the UK Companies Act requires Boards to have regard to "the impact of the company's operations on the community and the environment" this is not specified, leaving corporate responses fragmented.

Standards and certification have become a key tool for implementing sustainability within value chains. These cover private standards developed by retailers and manufacturers (such as the Sustainable Basket Metric launched by WWF and Tesco, but now covering multiple other retailers) as well as standards that are open to all, such as Global GAP (good agricultural practice), Fairtrade and Rainforest Alliance.

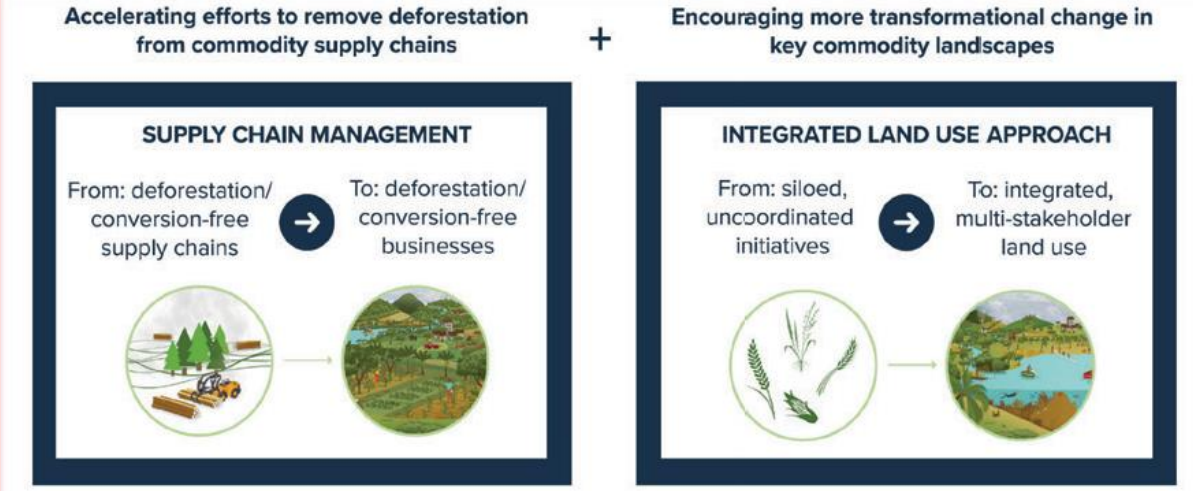
While these approaches to defining and implementing sustainable practices have grown in popularity and coverage, the degree to which they actually drive the desired environmental and socioeconomic impacts is not certain. CDP (formerly the Carbon Disclosure Project) publishes organisational and aggregated environmental data covering emissions, water and deforestation. CDP has noted that demand for such environmental disclosures is increasingly coming from key stakeholders, including customers, investors and purchasers, and in 2022, more than 680 investors with over US$130 trillion in assets and 280+ large purchasers with US$6.4 trillion in buying power requested data through CDP. Despite this, CDP reported for 2022 that almost 30,000 large businesses, collectively worth $25trn, failed to answer its requests for information against 18,700 that did.

One area of particular interest in standards setting is their application in emergent technology areas which are often characterised by multiple market entrants with proprietary systems. One important such area of innovation is the use of remote sensing and other technologies to support the verification of standards adherence – for example using satellite imagery to identify deforestation. Market forces, and the possible engagement of bodies such as the ISEAL Alliance and the International Standards Organisation (ISO) are likely to lead to harmonisation in the longer term, but uncertainty over platform lifetime may prove a barrier to adoption.

In addition to supply chain standards, voluntary agreements such as WRAP's Courtauld Commitment or the Deforestation Resolution of the Consumer Goods Forum (CGF) also play an important role in bringing together businesses to reach a common target. Some of these agreements come to be adopted into government policy, such as the Food Waste Reduction Roadmap (FWRR). There is sometimes a lack of standardisation amongst standards, however, with some tensions between global and national standards, and the role of voluntary agreements. The UK's approach to food waste, for example, is more stringent in some areas than the international (voluntary) definition on which it is based. Clarity for business can be hard to find, especially when having to justify to shareholders the costs associated with achieving and demonstrating compliance.



Figures 17 and 18: Examples of Standards & Certification Schemes: WRAP's data on emissions from the Courtauld Commitment 2030, and the Consumer Good Forum Theory of Change regarding deforestation.



The term Greenwashing was first coined in 1986 by an environmentalist Jay Westervelt in an essay on the hospitality industry. Whilst there is no one definition of the term, the Oxford English Dictionary describes it as “disinformation disseminated by an organisation so as to present an environmentally responsible public image; a public image of environmental responsibility promulgated by or for an organisation, etc., but perceived as being unfounded or intentionally misleading”. Consumer trust in business is not high as environmental and social claims abound. Many of these may be unintentionally misleading, but impact on stakeholder confidence, nonetheless. The source of consumer mistrust of business varies, but at its heart is the apparent discontinuity between a local profit motive and what is best for society as a whole, itself a highly contentious concept.

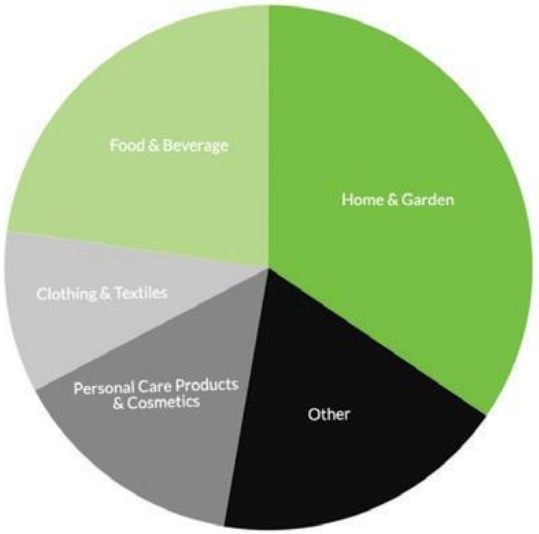


Figure 19: Data from TINA.org tracking more than 100 class-action lawsuits accusing marketers of making misleading environmental claims.

In 2021 the UK’s Competition and Markets Authority (CMA) published the Green Claims Code, based on existing consumer law, underlining that firms making green claims “must not omit or hide important information” and “must consider the full life cycle of the product”. Considering the complexity of producing a comprehensive Life Cycle Assessment (LCA), a process for which an International Standards Organisation (ISO) standard has been published, this is not a trivial requirement with which to comply. In 2023, UK Advertising Standards Authority (ASA) rulings over greenwash in advertising have censured organisations including Anglian Water, Lufthansa and Shell, and the Grantham research Institute on Climate Change and the Environment has reported 190 new cases of litigation against governments and corporates worldwide in 2022/23.

More commonly, organisations rely on independent voluntary accreditation schemes such as management systems standards including ISO14001 for environmental management systems (EMS), or consumer-facing labelling schemes such as Fairtrade. In common with all the ISO range of standards, ISO14001 defines an approach to setting out and providing evidence for a robust process of undertaking a particular task. External factors can impact on the ongoing validity of such claims including the need to house free range poultry indoors during outbreaks of avian influenza as happened in 2022 (see the section on zoonotic and plant diseases).

Development of relevant, robust and credible metrics is essential if stakeholders are to be reassured that organisations are conducting themselves in an appropriate manner. Existing statutory reporting such as the Stremlined Energy and Carbon Reporting (SECR) regulations go some way towards this but do not necessarily generate comparable outputs. Reporting through commercial and/or voluntary schemes is common throughout the agri-food system, but many of these schemes have inconsistencies in the data they require and necessitate duplicated effort in compliance. Consolidation of reporting data which combines usefulness of outputs with useability of the reporting systems would be beneficial.

A review of opportunities for the UN food systems summit published in early 2023 reported that over four million peer-reviewed scientific papers were published in 2018, of which over 550,000 related to agricultural, biological or environmental sciences. Advances in science and technology include gene editing, precision agriculture and digital agriculture, agro-ecology, vertical farming, alternative protein sources, active packaging, blockchain technologies, artificial intelligence (AI) and 'big data' analysis and whole-genome sequencing.
Innovation applies to processes as well as products, and the agri-food system has seen rapid change to channels to consumption, with home delivery from foodservice operations which have previously been primarily engaged in out-of-home consumption. Partly driven by responses to the COVID-19 pandemic, use of services such as Uber Eats and Deliveroo presents new challenges in maintaining the temperature control of products. Trials of 'robot' vehicle delivery systems seek to address the consumer need and the market conditions in which labour is at a premium.

As noted elsewhere, the move to plant-based proteins has seen rapid implementation of industrial biotechnology in some categories of meat analogues, and the development of food products suited to changing consumption patterns continues to drive innovation. The dietary and ecological impacts of some of these new systems form part of their market positioning, with at least one major UK manufacturer highlighting the low-fat and low-carbon nature of their meat-free products as much as their suitability for vegetarian or vegan diets.

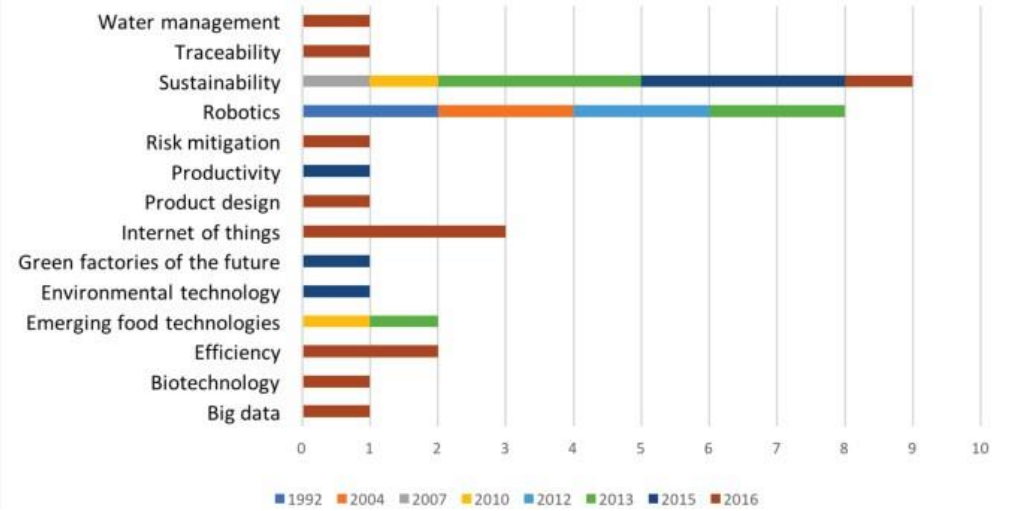


Figure 20: Demartini, M., Pinna, C., Tonelli, F., Terzi, S., Sansone, C., & Testa, C. (2018). Food industry digitalization: from challenges and trends to opportunities and solutions. IFAC-PapersOnLine, 51, 1371-1378.

The food manufacturing and processing sector has a critical role to play in a sustainable agri-food system. As a central link in the value chain, it has influence over the design of food products and packaging and the sourcing of ingredients - two key points for influencing the sustainability of food production and consumption. Food manufacturing will also play a pivotal role in creating a more circular food economy through reducing supply chain food waste and re-using by-products. Food manufacturing is itself a notable user of energy, water and raw materials. In the UK – for example it is the 4th largest emitter of greenhouse gases after energy-intensive sectors steel, cement and chemicals. Meat, baking and brewing sub-sectors are the top three users of primary energy in the food sector.

The concept of the ‘circular economy’ has gained significant popularity in recent years, the aim being to move away from the prevalent business model of “take-make-use-discard” and instead to “close the loop” of materials from waste into re-use in order to reduce resource consumption and pollution. The re-use philosophy applies both to ‘natural’ and ‘artificial’ products within the system. A circular food economy is one in which nutrients rather than primary products are recycled, by-products are fully utilised, waste is reduced, the use of water and other resources is managed, and consumer diets move toward a more diverse and more efficient food pattern. Achieving a circular economy would contribute significantly to addressing resource constraints, in particular a reliance on vulnerable extended supply chains, and reducing the impact of production and consumption. It features in policymaking in the UK, the EU and elsewhere.

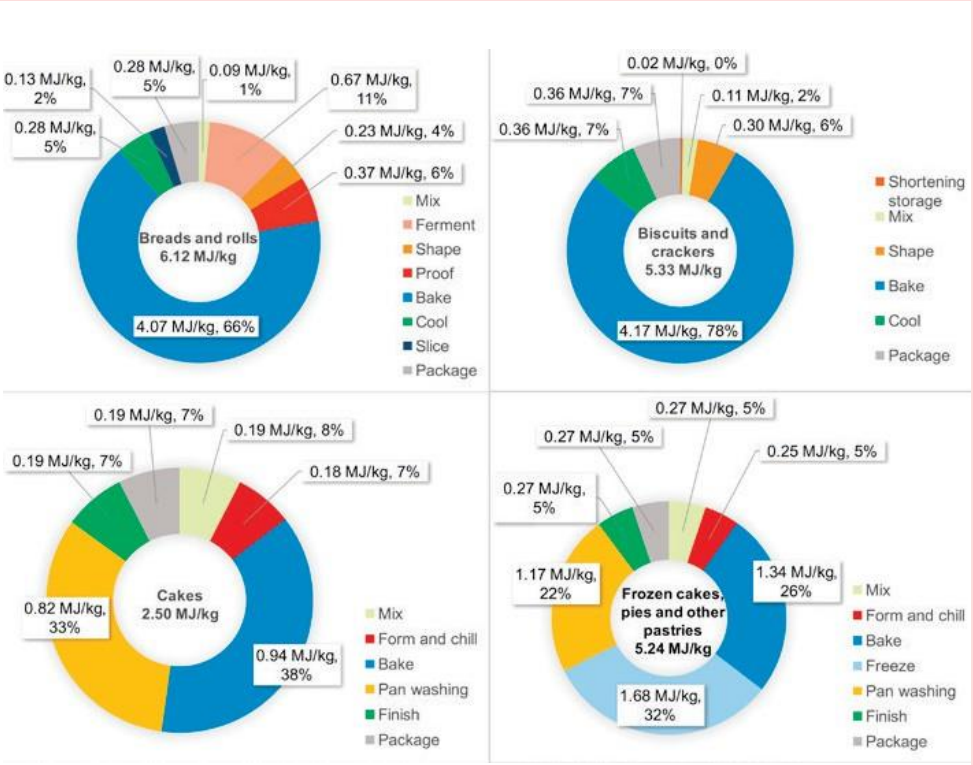


Figure 21: Energy consumed to produce bakery products. Alia Ladha-Sabur, Serafim Bakalis, Peter J. Fryer, Estefania Lopez-Quiroga, Mapping energy consumption in food manufacturing, Trends in Food Science & Technology, Volume 86, 2019, Pages 270-280, ISSN 0924-2244, https://doi.org/10.1016/j.tifs.2019.02.034.

Published at the end of 2018, the Waste and Resources Strategy for England trialled the subsequent Environment Bill which includes provisions allowing regulation in a range of areas to be brought forward with the power to set long-term, legally binding environmental targets, with at least one within the area of Resource Efficiency and Waste Reduction. Defra are exploring how targets can help to increase resource productivity, with crops and crop residues among the UK's top five waste categories. WRAP has identified a number of approaches to delivering improved resource efficiency for the UK's agri-food sector.

The Waste and Resources Strategy for England works with the 2021 Environment Bill and Defra's targets for:

Increasing resource productivity to reduce waste from the UK food system.

Delivering improved resources to mitigate crops and crop residues appearing among the UK's top five waste categories.

Intensive livestock production is acknowledged to be a major driver of global resource use and contributes significantly to GHG emissions. The emission footprint of ruminants is dominated by enteric methane, a potent greenhouse gas, whilst for monogastric species such as pigs and poultry it is dominated by feed, a major driver of land use change along with forest clearance for pasture. Many of the feed crops used for pigs and poultry, such as maize, soy and wheat, could readily be used directly for human consumption and at a much higher level of overall calorific efficiency.

With mounting land and resource pressures, producers are seeking to develop alternative animal feeds or to identify viable additives to mitigate methane generation from ruminants. Livestock feed must supply the two primary nutritional needs of energy and protein, in addition to micronutrients content. At a global level, corn (maize), wheat and barley are commonly used for energy, and while soy and alfalfa are used to meet protein needs. Livestock feed alternatives will then generally need to replace at least the energy or protein component, whilst maintaining an appropriate balance of nutrients such as amino acids. Crop breeding programmes for improved animal nutrition are well-established but are inherently slow in comparison to simple substitution, such as the use of sorghum in some geographies or legumes as feed crops, or of crop by-products.

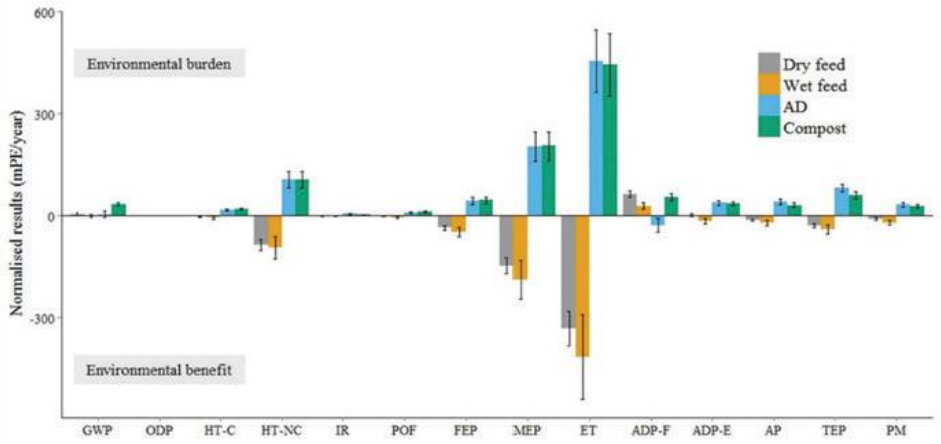
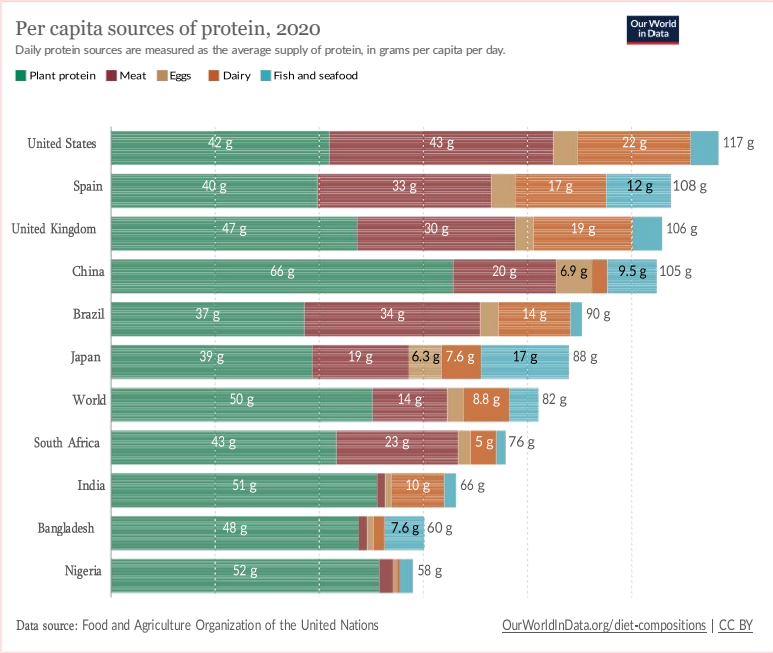


Figure 22: Fossil fuel requirements for the production of dry and wet feeds from food waste. The figure highlights the importance to consider relevant treatment and processing requirements associated with different disposal strategies for food waste, even when comparing different animal feeding strategies. Source: Salemdeeb et al. (2017).

Alternative protein sources for animal feed are starting to become commercialised. Bacterial strains grown in wastewater or other energy sources, specifically bred to produce oils, and insect protein, using waste food or other biomass as feedstock, both present significant opportunities in the efficient use of resources. The latter is already in place in the UK agri-food system, with significant scope for extension. With separate collection of domestic food waste becoming mandatory in England the use of such material as insect feed rather than composting or inefficient methane production via anaerobic digestion, as is currently the norm, becomes practical. The use of insect protein in human food is commonplace in some cultures but has high acceptance barriers in the West. Using insect meal for aquaculture and poultry, as occurs in natural systems, may represent a more palatable market proposition.

Pressure to reduce the land, water and carbon footprint of proteins that are edible for human consumption, including the development of alternative protein, arises from competition for land use from an increasing population, increasing per capita consumption and declining availability or quality of agricultural land. One key benefit of alternative proteins such as insects, algae and lab-grown meat include much smaller land requirements and lower GHG emissions than farming live animal species protein such as cattle, pigs, and chicken. Another is their capacity to be grown on substrates that either currently have little economic use (such as organic waste) or currently remain available in relative abundance, such as seawater for macroalgae (seaweed). Consumer acceptance in some markets may be a barrier to initial adoption of alternative proteins; additionally close attention is needed to address potential food safety risks and subsequent regulatory approval of these novel technologies and food sources.



In addition to alternative proteins, there is potential for new ingredients and foods to be experimented with for human consumption. As with alternative proteins, these may be natural or artificial, and are aimed at substituting products that have environmental resource limitations, require labour or skills which are not sufficiently available or have adverse dietary health impacts. Some novel products have a long-established market presence, such as mycoproteins, and protein from sources such as oats and nuts are commonplace. Some of the natural substitutes may yet bring their own challenges through large-scale exploitation and may not represent a viable long-term alternative. Some of these new ingredients are focused on giving consumers healthier alternatives for popular food ingredients, to aid the adoption of a more sustainable diet and to meet rising trends in reduced-meat or “flexitarian” diets. Regulatory systems may require modification to enable some novel foods to reach market.

Figure 23: Per capita sources of protein, 2020. Daily protein sources are measured as the average supply of protein, in grams per capita per day. Data Source: Food and Agriculture Organization of the United Nations – processed by Our World in Data.

Technological Innovation Increasing Automation and Mechanisation

Robotics companies are exploring the potential for agricultural processes, such as spraying, harvesting and grading, to be automated further. Automated technologies of this kind may bring many benefits to the agri-food system - such as reduced costs, increased safety, greater yields, increased operational flexibility and reduced waste. As a result of increased automation and sustained cost pressures, the UK Commission for Employment and Skills expects employment in agriculture to fall. Jobs in all parts of the food supply chain are at risk from automation and computerisation. An analysis by Oxford University published in 2014 concluded that jobs including food science technicians, farm labourers, food service staff, meat cutters and food manufacturing operatives were more than 80% likely to be automated, although the article did not specify a timeframe. The challenges in some economies of recruiting adequate labour in some parts of the agri-food chain are likely to accelerate such trends.

The FAO estimates that a 90% increase in global crop production will be needed to feed the future population. One way to balance the need for increased food production with finite land and resources with which to grow food is to improve productivity and efficiency. Past innovations have often been characterised by artificial inputs in the form of fertilisers and crop protection products. Current innovations are moving away from blanket approaches to more targeted interventions including machines capable of identifying and destroying the growth tips of weeds. Biological interventions including the use of so-called ‘beneficial’ species which attack pest species have become established and can be expected to grow in their application, along with biological pest control.

Precision agriculture, which targets inputs to the point of need, and reduced tillage, which minimises or eliminates soil disturbance, offer improved resource efficiency and lower emissions from on-farm operations. The accuracy of application of inputs extends to variation based on soil type and nutrient content, plant growth stage and precise physical location. Satellite and drone imagery is being used to assist in field mapping as an enabler of such approaches, and self-guided or lighter machinery reduces soil compaction in growing areas. Across the value chain there is likely to be a move towards increased mechanisation and automation of processes, driven by factors such as the cost and availability of labour mentioned above. New systems taking advantage of automation include automatic milking systems on dairy farms, and the use of drones in crop production for weather predictions, data collection on crop damage and yield potential, and, in the future, precision application of pesticides, herbicides, and fertilisers.

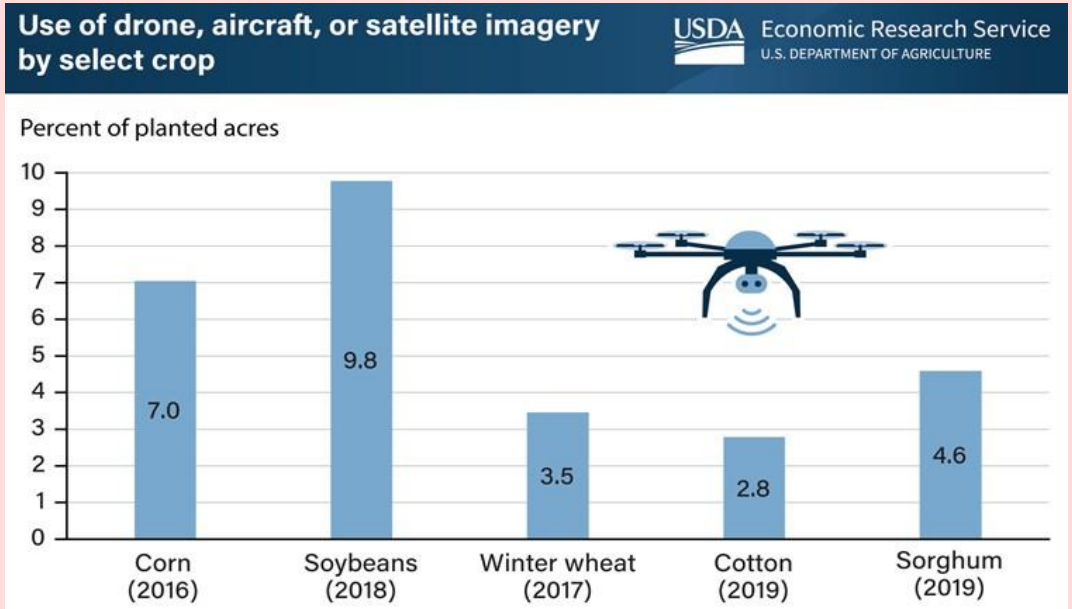


Figure 25: Use of drone, aircraft or satellite imagery by select crop (US). Economic Research Service, U.S. Department of Agriculture.

Examples of farming system innovations beyond traditional field-based crops include vertical farming and urban agriculture to capitalise on limited land in urban areas, although economic viability requires the relatively high energy demand of such protected cropping systems to be addressed. Indoor systems combine with soil-free growing techniques, such as hydroponics, aquaponics (with integrated aquaculture) and aeroponics. The enclosed nature of these systems reduces the risk of pest infestation and soil-borne pathogens.

Another way in which technology is likely to contribute to production efficiency is through genetic improvements to crop and livestock species. This involves improvements to crop and livestock traits through the use of both conventional breeding and genetic engineering technologies, with the latter being a major focus of research and development. An example of the use of this approach to improving nutrition and reducing resource use is the use of genetic modification to insert genes from algae into Camelina plants so that they produce omega-3, an essential amino acid normally found in foods such as fish oils. Improvements in genetic sequencing technologies will aid these innovations but considerable public opposition has proved a barrier to the uptake of the genetically engineered crops and animals in some parts of the world.

Genetic engineering is also giving rise to novel ingredients. “Lab-grown meat” is cultured meat originally grown from cells in a laboratory environment. In addition to ethical benefits, since the raising and slaughter of livestock is reduced or even removed from production, some studies report that lab-grown meat takes less energy and 99% less land to produce than conventional meat and reduces GHG emissions by up to 96%, however these figures depend on how the data is interpreted and therefore clear standards for comparison are needed. While the technology is still new and commercially uncompetitive at scale, the 2023 approval by the US Food and Drug Administration (FDA) of cultured meat using stem cells from fertilised hen eggs indicates a likely future market. Genetic techniques such as “Clustered Regularly Interspaced Short Palindromic Repeats” (CRISPR) are continuing to make gene level modifications simpler and more targeted but have yet to achieve market acceptance.

As with some of the alternative proteins and genetically modified crops, lab-grown meat may have some hurdles to overcome when it comes to consumer acceptance (see Standards and certification schemes). The Genetic Technology (Precision Breeding) Bill became law in March 2023 but the results of a parallel poll suggest there would be little support for lower regulations of so-called “precision bred organisms” (PBOs) compared to other GMOs in foods and farming. The YouGov Poll, commissioned by UK civil society group Beyond GM, found that 80% of adults in the UK are in favour of all GMOs in the farming and agri-food system to be regulated, traceable and labelled.

Technological advancement leads to genetic improvements and modifications to crops and livestock.

This can include adding genes from one organism to another, e.g. algae genes being added into Camelina plants so they can produce omega-3.

Lab-grown meat is also a way that technology is likely to contribute to sustainable production efficiency.

Technological Innovation ‘Intelligent’ Packaging

Packaging with functionality beyond that of containing and simply protecting the contents from contamination is starting to reach market, with a range of technologies and a range of potential applications for each one. Working with key industry partners and a major UK grocery retailer, the SPRITE project used a combination of flexible electronics and near field communication (NFC) technologies operated pilots in multiple physical stores over a period of several months in 2022. The manufacturer estimates that the carbon footprint of the sensor tag is around 1% that of the packaging and that it has the potential to contribute to significant improvements in plastic packaging recycling. Other traceability applications from similar implementations are clearly also practical, linked to improved upstream data collection and management. The 2022 Digital Sandwich project produced the first demonstrator that aims to deliver a national a digitalised food supply chain, using sandwich manufacturing as the use case, using an integrated digital platform incorporating technologies such as blockchain, Artificial Intelligence and Internet of Things sensors within a standard business Enterprise Resource Planning (ERP) platform.

Damage to food packaging during the transportation, handling, and storage introduces a risk to the integrity of the product, and research is underway to develop self-healing materials capable of repairing such loss of functionality. As with any food-contact material products with self-healing ability should be economic, non-toxic and non-tainting, the self-healing reactions should occur autonomously or be in response to an external stimulus and should repair both morphological and functional properties of the pack. Chemical and physical mechanisms include hydrogen bonding and electrostatic forces, with experimental systems often showing post-repair functionality retention levels in excess of 70%. Manufacturers such as D S Smith are already considering how such innovations could be brought to market in the form of a blueprint for how packaging could be made from organic, programmable fibres with the ability to self-heal, like biological skin, when damaged showing how packaging may evolve over the next 50 years.

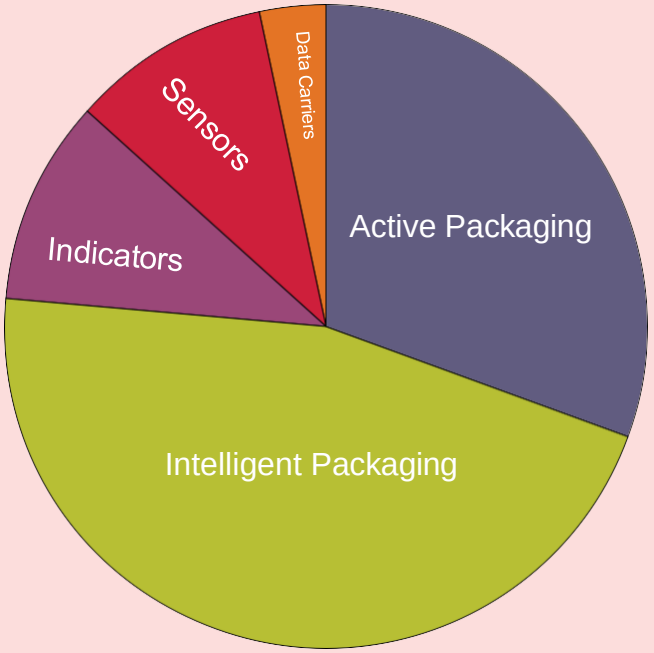


Figure 26. Adapted from: Smart Packaging Market, by Smart Technology 2022. Data source: https://www.maximizemarketresearch.com/market-report/global-smart-packaging-market/106604/

Key Future Focus Areas

There are key current and emergent themes in the realm of sustainability that look set to shape the food system over the coming years. Although they have been represented in the diagram below at various points in the intersection of environmental, social and governance considerations to show the typically dominant drivers for each, in reality they are all inter-linked.

Accountability. The growing expectation of a variety of stakeholders requires agri-food businesses to maintain comprehensive, robust and transparent systems for building on traceability with associated reporting.

Biodiversity and ecosystem services. The agri-food system is the economic sector with the greatest impact on habitat and biodiversity loss, despite being directly dependent on many of the ecosystem services provided by natural systems. Finding ways to enable supply chains to protect and restore the natural environment within which they operate will become increasingly important.

Carbon net-zero. Although there are many other impacts of the agri-food system, the carbon agenda associated with net-zero GHG emissions is currently the dominant theme across all sectors, driven by the urgency of the issue and supporting regulation. The secondary theme of carbon neutral food production will in time also gain traction.

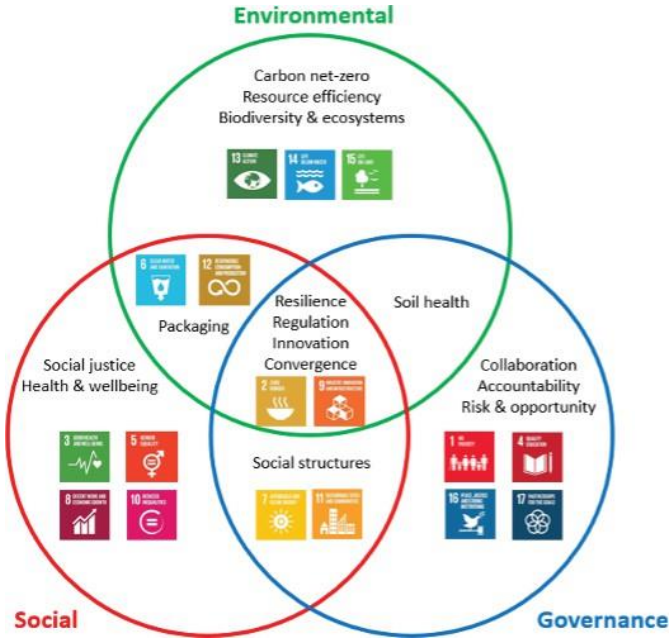


Figure 27: Key future focus areas for IFST mapped onto the UN SDGs.

Collaboration. The agri-food system is too large and complex for individual, isolated environmental and social interventions to address those issues requiring resolution. Actors need to work together pre-competitively along and across supply chains for meaningful sustainability impact to be achieved, including incorporation of food issues in the school curriculum.

Convergence. Multiple challenges and their impacts overlap and combine within the agri-food system and other parts of the economy. No one issue can be considered in isolation as they make an inter-connected 'whole' which is prone to unintended adverse consequences if this complexity is not fully considered.

Key Future Focus Areas

Health and wellbeing. Access to sufficient, affordable, safe nutritious food for all can only be achieved through considered design and execution of food systems from initial concept through to final product consumption. The circumstances of the people involved all along the value chain need to be taken into account in product design, manufacture and use.

Innovation. Effectively applied crop, animal, process and product innovation can all contribute to reduced environmental and social burdens as well as delivering improved economic outcomes.

Packaging. The functionality of packaging and the materials used in its manufacture are highly visible to consumers and the focus of both proactive and reactive regulation. Change should be planned, and any negative consequences appropriately mitigated.

Regulation. New obligations on businesses can arise from consumer sentiment as well as long-term statutory strategy, as has been demonstrated with plastics and refrigerant gases respectively. The UK's departure from the EU has some specific short-term consequences in terms of regulatory readjustment but ensuring alignment with multiple relevant legislatures and WTO requirements will continue to be essential in terms of trade and exports .

Resilience. The COVID-19 pandemic was an extreme example of a system shock, but shocks (acute challenges) will continue to arise and ongoing (chronic) stresses on businesses will increase as the consequences of uncertain economic, environmental and social conditions become normalised. Building the organisational capacity to withstand shocks and manage stresses is critical to effective long-term management of businesses and supply chains.

Resource efficiency. The energy price inflation seen in 2022 is a specific example of a shock that has led to a renewed drive for resource efficiency through reduced energy consumption, and an increase in use of renewable energy sources. Other resources, such as agricultural inputs, are as vulnerable to energy price and the rise in price of fossil fuel related inputs, and circular economy principles are one way of improving efficiency and reducing reliance on fossil fuels. Product design and operational execution both have a part to play in reducing the need for or more efficient use of raw materials, supporting cost management and improving resilience in the process.

Key Future Focus Areas

Risk and opportunity. Changes in the operating environment require effective early identification and mitigation of risk, which is linked to organisational resilience. Opportunity can also emerge through new products or new markets with the effective inclusion of environmental and social characteristics in business decision-making.

Social justice. Fair access to resources and fair reward for effort need to be recognised along value chains. Individual wellbeing of workers is one aspect of this, but a just transition to a new economy within and between nations has many more facets. The Loss and Damage fund announced at COP27 in 2022 is a global illustration of this.

Social structures. Changing demographics, developments in access to markets and new expectations of commercial entities will require new forms of engagement, linked to increased accountability.

Soil health. Soils quite literally underpin the entire agri-food system and emerging standards for restored soil health will result both in changes to land management practices and new opportunities for income generation for land managers which may be in competition with food production.

Glossary

AWC – Animal Welfare Committee, an advisory body to the UK governments on animal welfare issues.

BRCGS – British Retail Consortium Global Standard, a voluntary standards body specialising inagri-food systems.

CCC – Climate Change Committee, an independent, statutory body established under the Climate Change Act 2008 to advise the UK and devolved governments.

CGF – Consumer Goods Forum, an international consumer goods retailers and manufacturers member organisation.

CMA – Competition and Markets Authority, the UK's competition regulator.

Defra – department for the environment, food and rural affairs, a department of the UK government overseeing environmental, food and rural affairs issues in England.

ERP – enterprise resource planning, integrated software platforms to manage business operations such as, procurement, production, and supply chain operations.

EU – European Union, a political bloc encompassing 27 nations across Europe.

FAO – Food and Agriculture Organisation, part of the United Nations supporting governments and other actors to end hunger, promote food security and promote sustainable agriculture.

FDA – Food and Drug Administration, a federal agency of the United States Department of Health and Human Services.

FLAWRS – food loss and waste accounting and reporting standard, an internationally applied voluntary standard relating to food waste definition and measurement.

Glossary

FLEGT – Forest Law Enforcement, Governance and Trade regulations, the UK's regulatory mechanism for timber supply chains to ensure legal harvesting, encourage sustainable practices and support global forest governance.

FSB - The Financial Stability Board, an international body that monitors and makes recommendations about the global financial system.

FWRR – Food Waste Reduction Roadmap, a voluntary reporting scheme overseen by WRAP and the de facto delivery mechanism for the UK's commitment under target 12.3 of the UN SDGs.

GHG – greenhouse gases, a specified list of individual gases and classes of gases known to contribute to global warming, including carbon dioxide, methane and nitrous oxide.

GM – genetic modification, a technique to introduce genetic material into plant and animal species by direct alteration of parts of that organism's DNA.

GMO – genetically modified organism, an organism which has undergone GM.

IoT – internet of things, a network of physical objects embedded with sensors, software, and other technologies for connecting and exchanging data over the internet.

ISEAL Alliance – a voluntary standards organisation, based in the UK, working to improve the quality of accreditation standards globally.

ISO – International Standards Organisation, a developer and publisher of international standards.

LCA – life cycle assessment, a structured process for identifying environmental impacts of products and services.

Glossary

NFC – near field communication, a set of communication protocols enabling communication between electronic devices over very short distances.

NGO – non-governmental organisation, a non-profit organization operates independently of governments, typically to address environmental, social or political issues.

PBO – precision bred organisms, an organism that has been subject to a genomic alteration using a modern biotechnology, such as gene editing.

SDGs – sustainable development goals, a set of 17 broad social, environmental and economic ambitions launched by the UN in 2015.

TCFD – taskforce on climate-based financial disclosures, a working group of the FSB created to develop recommendations on the types of information that companies should disclose around risks related to climate change.

TNFD – taskforce on nature-based financial disclosures, a group of financial institution working on recommendations for how organisations incorporate nature-related risks and opportunities into strategic planning and risk management.

UKTR – UK timber regulations, more fully the Timber and Timber Products Placing on the Market Regulations

UN – the United Nations, an intergovernmental organisation maintaining international cooperation, peace and security.

UNEP – the United Nations Environment Programme, a UN delivery framework for the environment focusing on areas including climate, nature, pollution and sustainable development.

WEF – the World Economic Forum, an international non-profit foundation acting for public-private cooperation.

WRAP – the waste and resources action programme, a UK based environmental NGO.

Acknowledgements

Dr Gavin Milligan CChem MRSC FIFST FRSA

Gavin has over 30 years' experience in the chemical and food sectors in businesses of various sizes, from SMEs to large multinationals and has worked in diverse roles including operations, supply chain, procurement and sales.

Purity Hrisca CSci, FIFST

Purity is a Chartered Scientist experienced in food safety management, quality management, BRC, Risk assessments, project work, food safety training, supplier assurance, audits, food labelling, food regulations, and team management.

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Louise has worked for over 35 years in the agri-food supply chain in a range of roles. Her expertise is in the area of food security and food integrity including food safety, food quality, food crime, policy and governance, social and corporate responsibility, resilience, risk assessment and mitigation strategies. Louise is a Fellow of IFST.

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Craig is a Food Technologist at Campden BRI with extensive experience providing research and consultancy services to the food industry. He is a fellow of IFST, past chair of the IFST Food Processign Special Interest Group and past board member for IFST

Wayne Martindale Ph.D, FIFST

Wayne holds the post of Associate Professor leading the Food Insights and Sustainability Group at the National Centre for Food Manufacturing, UK where he directs a team of researchers delivering applied food system research. He is a trustee and Honorary Secretary for the Institute of Food Science and Technology.

Robert Edge-Partington

Robert is Senior Communications Manager at IFST, and has a background in climate, sustainability, and science communications. Previously a student and researcher at the University of Oxford, his focus is making science accessible to different audiences; he regularly delivers workshops and speaks at events covering a range of topics surrounding climate science and sustainability.

Acknowledgements

Helen Munday

Helen Munday is a trustee and Immediate Past President of the Institute of Food Science and Technology. Helen has a wealth of experience of the international food supply chain including 35+ years of international experience with major food companies (such as Mars and Coca-Cola) and the UK's Food and Drink Federation. She also has experience of Governmental organisations thanks to her time with Innovate UK. Helen now runs her own small farming and food business, producing flour in a water mill in the South West of England.

Thanks also to Stephen French and Robert Edge-Partington for acting as IFST Editors and to George Steedman Jones for the design and production of this refreshed report.

We would also like to express our thanks to the representatives of the following organisations who gave their time to contribute to a review of trends in the agri-food sector as part of the preparation of this report.

Campden BRI food and drink innovation

Food Ethics Council

Sheffield Hallam University
National Centre for Excellence in Food Engineering

CATAPULT Satellite Applications

University of Lincoln National Centre for Food Manufacturing

University of Oxford Environmental Change Institute agri-food system Transformation Group

Sustainable Soils Alliance

Tasting the Future Sustainable Food Systems Consultancy

WWF

Grasp Business Development

This report builds on the original work conducted for IFST by 3Keel, which constituted valuable source material for the refreshed content presented here.

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