Food and Agriculture
Organization of the
United Nations

Food safety foresight: approaches to identify future food safety issues

Funded by
the European Union

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Food and Agriculture Organization of the United Nations
Rome, 2025

Required citation:
Siligato, R., Trieb, J., Di Martino, M., Fattori, V. & Lipp, M. 2025. *Food safety foresight: approaches to identify future food safety issues.* Rome, FAO. https://doi.org/10.4060/cd6798en

ISBN 978-92-5-140096-8

This publication was funded by the European Union. Its contents are the sole responsibility of FAO and do not necessarily reflect the views of the European Union.

Cover illustration: Art&Design Srl

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Acknowledgements

The Food and Agriculture Organization of the United Nations (FAO) would like to thank the many people who were involved at various stages of development of this publication.

The research and drafting of this publication were carried out by Riccardo Siligato, Johanna Trieb and Maura Di Martino, under the supervision of Vittorio Fattori and Markus Lipp from the Agrifood Systems and Food Safety Division (ESF) at FAO. The contributions from other colleagues from the Agrifood Systems and Food Safety Division, in particular Magdalena Niegowska Conforti (ESF), Masami Takeuchi (ESF) and Eleonora Dupouy (ESF), are also gratefully acknowledged. Furthermore, we are grateful for the contribution of Keya Mukherjee, a former FAO ESF employee, and for the review and feedback provided by Pedro Alexandre Morais De Sousa from the Agrifood Economics and Policy Division (ESA) of FAO.

This publication was made possible thanks to valuable contributions from the following participants of the FAO Food Safety Foresight Framework Meeting, 1–3 April 2025 (**Appendix**). We sincerely thank: Aaron O'Sullivan (Danone); Ákos Jóźwiak (University of Veterinary Medicine Budapest); Angela Parry-Hanson Kunadu (University of Ghana); Angelo Maggiore (European Food Safety Authority); Cormac McElhinney (Food Safety Authority of Ireland); Diego Varela (Chilean Food Safety and Quality Agency); Francesco Mascherpa (World Food Programme); Greg Wasinski (Food Standards Agency); Heather Holland (Canadian Food Inspection Agency); Joanne Chan (Singapore Food Agency); Katharine Jones (Cranfield University); Nicola King (Institute of Environmental Science and Research); Peijie Yang (World Food Programme); Simone Moraes Raszl (World Health Organization); Vivian Hoffmann (International Food Policy Research Institute); Yongning Wu (China National Center for Food Safety Risk Assessment, China); Zeina Kassaify (Mars); and Zoe Morosini (Food Standards Australia New Zealand).

Several experts contributed their feedback to this publication. We thank: Arathi Kizhedath (Danone); Bethany Wolf (Mars); Eric Stevens (U.S. Food and Drug Administration); Janice Abbey (Food Standards Australia New Zealand); Jason Dietz (U.S. Food and Drug Administration); Jeffrey Farber (University of Guelph); Jossie Garthoff (Danone); Julie Moss (U.S. Food and Drug Administration); Leo Meunier (Danone); Michael McDonald (Mars); Richard Wood (Mars); Saher Hasnain (University of Oxford); Steven Hermansky (U.S. Food and Drug Administration); Yulia Barabanova (European Commission); and Zsuzsa Farkas (University of Veterinary Medicine Budapest).

Finally, we are grateful to Jane Feeney for copy-editing the document and to Art&Design Srl for the design and layout of the publication.

Abbreviations

AFA	Africa Foresight Academy
AHEM	animal health emergency management
AI	artificial intelligence
BCG	bio-circular-green
CFIA	Canadian Food Inspection Agency
CFSA	China National Center for Food Safety Risk Assessment
CFSIN	Canadian Food Safety Information Network
CIRAD	French Agricultural Research Centre for International Development
DG SANTE	European Commission's Directorate-General for Health and Food Safety
EFSA	European Food Safety Authority
ERIS	emerging risk identification system
ERISS	emerging risk identification and screening system
FAO	Food and Agriculture Organization of the United Nations
FDA	Food and Drug Administration
FoSTr	Foresight for Food Systems Transformation
FSA	Food Standards Agency
FSAI	Food Safety Authority of Ireland
FSANZ	Food Standards Australia New Zealand
HOLiFOOD	Holistic approach for tackling food systems risks in a changing global environment
IFPRI	International Food Policy Research Institute
INFOSAN	FAO/WHO International Food Safety Authorities Network
JRC	Joint Research Centre
LMICs	low- and middle-income countries
ML	machine learning
NFPS	new food sources and production systems
NLP	natural language processing
NZFSSRC	New Zealand Food Safety Science and Research Centre
OECD	Organisation for Economic Co-operation and Development
OSF	overarching strategic foresight
PESTLE	political, economic, sociological, technological, legal and environmental
SDG	Sustainable Development Goal
SFA	Singapore Food Agency
SUSFANS	Metrics, Models and Foresight for European Sustainable Food and Nutrition Security
VIBE	Vigilance and Intelligence Before food issues Emerge
WHO	World Health Organization
WUR	Wageningen University and Research

Executive summary

Global agrifood systems are undergoing rapid transformation, with potential impacts for food safety, food chains and consumer health worldwide. Multiple drivers and trends – such as global trade, climate change, urbanization, geopolitical shifts, consumption patterns, and scientific and technological advancements – are increasing the interconnectedness and complexity of agrifood systems. The resulting emerging food safety issues provide both opportunities and challenges to be identified and addressed.

It is essential to adapt and stay ahead of these transformations to ensure resilient agrifood systems. A successful food safety foresight approach empowers policymakers and private sector stakeholders to anticipate and proactively address emerging food safety issues in the medium to long term. Foresight includes a collection of forward-looking techniques that supports stakeholders (authorities, international organizations, civil society organizations, industry, academia and consumers) in their planning and policy-making processes. Various types of data and information are gathered and analysed to help anticipate possible medium- to long-term future scenarios and their implications in a structured and inclusive way.

The Food and Agriculture Organization of the United Nations (FAO) Food Safety Foresight Programme proactively identifies, assesses and prioritizes emerging trends and drivers shaping agrifood systems that may have implications for food safety. In April 2025, FAO brought together global experts to share their knowledge of food safety foresight approaches and build a network supporting future activities. As food safety challenges evolve, multisectoral collaboration, knowledge sharing, and open and transdisciplinary communication are critical for the proactive identification of emerging food safety issues and preparedness for future scenarios.

This publication outlines food safety foresight approaches conducted by a range of experts from governments, international organizations, research institutes and universities, and the private sector. It captures best practices and outlines key guiding principles for foresight applied to food safety, particularly in light of advances in digital tools such as artificial intelligence. Human expertise is essential to leverage emerging digital tools, as is fostering strong knowledge partnerships among stakeholders. This publication aims to strengthen global collaboration to enhance food safety foresight capabilities among stakeholders, ultimately supporting the development of effective strategies to safeguard food safety in an increasingly complex world.

Background

The 2030 Agenda for Sustainable Development emphasizes the need for sustainable food production systems and resilient agricultural practices that provide healthy and affordable diets (United Nations, 2015). To ensure that agrifood systems are transformed strategically to provide safe and nutritious food for everyone, the Food and Agriculture Organization of the United Nations (FAO) Strategic Framework 2022-2031 is organized around four aspirations: *better production, better nutrition, better environment*, and *better life*, leaving no one behind (FAO, 2021). The "four betters" underpin FAO's efforts to support the 2030 Agenda and meet the Sustainable Development Goals (SDGs), in particular SDG 1 (No Poverty), SDG 2 (Zero Hunger), SDG 8 (Decent Work and Economic Growth), SDG 10 (Reduced Inequalities) and SDG 12 (Responsible Consumption and Production). With less than five years remaining to meet the SDG targets, the need to transform agrifood systems while ensuring food safety has become increasingly urgent. Up to and beyond 2030, a crucial part of the 2030 Agenda is anticipating foods safety risks, for which foresight proves to be a fundamental tool. Foresight is defined as "a collection of forward-thinking methodologies that are generally applied to improve institutional planning or policy making for potential future situations, hazards or opportunities" (FAO, 2014, p. v).

Food safety is paramount for public health. Although food safety is a concern for all countries, low- and middle-income countries (LMICs) disproportionately bear the burden of foodborne diseases, with children being the most vulnerable to biological and chemical hazards (WHO, 2015). In addition, physical and allergen risks pose further safety concerns. Beyond health impacts and the associated costs, unsafe food causes a significant economic impact, for example through loss of productivity due to food illness, morbidity and mortality (Jaffee *et al.*, 2019). Investing in food safety and preventive measures safeguards public health, fosters economic growth and contributes to achieving the SDGs. While a reactive approach to food safety addresses immediate food safety issues and mitigates the health and economic impacts, foresight is essential as part of a preventive approach.

Shifting global dynamics are rapidly transforming agrifood systems, affecting future food supply and safety. This transformation is influenced by multifaceted and interconnected drivers and trends, such as climate change; changing consumer behaviour, beliefs and food consumption patterns; supply chain disruptions; national and international policy approaches; new and emerging food sources and production systems; evolving geopolitical contexts; urbanization and urban agriculture; technological innovations and scientific advances; circular economy; and food fraud (FAO, 2022a). By 2050, the global population could reach 9.8 billion, of which 70 percent are expected to live in urban areas (FAO, 2009, 2022b; United Nations, 2020), impacting supply chain demands. According to some estimates, the expected global population growth will contribute to an increase in global food consumption (in calories) of 1.3 percent per year over the next decade (OECD and FAO, 2023).

Global mean temperatures during the period 2013-2023 were 1.19 to 1.22°C warmer than the pre-industrial level (EEA, 2024) and 2024 was the hottest year on record, exceeding for the first time the 1.5°C threshold set by the Paris Agreement (Copernicus Climate Change Service, 2025). Negative impacts of climate change, with reductions in crop yields in some areas, intensification of extreme weather events, and depletion and degradation of natural resources (e.g. soil), will likely exacerbate existing challenges for the global agrifood system and for food safety in particular (FAO, 2017). Water scarcity and the impact of flooding on water resources call for improved monitoring and data sharing to manage these risks effectively (World Meteorological Organization, 2023).

The intensification of food production in LMICs is another important trend that can have implications for food safety. For instance, raising animals in crowded conditions without strong safety measures or using antimicrobials to prevent or treat unconfirmed illnesses could increase the risk of foodborne diseases and antimicrobial resistance (Waage *et al.*, 2022.). However, the increasing presence of larger, formally registered and often vertically integrated food businesses in LMICs offers significant opportunities to enhance their capacity to meet food safety standards and improve regulatory oversight (Barrett *et al.*, 2022). In addition, widespread global access to mobile internet implies opportunities for crowdsourcing data on outbreaks of foodborne illness (Shanahan and Bahia, 2024). This opportunity could be especially important in countries where health system reporting structures are not well developed.

In parallel, the emergence of new food sources and production systems presents both opportunities and challenges for future agrifood systems (LaCanne and Lundgren, 2018; Mukherjee *et al.*, 2025). For example, edible insects have been consumed in some regions for centuries but are gaining traction in other parts of the world (Tang *et al.*, 2019; van Huis *et al.*, 2013). However, their adoption as animal feed is hindered by high production costs (Biteau *et al.*, 2024), and consumer demand for insects as food remains limited (Giotis and Drichoutis, 2021). Plant-based meat alternatives, another new food gaining interest, can offer environmental and nutritional benefits but can potentially expose consumers to allergen risks (FAO, 2022a; Kopko *et al.*, 2022). More than 3 billion people around the world get at least 20 percent of their daily animal protein intake from fish, therefore new foods from marine origin play an important role in this transformation (Barranco *et al.*, 2024).

Sustainability-driven practices such as the circular economy can support more efficient and environmentally friendly food systems, but they also introduce new food safety risks that must be identified and monitored (FAO, 2024a; James, Millington and Randall, 2022). Microbiological, chemical or physical contaminants can be introduced and potentially accumulate during such circular processes. For example, using water contaminated with pathogens for irrigation is a recognized source of microbial contamination in crops (FAO, 2024a).

Digitization, digitalization, digital transformation, and the new associated analytical tools, have profoundly transformed the landscape of data management and utilization, significantly impacting agrifood systems (**Glossary**). In this report, digitalization refers to the increasing use of digital tools, technologies and platforms to improve how data are collected, processed, analysed, and shared across the food value chain. Over time, the integration of digital technologies has enabled more efficient data collection, analysis and sharing, enhancing the productivity and sustainability of agrifood systems (Schroeder, Lampietti and Elabed, 2021). For instance, precision agriculture technologies allow farmers to optimize resource use through data-driven insights, improving yield and reducing waste (Getahun, Kefale and Gelaye, 2024). Smart and data-driven food traceability may also significantly improve food safety in global food supply chains, for example through more rapid responses, enhanced transparency, and higher automation and efficiency rates (Yu *et al.*, 2020). However, this digital shift also introduces new risks, such as data integrity, data privacy and ownership concerns, as well as increased costs, demands for expertise, cybersecurity threats, and technological dependency. As digital tools become more widespread, there is a growing need for robust frameworks and skills development to manage the risks and ensure the benefits are equitably distributed across agrifood systems. It is crucial that these tools remain accessible and do not widen existing inequalities, particularly for LMICs.

Anticipating and preparing for potential disruptions and seizing on emerging opportunities is key to building more resilient agrifood systems. Foresight supports proactive decision making by enabling a clearer understanding of possible future challenges and opportunities. It is therefore an indispensable tool for enhancing societal preparedness, safeguarding food access, supply and quality, building preventative national food control systems, and protecting human health by addressing potential food safety issues.

Objectives

This document outlines the general principles that enable stakeholders to build and tailor their foresight approaches to their unique interests, needs and resources. It could serve as the foundation for future guidance material to support the implementation of an adaptable food safety foresight process or programme within a range of different organizations. The information provided is relevant to anyone interested in the systematic identification of emerging food safety issues.

To this end, the document aims to:

- provide an overview of existing approaches and methodologies for identifying emerging food safety issues;
- provide high-level guidance for organizations to implement foresight at national or regional levels;
- highlight the opportunities for early identification of emerging issues brought about by recent technological advances, for example in artificial intelligence (AI) such as machine learning (ML) and natural language processing (NLP);
- share best practices for a successful food safety foresight exercise, addressing the challenges and opportunities of integrating human expertise with digital advancements;
- foster global collaboration to increase foresight capabilities among stakeholders.

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Foresight approaches

Foresight is a systematic, medium- to long-term view of possible futures to appropriately guide present-day decisions (FAO, 2022a). It uses methodologies to improve institutional planning or policymaking for potential future situations, hazards or opportunities (FAO, 2014). Foresight approaches enable the development of a methodological framework that:

- facilitates the proactive identification of trends and drivers expected to impact agrifood systems and food safety in particular;
- prepares regulators and policymakers to address future needs and risks;
- informs the updating of strategies and work programmes.

The early identification of emerging issues is necessary to implement timely and effective measures that ensure future food safety. There is increasing interest in foresight across society, including from national authorities, international organizations, academia and industry, to better anticipate and prepare for future challenges. A wide range of food safety-focused foresight approaches and methodologies are being developed or have been established by stakeholders for different purposes.

Recent technological developments, such as AI, have created opportunities to enhance foresight efforts and improve the identification of emerging issues. This document explores the key components of a foresight approach that integrates human expertise and digital tools to provide deeper insights into future global food safety issues, including risks and opportunities. It is timely to consider what an integrated approach may look like, involving multiple stakeholders. Given that foresight activities may serve different purposes and must fit within available resources, there is no one-size-fits-all approach.

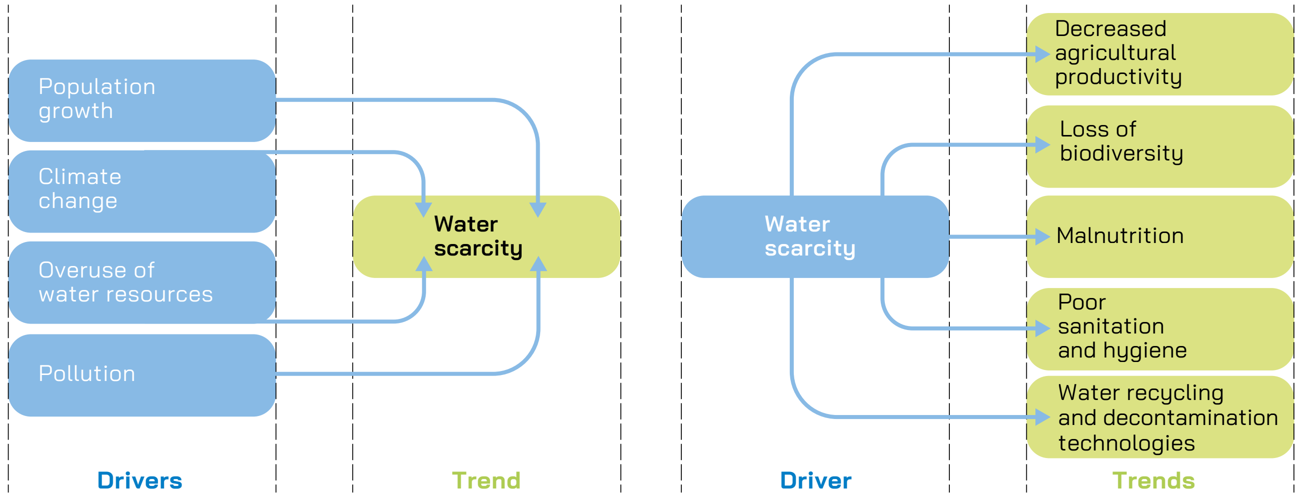
KEY TERMINOLOGY

This section outlines some key foresight-related terminology. A comprehensive overview of key terms can be found in **Glossary**.

- The FAO Food Safety Foresight Programme defines **drivers** as "macro-level factors that derive from a broad spectrum of areas: societal, environmental, technological, political and economic. Drivers can be slow to form, but once in place cause changes with obvious wide-reaching impacts across a range of sectors, spanning different geographic areas and over varying time frames" (FAO, 2022a, p. 23). Legislation can also heavily influence future food safety scenarios. Examples of drivers include population growth, ecosystem degradation, climate change, and resource depletion/scarcity.
- A **trend**, on the other hand, is "a general pattern or direction of change that has been observed over time, which may continue or shift in the future. Trends can be strong or weak, increasing, decreasing, or stable, and are used in foresight to understand the trajectory of developments" (UN Global Pulse, 2023). Examples of trends include new food sources and production systems. By their nature, trends can grow, peak and decrease over time.

It is important to note that something can be both a trend and a driver, depending on the context. For example, climate change may be a driver of decreased water availability (trend), yet decreased water availability may also be a driver of increased uptake of water recycling technologies (trend). Multiple drivers can cause or affect a single trend, and multiple trends can generate from a single driver (**Figure 1**).

Figure 1. The multifaceted nature of drivers and trends



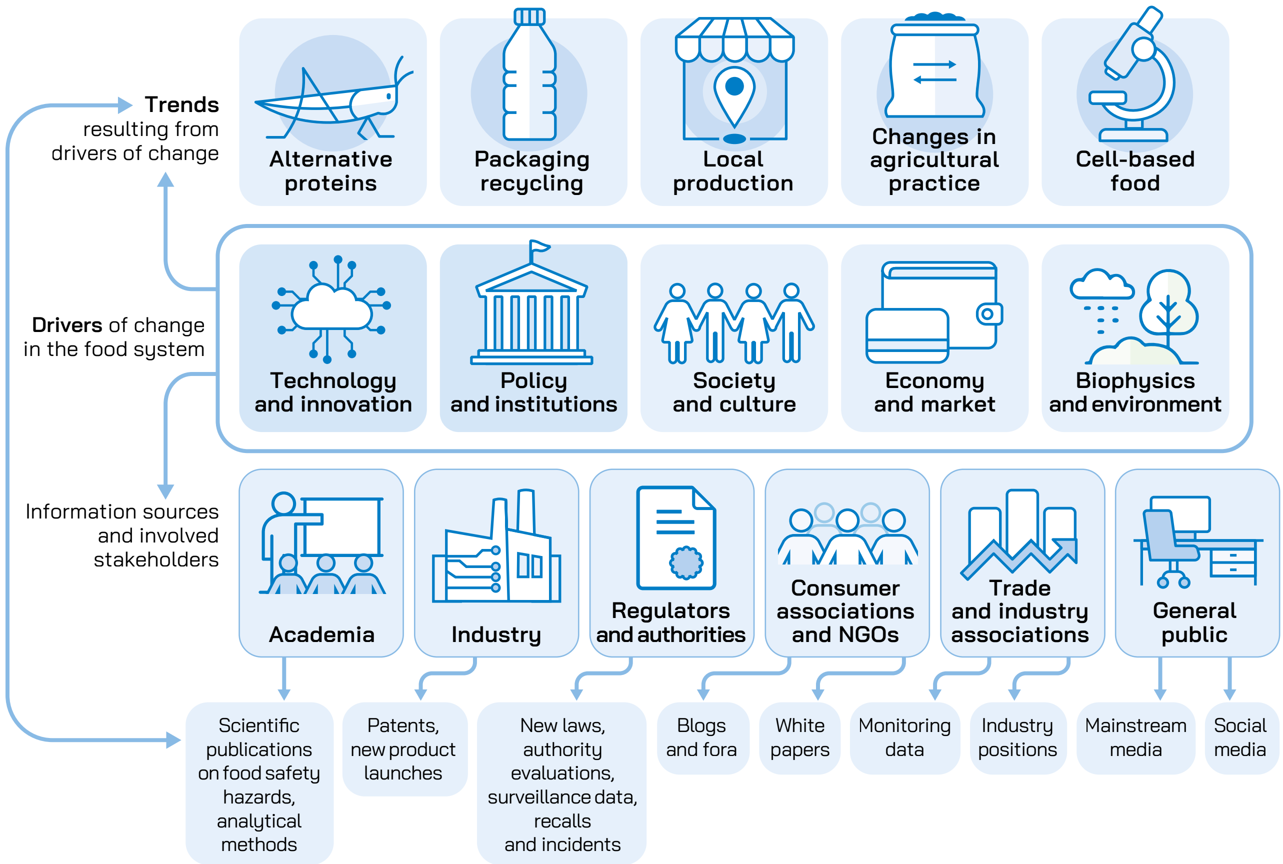
Note: Multiple drivers may contribute to the same trend, and a single driver may contribute to several trends. As an example, climate change and pollution are among the drivers contributing to water scarcity globally, which is also a driver for other trends, including malnutrition and loss of biodiversity, but also innovation in agrifood systems to reduce water consumption and reuse other water sources.

Source: Authors' own elaboration.

- The United Nations Expert Group Meeting for the Global Sustainable Development Report considered an **emerging issue** as "an issue that is not yet generally recognized, but could have major impact on sustainable development if not addressed. Although often perceived as risks, emerging issues could also be positive, meaning that there was a need to recognize potential opportunities. There is often an element of newness, but the issue would not necessarily be considered as unheard of or surprising" (United Nations Department of Economic and Social Affairs, 2016, p. 4). In the present publication, issues are considered new, or emerging, if they have recently been associated with the potential to pose significant risks/challenges or provide benefits/opportunities for food safety. If not addressed in a timely manner, these issues may lead to risks or missed opportunities. It is important to keep in mind that an emerging issue in one sociocultural context or sector may not be new or emerging in another, either because in that context or sector it is not relevant, or because it has already been in place for some time.
- An **emerging risk** is a "risk to human, animal, and/or plant health … resulting from a newly identified hazard to which a significant exposure may occur or from an unexpected new or increased significant exposure and/or susceptibility to a known hazard" (EFSA, 2007, p. 1). Emerging risks, therefore, are a subset of overarching emerging issues.

The relationship between trends, drivers of change, and information sources is dynamic and cyclical rather than linear. Over different time frames, information sources can shape the drivers of change, which in turn influence emerging trends in food safety. In the longer term, these evolving trends may give rise to new information sources, thereby renewing and reshaping the cycle (Figure 2). For example, social media posts may influence the consumer behaviour and consumption patterns that have a direct impact on food safety risks.

Figure 2. Illustration of the relationship between information sources, drivers and emerging trends in agrifood systems



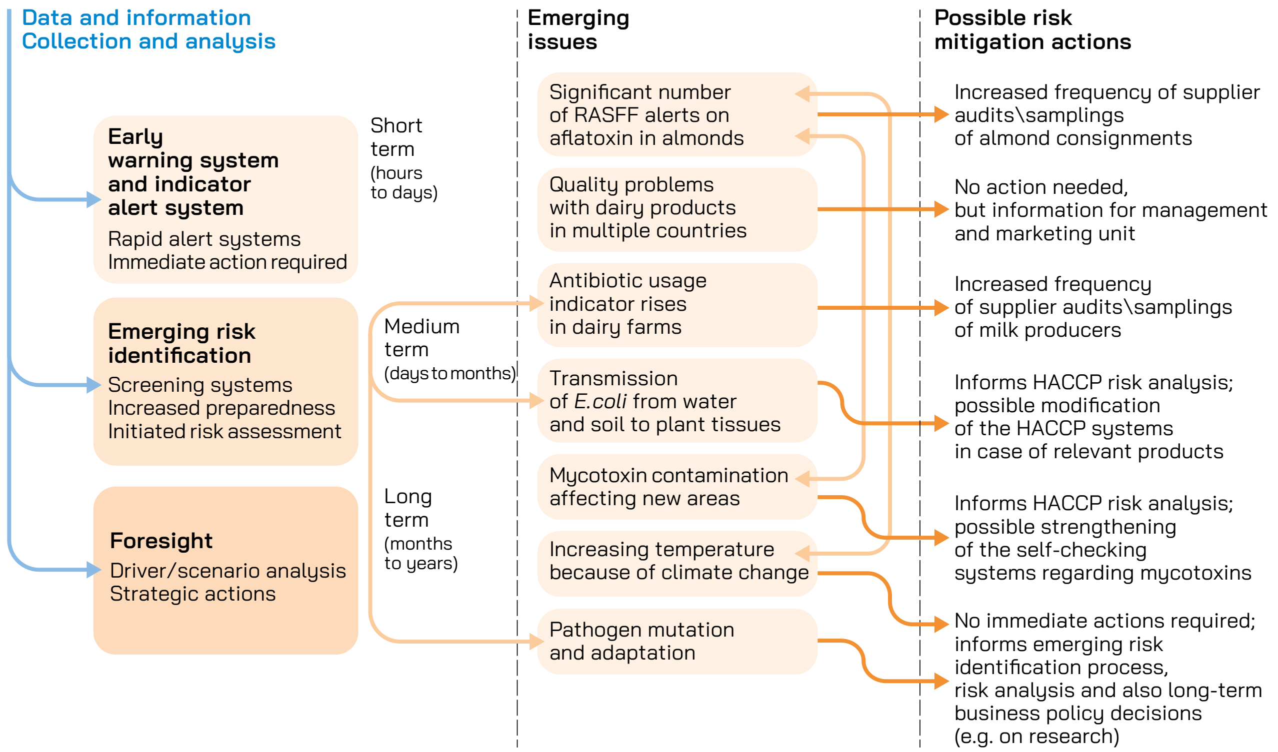
Source: Adapted from **Garthoff, J.** 2024. *Drivers of change and trends in the food system.* Danone. Internal document.

EXISTING APPROACHES AND METHODOLOGIES

There are various approaches and methods aimed at identifying and predicting emerging food safety issues that could pose significant risks to human health. While we might categorize these approaches and methods as applicable in the short-, medium- or long-term future, they can also be understood as part of a continuum and can be tailored across different time frames according to the needs and context. For instance, early warning systems are typically used to detect immediate or near-future threats, while emerging risk identification techniques are more relevant to the medium term, and foresight methodologies help explore long-term drivers and trends. These timelines are not distinct; they are interlinked and influence one another. Long-term drivers can eventually give rise to medium-term emerging risks and short-term issues, highlighting the need for a systems perspective that connects signals across time.

Crucially, identifying emerging issues is only the first step in the effective use of foresight: this must translate into the decision-making process to mitigate future impacts and support the design of resilient food safety systems. An example of the interplay between the different timelines within a food safety foresight approach is shown in Figure 3.

Figure 3. An example of a food safety foresight approach, highlighting the interplay between the different timelines and possible risk mitigation actions



Source: Adapted from **Ákos Jóźwiak** (University of Veterinary Medicine Budapest).
Notes: RASFF = Rapid Alert System for Food and Feed, HACCP = Hazard Analysis and Critical Control Point.

Immediate to near future

In the context of food safety, early warning systems can be defined as the variety of tools, technologies, processes and resources used to monitor, detect and verify early warning signals and already known food safety risks. This includes analysing data and information arising from such signals and disseminating and communicating alerts to stakeholders at appropriate levels for the purpose of providing rapid warnings, informing risk management actions and decision making, and ultimately mitigating associated risks (FAO, 2015). When used predictively, early warning signals are based on known hazards that are expected to develop into risks in the near future. Therefore, the purpose of early warning systems is not to verify emerging risks directly, but to anticipate developments related to known hazards.

Early warning signals can be understood as "initial information suggesting that a potential ongoing or emerging food safety hazard or threat is occurring or could occur" (FAO, 2015, p. vi). Signals can be generated by traditional food safety surveillance systems or digital-assisted food safety expertise. These signals then enable the determination of the urgency and priority for action in terms of hours to days, days to weeks, or months to years. Although early warning systems are not a foresight tool, they are designed to improve the ability to rapidly respond to food contamination events and predict, to the extent possible, the time and place of future outbreaks using available parameters such as supply chain factors.

Three categories of early warning systems, and combinations thereof, exist (FAO, 2023a):

- **Risk-based predictive systems**, such as predictive modelling, are based on existing knowledge of hazards which may develop into risks. Prediction of mycotoxin contamination in crops based on agronomic and meteorological data is an example of such a system (Mu *et al.*, 2024).
- **Reactive food safety hazard-focused early warning systems** focus on an already identified presence of hazards in food, including biological, chemical and physical hazards and allergens. Rapid alert systems are a common example.
- **Reactive foodborne illness-focused early warning systems** cover cases in which a food incident has already occurred, with the aim to prevent the further spread or reoccurrence of reported foodborne diseases and poisoning (WHO, 2014).

Early warning systems are evolving towards more proactive processes and systems that focus on predicting food safety risks that could emerge in the near future, enabling action before an incident becomes a crisis (Marvin *et al.*, 2013). Moreover, the retrospective analysis of data generated by early warning systems over a long period of time creates an opportunity to identify patterns and trends, which generate insights into potential emerging issues. This presents a significant advancement from previous early warning systems that were more reactive, focusing on existing food incidents.

FAO/WHO International Food Safety Authorities Network

Due to the interconnected global food supply, food safety risks can rapidly expand into an international emergency. The FAO/WHO International Food Safety Authorities Network (INFOSAN) is an international network of food safety authorities created in 2004 to facilitate information exchange on food safety events between its members, and support planning and capacity development for food safety emergency response. INFOSAN is a practical risk management tool acting as an early warning system to prevent the spread of contaminated food and associated foodborne disease outbreaks. INFOSAN members report internationally relevant food safety events to the Secretariat, provide any necessary information when requested from the INFOSAN Secretariat during the verification of the events, request international assistance to respond to food safety events, take action on alerts and disseminate information, collaborate with respective National Emergency Contact Points and institutional Focal Points, and share experiences and best practices of emergency management. The Global INFOSAN Strategic Plan 2020–2025 recognized the need for a proactive approach to emerging risk identification and supports countries to develop capabilities for early warning and food safety emergency response.

Source: **WHO & FAO.** 2019. *Global INFOSAN strategic plan 2020-2025*. Geneva, World Health Organization. https://iris.who.int/handle/10665/329913

Case study: Harmful algal bloom monitoring in Los Lagos, Chile

The Los Lagos region, located in the south of Chile, exhibits unique characteristics within the country, with particularities that set it apart from other shellfish harvesting areas worldwide. On its own, it possesses 100 percent of the national export mussel aquaculture centres, an industry that positions Chile as the world's leading exporter of mussels and the second largest producer after China. However, of the country's total marine toxin-affected shellfish landings, 96 percent (411 710 tonnes) come from the Los Lagos region. Although not directly related to foodborne intoxications from marine toxins, it also houses a large percentage of the salmon farming industry, the second largest in terms of global exports, with 28 percent of production. Consequently, the occurrence of harmful algal blooms in the region is of national relevance from the standpoint of public health, trade and related activities such as tourism.

The extensive harmful algal blooms recorded in Los Lagos and neighbouring Aysén have led to the convergence of state institutions with competence in harmful algal blooms to establish an early warning system based on the constant monitoring of the relative abundance of toxic phytoplankton, determination of toxin concentrations in shellfish, and environmental and oceanographic variables that influence the occurrence of harmful algal blooms (sea surface temperature, pH, nutrients, winds, etc.), as well as the observation of satellite images. With the collected information, a mathematical model assesses the marine geographic zone and the extent of an actual or potential bloom is estimated. With this information, risk communication is issued to authorities and the general public through a mobile app and an official website.

Source: **Ministry of Health, Chile.**

Medium-term future

While early warning systems detect immediate or near-future threats, the actual emergence of risks tends to occur at a medium-term timescale. For example, this could span days to weeks, months and potentially longer. The identification of emerging risks in the food chain is a multifaceted task. It aims to safeguard human, animal and plant health and support strategic planning, decision-making processes, sampling and control plans, and the risk analysis paradigm. Timely identification of emerging risks allows necessary mitigation actions to be implemented to contain the risk and its impacts. Notably, the emergence of risks may stem from newly identified hazards and/or increased exposure and susceptibility, adding further complexity to the risk identification process (Farkas *et al.*, 2023).

These identification methods mainly work with textual data, and look for patterns and signals in scientific publications, news, social media, patents and other sources. The identification process usually aims to identify the hazards or the increased exposure. A typical example would be a discovery of a new microbial strain or emerging evidence of a new adverse health effect caused by a chemical contaminant. The emerging risk identification process aims to identify emerging textual patterns, and it can benefit from recent developments in the digital domain such as text mining, network science, NLP and AI methods. Examples of methods used include weak signal mining, topic detection, dynamic topic modelling, co-occurrence network analysis, structural hole analysis, and intellectual ecology analysis (Baranyi *et al.*, 2024).

Long-term future

Systematic long-term future-thinking proactively identifies emerging issues affecting food safety. As opposed to early warning systems, foresight is focused on identifying and characterizing emerging issues and the ways in which they may manifest and evolve over a longer period of time. For example, this could be over a time frame of months to years. This can bring knowledge on food safety risks and opportunities before they occur, enabling the development of strategies to mitigate and manage future challenges, and shape future opportunities.

Foresight approaches are gaining popularity as agrifood systems are expected to significantly transform in response to rapidly evolving, complex socioeconomic, scientific and technological, environmental and political trends and drivers. A key element to studying possible future agrifood systems and related food safety issues is to gain insights into the range of possible changes to the system caused by these trends and drivers. The identification and evaluation of such possible changes, as well as their potential realization through scenario development, are thus the basis of foresight. The analysis of the effects of these drivers and trends requires a comprehensive understanding of the interconnectedness of the global agrifood system with global socioeconomic and environmental systems (FAO, 2022b). Systems thinking, tightly interlinked with foresight, helps identify the elements of agrifood systems and understand their dynamic interactions, possible feedback loops, and ultimately the behaviour of the systems within their social and environmental context. This is particularly useful for understanding possible trade-offs and synergies from strategic interventions.

Case study: Integrating the different timelines

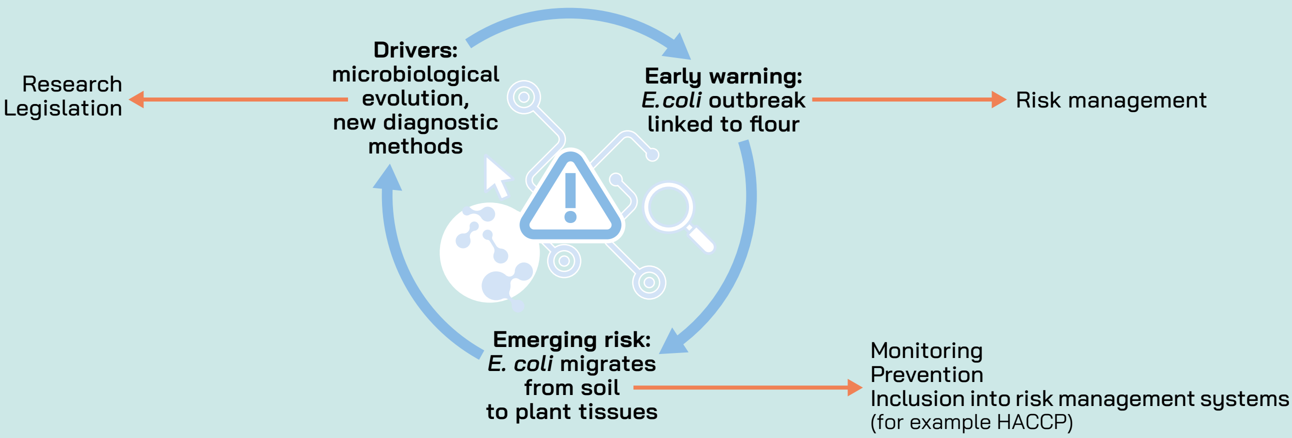
The 2016 *E. coli* O121 contamination in flour food event in Canada is one example of how food safety events unfold over short-, medium- and long-term timelines (Figure 4). In late 2016, Canada identified a cluster of *E. coli* O121 infections. Initially, the food source was unclear, but reinterviews with patients revealed a consistent exposure: raw flour. Laboratory testing confirmed the presence of *E. coli* O121 in several brands of flour, prompting widespread product recalls in early 2017. In the short-term timeline, immediate public health responses were initiated, including investigations, recalls and public warnings, to respond to the outbreak.

The medium-term timeline focused on tracing the contamination pathway and understanding contributing factors. Investigations by the Canadian Food Inspection Agency (CFIA) and the implicated producer were unable to determine the exact source of the contamination within the implicated flour products. However, it became evident that wheat, as a raw agricultural product, is vulnerable to microbial contamination during growing and harvesting. The event and corresponding food safety investigation highlighted the role of advancements in methodology to detect foodborne pathogens alongside new analytical approaches used in outbreak investigations by both the Public Health Agency of Canada and the CFIA to increase the agencies' ability to identify causes of illness for new food hazard combinations such as *E. coli* O121 in flour. In addition, consumers were advised of the potential health risks associated with the consumption of raw flour, and associated safety tips when handling flour (Health Canada, 2021). The CFIA also shared its experience with other countries through the International Food Safety Authorities Network (INFOSAN), raising awareness of the risks of pathogenic *E. coli* in flour.

In the long term, this event was the impetus for a survey conducted by the CFIA in 2018-2019 to gain baseline information on the prevalence of pathogens in wheat flour, and to continue to raise consumer awareness, recognizing that flour can become contaminated and should not be consumed raw.

Independent of the actions taken by the CFIA, other countries conducted further research on this food-hazard combination, and discovered that *E. coli* can travel through soil, infiltrate plant roots and colonize internal plant tissues, including seeds. These scientific insights support the proactive re-evaluation of microbiological risks in low moisture foods like flour, which had previously been considered low risk.

Figure 4. Transmission of *E. coli* from contaminated water and soil to plant tissues



Source: Adapted from **Ákos Jóźwiak** (University of Veterinary Medicine Budapest). *Notes*: HACCP = Hazard Analysis and Critical Control Point.

Sources: **BfR (German Federal Institute for Risk Assessment).** 2020. *Escherichia coli in flour – sources, risks and prevention. BfR opinion No 004/2020 issued 20 January 2020.* https://www.bfr.bund.de/cm/349/escherichia-coli-in-flour-sources-risks-and-prevention.pdf;
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https://inspection.canada.ca/en/about-cfia/transparency/regulatory-transparency-and-openness/food-safety-investigations/flour-products-e-coli-o121;
Health Canada. 2021. Safe handling of flour. In: *Government of Canada*. [Cited 23 June 2025].
https://www.canada.ca/en/health-canada/services/general-food-safety-tips/safe-handling-flour.html;
Zhang, H., Yamamoto, E., Murphy, J., Carrillo, C., Hardie, K., & Locas, A. 2020. Microbiological Survey of Wheat Flour Sold at Retail in Canada, 2018 to 2019. *Journal of Food Protection*, 84(4), 647–654. https://doi.org/10.4315/jfp-20-297

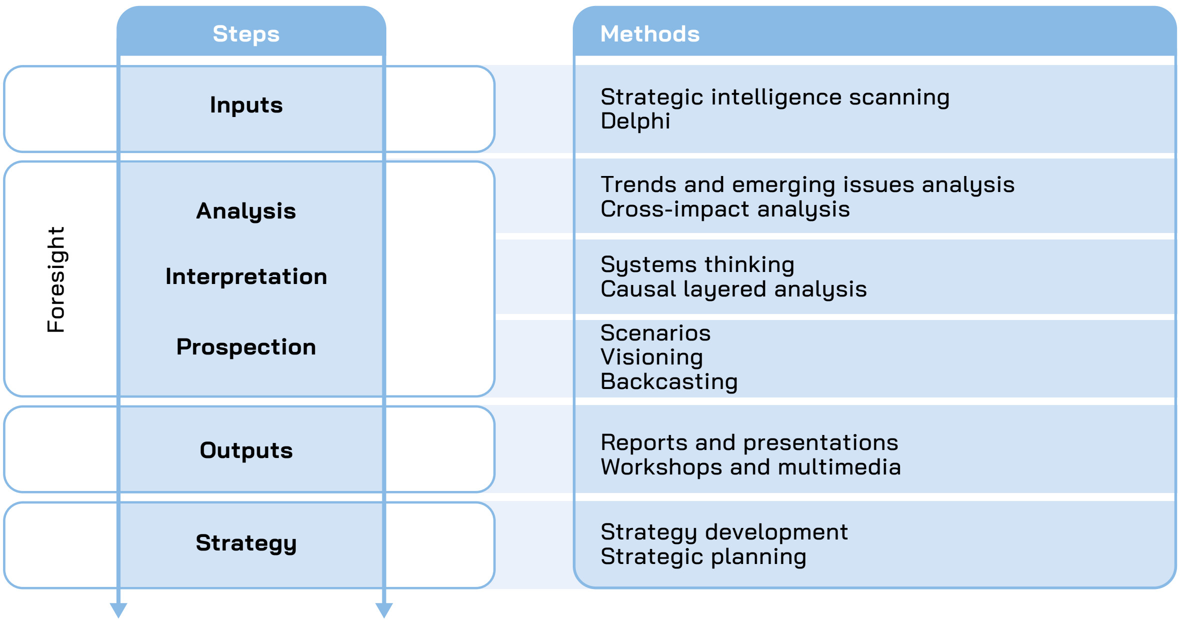
A food safety foresight approach

Foresight provides a foundation for identifying possible future food safety scenarios and the various implications for an organization, ultimately informing decisions and strategic planning. A variety of qualitative and quantitative foresight methodologies exist which help structure future-thinking (Sullivan *et al.*, 2024.), for example:

- **Trends and emerging issue analysis:** a historical trend analysis of systemic drivers that can help detect weak signals that serve as the foundation for building scenarios. This process enables the diagnosis of ongoing and recurring challenges, as well as their potential root causes. By understanding these origins, it becomes possible to activate transformative triggers through difficult – but necessary – tailor-made strategic policy options. These options aim to overcome short-term incentives, break persistent patterns, and redirect development towards a more sustainable and desirable future.
- **Horizon scanning:** a systematic process of scanning the external environment for future developments (emerging trends, issues, opportunities and threats) that could affect the future of an organization or a system and are at the margins of current thinking and planning. It acquires information about broad signals or trends via research and expert elicitation to provide policymakers with a view of future conditions to support decision making in the present (FAO, 2015). It can also be defined as an approach that "may explore novel and unexpected issues, as well as persistent problems and trends" (DEFRA, 2002).
- **Backcasting:** a strategic approach that begins with a desired future vision and then works backwards to determine the necessary actions, policies and strategies to reach that goal.
- **The Delphi method:** a structured, iterative process used in modern foresight that involves soliciting and aggregating expert opinions on a specific topic or question through rounds of anonymous feedback and consensus-building. It aims to promote group interaction and research while mapping the convergence (or lack thereof) of expert opinions.
- **Trend extrapolation:** a forecasting method that uses historical data to predict future developments by assuming that existing patterns and growth rates will continue in a predictable manner. It involves applying mathematical models and statistical techniques to extend current trends into the future, projecting future values of a variable or system.
- **Technology assessment:** a method that systematically evaluates the potential impacts, benefits and risks of new or emerging technologies on society, the economy and the environment. It aims to support informed decision making and enhance the capacity for sound reasoning in shaping technological advancements, ensuring their outcomes contribute to sustainable development.
- **Roadmapping:** a collaborative foresight process that develops a set of plans and strategies to achieve a future goal. It provides a visual representation of the connections between strategic goals, technological developments, market opportunities and action plans over time.

These tools, and combinations thereof, can be useful for identifying strategic interventions to help ensure future food safety as well as prevent – or at least anticipate and prepare for – food safety threats. The process of foresight is important for building connections between decision makers and wider stakeholder groups, potentially opening up new perspectives and ideas. The steps and possible methods involved in foresight are presented in Figure 5. However, stakeholders may tailor their food safety foresight approach, considering that sophisticated and advanced systems, tools and methodologies may not be practical or suitable for all contexts. It is essential to balance the complexity and capabilities of the system with the varying resources, needs and capacities of different users to ensure it remains accessible and effective. Developing a food safety foresight approach can begin on a small scale and gradually become more complex over time.

Figure 5. The main steps and possible methods in a foresight process



Source: Adapted from **Voros, J.** 2003. A generic foresight process framework. *Foresight*, 5: 10–21. https://doi.org/10.1108/14636680310698379

INPUTS

Data play a crucial role in foresight by providing the foundation for identifying and analysing emerging trends, challenges and opportunities. Accurate and comprehensive data enable food safety foresight practitioners to develop informed projections about future developments in food safety. By drawing on data from diverse sources, such as scientific research and market analysis, and leveraging technological advancements, foresight efforts can uncover patterns and insights that might otherwise stay hidden, enhancing the reliability and effectiveness of the resulting strategies.

Organizations have access to a wide range of external and internal information sources for their foresight processes, providing real-time and forecasted data. External sources encompass publicly available open-source information, data from international organizations, and the wider media, such as blogs, social media, surveys, and discussions at trade and industry associations. Internal sources include laboratory results, inspection reports, quality assurance reports, and business intelligence. Additionally, recalls, incidents, scientific publications, regulations, patents, product launches, and purchasing and consumption data provide valuable insights. It is crucial to recognize the limitations of each data source. Information from news or social media may not be as credible or verifiable as internal or scientifically reviewed data. Therefore, the integrity and scientific value of all information must be carefully considered. Ultimately, the integration of robust and high-quality data into foresight processes empowers stakeholders to make proactive, well-informed decisions that safeguard global food safety.

In conventional models, the number of data sources used for food safety scanning, including foodborne diseases, is limited, with data primarily collected from food inspections, controls and surveillance. Relevant information is identified, collected and analysed manually, with resulting key insights later communicated to decision makers, common to many areas other than food safety. This approach is resource-intensive, highly expert-dependent, and can result in the subjective, scattered and heterogeneous collection of data. Manual input is required for information handling and analysis, decreasing the amount of time available for contextualization and consolidation, which are the key aspects of insight generation and are necessary to support decision making.

New diverse sources of data are emerging due to new advancements in information technology. This includes the internet of things, sensors, social media, satellites/remote sensing and geographic information systems. These technologies provide real-time information on food safety in many areas of the agrifood system, potentially enhancing food traceability and contributing to early prevention of possible food safety risks, although the robustness of the data may vary. In addition to the new data sources available, advanced digital tools may be used to enable the screening and processing of a wider range of data to be integrated into a single system to provide advanced outputs relevant to food safety. Examples include data on climate trends, weather patterns, trade and demographics. Citizen science and crowdsourcing may increase the number of people involved in sharing and contributing to data monitoring and collection activities.

Integrating these diverse data sets into food safety scanning can enhance the capability for projection and signal identification, but it is not without its difficulties. Generating useful insights is challenging due to the complexity of agrifood systems. It involves large volumes of data from diverse sources, which must be assessed for relevance and quality. Additional obstacles include barriers to data sharing, issues with access rights, and the global, interconnected nature of agrifood systems, which expands the geographic scope of relevant information and requires careful contextualization to suit individual organizations.

Without the appropriate analytical tools, stakeholders across global agrifood systems risk becoming overwhelmed by information, yet still lacking reliable and actionable evidence, knowledge and insights to guide decision making.

The vast array and variable quality of data available today presents trade-offs between dedicating resources to gather more data or using the same resources to analyse existing data. At this point, it may be advantageous to apply various analytical techniques, such as the "value of information" approach, a concept used to quantify the benefit of obtaining additional information prior to making a decision. This approach helps decision makers assess how much they are willing to invest in information that reduces uncertainty and enhances decision outcomes (Jackson *et al.*, 2022). These techniques could be considered to support the appropriate contextualization and utilization of diverse data sources, enabling organizations to prioritize data collection efforts and allocate resources efficiently, ensuring that the information gathered delivers maximum benefit.

Today, there is an opportunity to make use of large volumes of data to understand potential correlations and pick up trends and weak signals of emerging food safety risks to better support decision making. Data analysis technologies, already extensively used in other domains, are possible enablers to analyse complex information and facilitate knowledge and insight generation, thereby improving the effectiveness of foresight activities. Immediate access to advanced technological tools is not an absolute necessity; a strong national foresight approach can be developed and refined using existing resources and traditional methods. Thus, prioritizing the development of human capabilities for data collection and analysis is just as crucial as investing in technological infrastructure. Although technological tools significantly enhance data collection, manual data collection remains valuable.

ANALYSIS, INTERPRETATION AND PROSPECTION

Digital transformation in food safety: opportunities and challenges

Advances in digital technologies, automation and semi-automation present promising opportunities for the agrifood sector to generate and analyse digital food safety data. OECD defines an AI system as "a machine-based system that, for explicit or implicit objectives, infers, from the input it receives, how to generate outputs such as predictions, content, recommendations, or decisions that can influence physical or virtual environments. Different AI systems vary in their levels of autonomy and adaptiveness after deployment" (OECD, 2024). ML, a subset of AI, uses algorithms to learn insights and recognize patterns from data, applying that learning to make decisions (Columbia Engineering, n.d.).

Different AI tools can be applied in different ways, depending on the purpose of the work, for example to improve early warning systems, enhance predictive models or improve foresight by revealing early signals of potential emerging issues.

Most AI-integrated approaches today are focused on early warning systems (El Morr *et al.*, 2024). Currently, AI appears to perform best when looking at the near-term future and especially in the processing and synthesis of information. When looking at the long-term future, generative creative and novel thinking from human beings is required. The application of AI for this purpose is indeed still underexplored (Brandtner and Mates, 2021). Besides predictive machine learning models, other relevant AI tools are large language models, which are capable of parsing through immense amounts of text to define and extract relevant information. Although emerging issues are highly context-dependent (i.e. different issues might be new for different institutions), the latest large language models are capable of understanding the context and providing very advanced semantic reasoning. These tools are already used to some extent in other adjacent areas, like systematic literature reviews, data extractions, meta-analyses and evidence synthesis in general, and their application is being extended to the emerging issue identification space as well. With tailor-made prompting and/or retrieval-augmented generation techniques, it is possible to provide context and automatically screen large text corpora to pre-filter relevant information for emerging issue identification (Li, Sun and Tan, 2024; O'Connor *et al.*, 2024; Shahzad *et al.*, 2025).

AI is already being employed in blockchain technologies, real-time monitoring at retail and production level, traceability tools and detection of food fraud (Gbashi and Njobeh, 2024). AI significantly enhances food safety by enabling real-time contamination detection, predictive risk assessment and compliance monitoring, thereby contributing to the reduction of public health risks. It also supports food quality and security through automation, improved processing techniques and integration with technologies like the internet of things and blockchain, promoting transparency, efficiency and informed decision making across the food system (Dhal and Kar, 2025). AI tools can assist food safety experts in managing vast volumes of information and identifying emerging issues at an early stage (Mu *et al.*, 2024; Röhrs, Rohn and Pfeifer, 2024), by autonomously learning to recognize patterns and generate predictions. ML models can also adapt to new data inputs, enabling them to respond to dynamic conditions and support decision making (e.g. risk prioritization) across various areas of the agrifood system. Additionally, AI can aid in signal detection through horizon scanning, and in the development of insights and scenario planning. However, for AI tools to work effectively, a critical mass of data in combination with food safety human expertise inputs is necessary to train the machine effectively to reduce bias and increase impact.

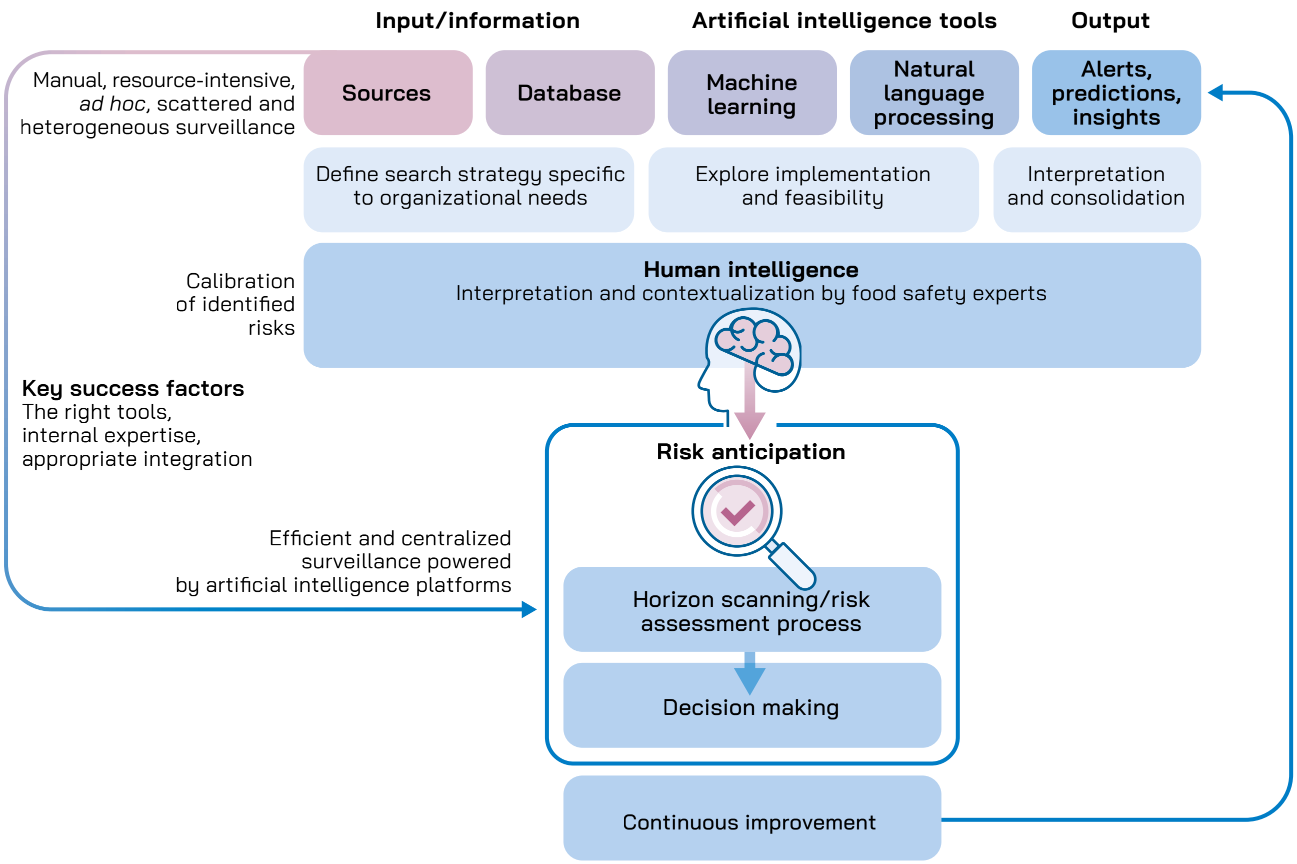
The need for human expertise: an integrated approach

Identifying emerging food safety issues involves gathering, analysing and interpreting information to anticipate trends, opportunities and threats, guiding proactive decision making. Digital tools and predictive analytics significantly enhance the ability to screen incoming information, especially when manual management becomes unfeasible. In domains like food safety, human expertise and technical skills are indispensable throughout AI applications. Human involvement is crucial for data preparation, framing research questions, training models and ensuring AI tools are fit for purpose and operate ethically. Additionally, human expertise is essential for defining inputs, understanding the significance of food safety outputs and interpreting them within system limitations.

The synergy between human expertise and AI could create robust, reliable and trustworthy systems that benefit society. Understanding food safety implications continues to require human judgement, creativity and imagination, supported by appropriate education in fields including a range of scientific streams, food integrity, food technology, data analysis, information and communication technologies, policy, social sciences, law, and decision making. To tackle the complex challenges arising as a result of short-term thinking, it is essential to cultivate future literacy skills, creativity and imagination (Böhme, 2023). In an AI-integrated workflow, human expertise helps define search strategies tailored to user needs. AI tools sift through data to identify trends and insights, while human feedback helps train AI algorithms to recognize emerging signals and anticipate future developments. These models evolve with new data, learning from feedback to improve over time. The resulting outputs – such as alerts and predictions – are interpreted and contextualized by food safety experts in collaboration with a multidisciplinary team that are well equipped to work with these tools. In short, this means that AI should not operate alone without human expertise and its interpretation of the data must be scrutinized for errors, misinterpretations and inaccuracies. In addition to expert knowledge, AI can be used to refine the relevance of detected signals (FAO, 2023a). Figure 6 illustrates an example of such an integrated approach.

An effective foresight approach requires the optimal integration of digital tools into existing workflows, which may vary depending on the needs of the user and the intended purpose of the foresight output. There is no one-size-fits-all approach, as different tools are more suited to different application areas, for example whether it is for scientific or regulatory use, with outputs ranging from analytics and alerts to key insights and reports. Digital tools may be integrated according to the needs of the user, as their application will vary if geared more towards an early warning system or to a comprehensive foresight approach. Staying up to date with advances in digital tools is key to ensuring their optimal application in food safety foresight.

Figure 6. Example of an integrated foresight approach applied to food safety



Source: Adapted from **Kizhedath, A.** 2024. *Example integrated AI foresight framework applied to food safety*. Danone. Internal document.

OUTPUTS AND STRATEGY

A food safety foresight approach integrating digital tools and human expertise offers enhanced opportunities for international organizations, authorities, research institutes, universities and industry to cultivate a proactive culture of anticipation and prevention, rather than focusing on short-term events. Resulting anticipated risks can be used to inform decision making, guiding strategic planning and policy development. Multidisciplinary and cross-functional teams can leverage the anticipated risks to draft a comprehensive food safety strategy that addresses emerging food safety issues.

Outputs from this foresight approach, such as detailed risk assessments, predictive models, and early warning alerts, enhance situational awareness among stakeholders. These outputs enable decision makers to stay informed about potential threats and opportunities, allowing them to respond proactively. By shaping future trends and drivers through specific policies and laws impacting the food sector and its stakeholders, decision makers can influence long-term scenarios. This iterative process ultimately feeds the data sources with more information on priority societal topics.

Foresight outputs are intended for a wide audience, including policymakers, competent authorities, industry, academia and consumers, to name a few. By fostering a food safety foresight community, these stakeholders can collaborate to share insights, refine methodologies, and develop innovative solutions to ensure food safety. This collaborative effort enhances the overall effectiveness of food safety strategies, ensuring they are robust, reliable and adaptable to future challenges.

KEY CONSIDERATIONS

Food safety foresight approaches will be unique to each food safety context. A modular system relying on different commercial and/or in-house tools offers an alternative approach to a one-size-fits-all strategy.

The most resource-intensive domain will continue to be surveillance. Despite the use of digital tools, one significant challenge is the inherent complexity of emerging trends, making it difficult to determine which upstream sources should be considered to accurately predict downstream emerging issues. An approach where human expertise leverages digital advancements at the right point could present a promising food safety foresight strategy. Human expertise will remain a critical factor, particularly for interpreting and translating outputs into stakeholder contexts, even when using AI tools. Resource requirements for a hybrid AI-human food safety foresight strategy differ from conventional approaches, needing additional expertise, training, skills, financial commitments, time and people's energy.

Thanks to emerging technologies and digital tools, big data can now be more easily screened, and more information sources can be covered. It is essential to leverage human expertise, especially when interpreting the outputs and making decisions based on the insights gained. However, further refinement is needed in order to fully realize the potential of these technologies. Some necessary improvements include increasing the capability and performance of the tools, improving data integration and accessibility and developing methods to evaluate the impact of digital tools (especially AI tools).

Systems approaches require the involvement of a variety of stakeholders (e.g. industry and technology providers). Therefore, collaboration and sharing of key learnings and best practices are essential to effectively collect, interpret and utilize data and information, advancing knowledge and avoiding overlaps or duplications, for example through the development of a central database or repository. In addition, joint interinstitutional horizon scanning and scenario development exercises help to harmonize foresight methodologies and improve consistency across agencies, ultimately improving mutual understanding and response coordination.

In the future, food safety foresight may more frequently include an end-to-end integrated AI early identification system, which goes one step further, as it combines multiple digital technologies for the better identification and projection of food safety trends. However, developing and maintaining such systems requires additional resources, including energy, financial and human resources. Furthermore, additional computing requirements and specialist skills (e.g. emerging risks data analytics professionals) would be needed to train, test and interpret results from such a system.

Several open questions and challenges still remain, including on data protection, interpretability, bias, ethics, cost, carbon footprint, predictability, transparency, and confidence in the outputs of AI tools. Typical AI models require learning through data which are then extrapolated to make, for example, predictions or classifications. However, regardless of how good a system is, society is faced with black swan events ("unknown unknowns"). It is paramount to design systems that can instil the capacity and capability to respond to unpredictable events, enabling faster and more efficient action.

As the certainty of predictions decreases over longer time frames, it is pivotal to clearly communicate the validity of the scientific process to decision makers, stakeholders and citizens. This can be achieved by accompanying a structured foresight process with a robust, fit-for-purpose communication strategy, ultimately increasing the impact of foresight activities and the uptake of the related outcomes into decision making and strategic processes.

Despite all the tools available, it remains difficult to discern truly emerging food safety issues within the broader context in which they unfold – such as shifting climate patterns or evolving geopolitical dynamics – making it challenging to isolate their specific impacts on the food chain. Nevertheless, food safety foresight has never been more important, as the global contexts are shifting at unprecedented speed. It is essential that modular frameworks exist to enable the early detection and effective communication of future food safety issues, if serious public health risks are to be prevented and relevant opportunities seized.

Examples of existing foresight frameworks across different sectors

To illustrate the breadth and depth of existing food safety foresight activities, this section presents examples of frameworks and current approaches to identify emerging food safety issues using foresight methodologies. The examples are from a range of stakeholders from the public and private sectors, including international organizations, regional and national food safety authorities, research institutes and universities. The list is intended to showcase a selection of existing frameworks and does not aim to be exhaustive.

INTERNATIONAL ORGANIZATIONS

1. Food and Agriculture Organization of the United Nations

FAO's Overarching Strategic Foresight (OSF) is a multidisciplinary initiative that gathers intelligence from both internal FAO and external sources. It extends its analysis beyond agrifood systems, considering the significant impact of broader socioeconomic and environmental factors. OSF looks at multiple time frames – 2030, 2050 and 2100 – and explores various possible futures, rather than focusing on a single scenario. The process, by considering "worst-case" scenarios in relation to the 2030 Agenda, helps identify risks, allowing proactive measures and contingency plans. It also explores desirable futures, guiding policy pathways to achieve what might otherwise seem unattainable. Through objective analysis, OSF confronts complex political economy constraints that would otherwise be difficult to address (FAO, 2024b). FAO applies an OSF forward-looking exploratory approach to identify trends and challenges that agrifood systems are expected to face in the dynamic global context and to understand their nature. The FAO-OSF Corporate Strategic Foresight Exercise, conducted between 2020 and 2022, served this purpose, gathering insights from internal expert surveys, external consultations and analytical work performed by different FAO technical units. The exercise aimed to inspire strategic thinking about the future to help develop present-day actions which could transform agrifood systems towards sustainability and resilience, providing critical inputs for the development of the FAO Strategic Framework 2022-31 (FAO, 2021). As part of the foresight methodology, the Corporate Strategic Foresight Exercise identified drivers of socioeconomic, environmental and agrifood systems changes, analysed their past and recent trends and interactions, extracted weak signals, and analysed possible future pathways through scenario narratives using a combination of qualitative and quantitative methods (FAO, 2017, 2018, 2024c). The exercise also identified challenges by domain and key "triggers" of transformation, which, when appropriately activated, could lead to the desired *Trading Off for Sustainability (TOS)* future, with sustainable resilient agrifood systems (FAO, 2022b). Possible conflicts and short-term trade-offs of strategic policy options were considered in the exercise.

Furthermore, FAO and the French Agricultural Research Centre for International Development (CIRAD) released a joint global foresight synthesis report, *Harvesting change: Harnessing emerging technologies and innovations for agrifood systems transformation*. Using foresight methodologies, including horizon scanning and scenario building, the study identified various trends and drivers of change in the agrifood space and developed possible technological future scenarios to inspire strategic thinking about the range of implications of technologies and innovations on future agrifood systems (Alexandrova-Stefanova *et al.*, 2023).

1.1 FAO Food Safety Foresight Programme

The FAO Food Safety Foresight Programme contributes to the corporate FAO foresight activities described above and is also supported by in-house cross-sectoral intelligence related to agrifood production, such as fisheries, animal and plant production, socioeconomic development, as well as sustainability centred on climate, energy, land and waste (FAO, 2025). The Food Safety Foresight Programme aims to identify and analyse emerging issues or trends from a food safety perspective to develop technical guidance and ultimately support decision making.

FAO has developed a horizon scanning methodology to proactively identify, prioritize and monitor emerging global drivers and trends with implications for food safety. The approach aims to promote preparedness for emerging challenges and opportunities in the medium- to long-term time frame. To that end, a wide variety of data sources, including scientific articles, published documents from relevant organizations, news and social media, are examined and assembled using a digital platform. The approach involves gathering information on areas that fall both within and beyond the traditional food safety realm, which tends to focus on topics such as emerging contaminants or changes to regulatory frameworks. Some of the areas that fall outside the traditional scope include sustainability and circular economy, consumer behaviours and paradigms – aspects that influence the transformation of agrifood systems.

Collected information is analysed and interpreted in-house based on a range of criteria (e.g. novelty, expected scale and time of impact). This analysis is useful to describe how the emerging trends and drivers can affect food safety, and to identify knowledge gaps that will require regular monitoring in the future. Finally, to ensure the information can be used holistically to inform agrifood system-related decision making and aid in the development of adequate policies and strategies for the management of potential risks and benefits, the collected knowledge is disseminated to a variety of target audiences. In addition to FAO's vast in-house expertise, expert surveys and consultations are often used to support the foresight process. Consultations with a global technical network of stakeholders from food safety authorities, academia, the private sector as well as Codex Alimentarius technical committees, spanning multiple areas pertinent to the food sector, provide valuable additional insights into early signs of change.

Foresight technical workshops and meetings are another instrument used to pre-emptively identify emerging food safety issues. The Food Safety Foresight Technical Meeting on New Food Sources and Production Systems organized by FAO in 2023 is an example of how deeper discussions with relevant stakeholders on foresight and emerging food safety issues can help identify emerging innovations, characterize related challenges and opportunities, and highlight data gaps and research needs to optimize opportunities and circumvent the challenges (Mukherjee *et al.*, 2025).

The activities of the FAO Food Safety Foresight Programme align with the FAO Strategic Priorities for Food Safety 2022-2031 (FAO, 2023b), which recognizes foresight as an essential tool to support the transformation of agrifood systems. This transformation aims to ensure that safe and diverse food is accessible to a global population projected to reach 10 billion people by 2050. The document emphasizes the importance of broadening and deepening foresight to proactively identify emerging issues that may pose food safety risks or present opportunities, including those of regulatory significance. This approach enables timely decision making when combined with appropriate science- and evidence-based risk assessments.

1.2 New food sources and new food production systems

Through the horizon scanning approach described above, FAO's Agrifood Systems and Food Safety Division identified several key drivers expected to have implications for future food safety, including rapid urbanization, technological and scientific advances, and new food sources and production systems (NFPS) (FAO, 2022a). Drawing on the horizon scanning outputs, the FAO Food Safety Foresight Programme applied a structured multiphase foresight approach, using a mixed qualitative and semi-quantitative methodology with Delphi survey and mind mapping, to gather further food safety intelligence. The general objective of the foresight exercise was to examine the identified key driver in greater depth by exploring concrete NFPS, their impacts on the agrifood system and food safety, and strategies to harness opportunities while addressing potential challenges.

The exercise resulted in a comprehensive list of various NFPS expected to gain significance in the next 5–25 years, as well as the opportunities and challenges they bring for agrifood systems and food safety. Participants indicated expected time frames for when the innovations are likely to emerge, come to market or otherwise find utilization in the food sector, and analysed the expected feasibility and impacts of the innovations. The foresight exercise then assessed the readiness of food safety authorities to deal with the identified innovations. It outlined key actions needed to realize the benefits and avoid the unwanted effects of the innovations in the expected time frames, including research and collaborations between specific stakeholders. Finally, social, technological, economic, environmental and political obstacles that might prevent action were explored, as well as strategies to overcome these (Mukherjee et al., 2025).

1.3 Lessons learned

Communication has proven essential for data collection – through knowledge exchange with FAO in-house experts and external partners feeding into the horizon scanning process – and for broadening the knowledge dissemination channels to reach a wide array of potential beneficiaries within the global food safety community and beyond. Expanding the food safety foresight network through multistakeholder engagement is a continuous initiative to improve knowledge gathering and sharing. When multiple stakeholder groups contribute to the foresight process, this provides diverse perspectives essential for minimizing bias and ensuring a sufficient level of objectivity.

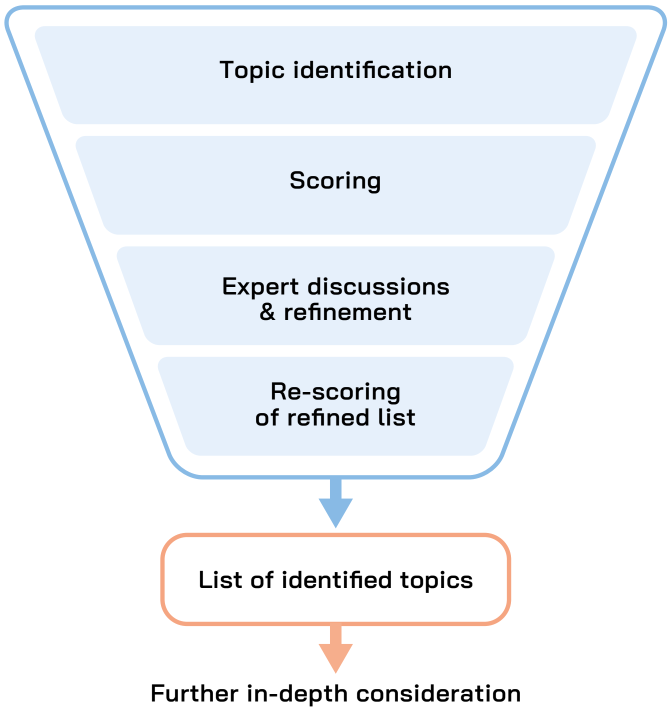
The digitalization of foresight processes plays a critical role in updating and strengthening data collection, curation and categorization methods to improve the identification of emerging food safety issues. Digital technologies are key in FAO's current horizon scanning process to promptly detect early signs of change amid an overwhelming amount of information and enable trend analysis. Digital tools offer an exciting opportunity to make the scanning of data sources less resource-intensive and more time-efficient, supporting early strategic planning to deal with issues before they escalate. In a comprehensive food safety foresight approach, it is increasingly important to broaden the scope of information sources beyond scientific publications and patents, and to accelerate speed of information scanning, especially since research outcomes often become available long after an emerging issue has raised attention.

2. World Health Organization

The World Health Organization (WHO) aims to proactively identify, anticipate and prepare for emerging issues that pose a potential risk for global health. In 2020, the WHO Science Division established a Global Health Foresight function to help implement futures-thinking and horizon scanning capabilities into the health planning frameworks of its Member States (WHO, 2024). The aim of horizon scanning is to better anticipate and prepare for emerging risks and seize emerging opportunities to address them. Horizon scanning has been used at WHO to identify emerging risks and opportunities associated with particular societal and technological changes. Experts from a range of disciplines have analysed, for example, scientific and technological changes with possible global health implications over the next two decades (WHO, 2022a). Following the analysis, 15 developments were prioritized and classified according to expected time frames (Figure 7).

In an incredibly dynamic environment, when the rate of change is increasing, governments must be ready for expected and unexpected changes in global food systems and the potential impact these changes could have on food and feed safety. Identifying, monitoring and adapting to the emergence of important hazards or issues is necessary at the global, regional and/or country level – and these activities are critical to include in international food safety foresight activities.

Figure 7. The general horizon scanning workflow of the WHO Science Division



Source: Adapted from **World Health Organization.** 2022. *Emerging trends and technologies: a horizon scan for global public health.* Geneva. https://iris.who.int/bitstream/handle/10665/352385/9789240044173-eng.pdf?sequence=1

2.1 WHO Global Strategy for Food Safety 2022-2030

WHO published the Global Strategy for Food Safety 2022-2030 (WHO, 2022b), with the vision that all people, everywhere, consume safe and healthy food to reduce the burden of foodborne disease. The strategy envisages action towards building food safety systems that are forward-looking, evidence-based, people-centred and cost-effective, with coordinated governance and adequate infrastructures. The strategy is a response to requests from Member States to update the 2002 strategy to address current and emerging challenges, incorporate new technologies and include innovative approaches for strengthening national food safety systems. The updated strategy outlines five interlinked and mutually supportive strategic priorities, with Strategic Priority 2, *Identifying and responding to food safety challenges resulting from global changes and food systems transformation*, being particularly relevant for food safety horizon scanning and foresight-related activities. Member State activities related to Strategic Objective 2.1, *Identify and evaluate food safety impacts arising from global changes and food systems transformations and movement of food* and Strategic Objective 2.2, *Adapt risk management options to emerging foodborne risks brought about by transformation and changes in global food systems and movement of food* can inform capabilities, capacities, and key inputs for food safety foresight activities. As such, WHO, in collaboration with the International Finance Corporation, is finalizing the Global Strategy for Food Safety Roadmap Tool to assist Member States in identifying their country-specific level of implementation of the new WHO Strategy and outline a plan to strengthen key areas, including those covered in Strategic Priority 2.

REGIONAL/NATIONAL AUTHORITIES AND ORGANIZATIONS

3. European Commission

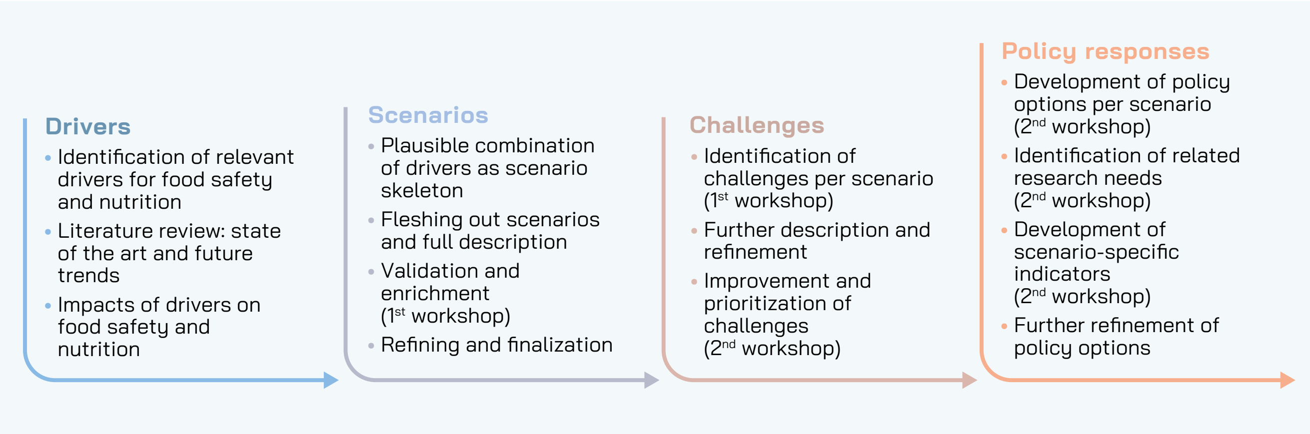
The aim of the European Commission's Directorate-General for Health and Food Safety (DG SANTE) is to ensure the safety and sustainability of food, improve consumer health, protect the health of crops and forests, and ensure the welfare of farm animals. For this purpose, DG SANTE funds a variety of projects, including in-house foresight projects with the Joint Research Centre (JRC).

In addition to DG SANTE, the EU Policy Lab: Foresight, Design, and Behavioural Insights Unit of the JRC is a collaborative space to explore innovative policymaking at European level using systemic forward-looking approaches. The EU Policy Lab applies a variety of foresight methodologies to help the European Union prepare for the complex future problems ahead, including future diets and nutrition, and global food security (Maggio, Van Criekinge and Malingreau, 2015).

3.1 Foresight initiative on food safety and nutrition

To identify possible future challenges for food safety and nutrition in the European Union and assess the preparedness of the legislative framework on food, the European Commission's JRC and DG SANTE carried out a comprehensive foresight process in 2016. This process began with a scoping study to identify relevant drivers of change and develop driver-specific scenarios (European Commission, 2013). The exercise was followed up with the foresight study *Delivering on EU food safety and nutrition in 2050 - future challenges and policy preparedness*, aimed at identifying possible future challenges for food safety and nutrition and possible policy measures to address them (Mylona *et al.*, 2016). The study was carried out in collaboration with over 30 external experts and stakeholders working in various areas of the agrifood system. The study aimed to assess the resilience of the current food policy and regulatory framework over the next several decades. Within the study, scenarios for the European Union in 2050 were developed to help identify possible future challenges to agrifood systems and their impact on food safety and nutrition. Policy measures and related research needs were proposed to ensure the resilience of the agrifood system and food safety and nutrition in the European Union. And finally, scenario-specific indicators were developed to provide early signals for specific issues, enabling policymakers to implement appropriate actions promptly (**Figure 8**).

Figure 8. A general overview of the foresight methodology used for the JRC/DG SANTE foresight study on food safety and nutrition in the future



Source: Adapted from **Mylona, K., Maragkoudakis, P. A., Bock, A., Wollgast, J., Louro Caldeira, S. & Ulberth, F.** 2016. *Delivering on EU Food Safety and Nutrition in 2050 - Future challenges and policy preparedness*. EUR 27957. Geel, Belgium, Publications Office of the European Union. https://doi.org/10.2787/625130

4. European Food Safety Authority

The European Food Safety Authority (EFSA)'s process of "environmental scanning and strategic options definition" aims to: 1) identify/anticipate gaps that would prevent EFSA from fulfilling its mission and opportunities that would allow EFSA to fulfil its mission more efficiently; 2) contribute to the definition of EFSA's working agenda and long-term strategy; 3) analyse strategic competencies/skills needed – definition of EFSA's partners ecosystem and; 4) identify trends, drivers of change and emerging risks in the fields within EFSA's mission. The process consists of two workflows: horizon scanning and emerging risks analysis.

In the horizon scanning workflow, the collected topics, signals, trends or upcoming policy developments are analysed by the Knowledge, Innovation and Partnership Management Unit and the Chief Scientist Office. If the topics do not fall under existing programmes or are not covered by the current strategy, and if relevant for EFSA, they are further characterized with the aid of various EFSA units and panels. The submitted topics are assessed based on the following aspects: (a) whether they have already been addressed by EFSA or its partners, (b) whether EFSA possesses the in-house expertise to address the topics and, if not, where the required expertise is available, (c) whether the submitted topics are consensual enough to be considered in regulatory science. All information collected is summarized in a factsheet that is brought to the attention of the EFSA Preparedness Council. If confirmed relevant for EFSA's future work programme and/or strategy, the topic is prioritized.

The emerging risks analysis workflow focuses on the identification and characterization of issues arising from surveillance activities, screening of scientific publications, media monitoring, experts' networks and analytical screening. Automatic identification tools have been considered. In particular, EFSA has tested the solutions provided by the JRC for emerging chemicals risks identification. Tools for Innovation Monitoring Technology has been used for the screening of structured data such as scientific publications, patents, European Union-funded projects, while the Europe Media Monitor system has been used for news media articles (EFSA *et al.*, 2023). The tool has also been used for the detection of weak signals and emerging risks from new food/feed sources and production technologies. Weak signals are generally understood as current or past developments with unclear implications for future developments. These may or may not be relevant and are generally difficult to identify (FAO, 2014).

Following pre-screening by EFSA, the analysis of emerging risks is conducted through the Emerging Risks Exchange Network and the Stakeholders Discussion Group, supported by the EFSA scientific units, other European Union institutions and international parties like WHO and FAO, giving access to a broad range of expertise in all fields related to EFSA's remit (EFSA, 2015). The objective of the Emerging Risks Exchange Network is to increase EFSA's capacity to anticipate emerging scientific or societal issues through the cooperation between EFSA and risk assessors of the European Union Member States and countries of the European Free Trade Association, as well as observers from the European Commission, European Agencies, WHO, FAO, Food Standards Australia New Zealand, and the United States Food and Drug Administration (FDA). The Stakeholders Discussion Group, on the other hand, facilitates the exchange of information between EFSA and registered stakeholder organizations from the private sector, consumers associations, and non-governmental organizations.

The emerging issues are assessed based on a set of predetermined criteria, according to EFSA's definitions of emerging issue and emerging risk: (a) new hazard; (b) new or increased exposure; (c) new susceptible group; and (d) new driver. All emerging risks characterization and analysis activities are centralized on the Emerging Risk Analysis Platform, where information is shared within the collaborative networks and stored for future analysis or updating. It is a centralized platform for the identification and reporting of emerging risks and is accessible to all parties involved. It also functions as a process management system (EFSA, 2023).

Case study: Food fraud incidents as drivers for food safety emerging risks

The European Food Safety Authority FFRAUD-ER project was commissioned to develop a computational model to proactively identify food fraud incidents as potential drivers of emerging food safety risks. Given the increasing complexity and globalization of food supply chains, traditional methods of monitoring and managing food safety are becoming less effective in mitigating the threats posed by food fraud. This project aims to address this gap by introducing a model that combines natural language processing (NLP) and feature selection techniques to analyse vast amounts of data from various sources, such as regulatory reports, scientific literature and social media. The methodology applied is divided into key sections including the identification and prioritization of the data sources, data preparation and the development of a labelled dataset including more 20 000 labelled records. The computational model focuses on using NLP deep learning methods to process the labelled data to identify food safety incidents posing food safety concerns. The proposed methods for identifying emerging risks from these incidents include a) weight allocation method, featuring extraction and inverse frequency calculations, and b) logistic regression methods, calculating coefficients and comparing month-by-month changes to identify emerging risks.

Source: **Aristodemou, G., Braun, A., Frangos, A., Papadopoulos, A. & Vrachimis, V.** 2025. FFRAUD-ER: Development of a computational model for identifying Food Fraud incidents as drivers for Food Safety Emerging Risks. EFSA *Supporting Publications,* 22(2): 9301E. https://doi.org/10.2903/sp.efsa.2025.EN-9301

5. Food Standards Australia New Zealand

Food Standards Australia New Zealand (FSANZ) is an independent bi-national food safety statutory authority in the Australia Government Health Portfolio. FSANZ is responsible for developing evidence-based food standards so consumers can be confident that the food supply is safe and suitable.

As part of maintaining a safe food supply, FSANZ undertakes regular horizon scanning and foresighting activities in preparedness for relevant emerging food matters. Global instability, food sustainability, changing consumer expectations, technological and climate change have been some of the drivers of food innovation in recent years. Given the dynamic agrifood landscape, horizon scanning and foresighting activities are essential to support the operational and strategic direction of modern food regulatory systems facing such change and to maintain consumer trust in a safe food supply.

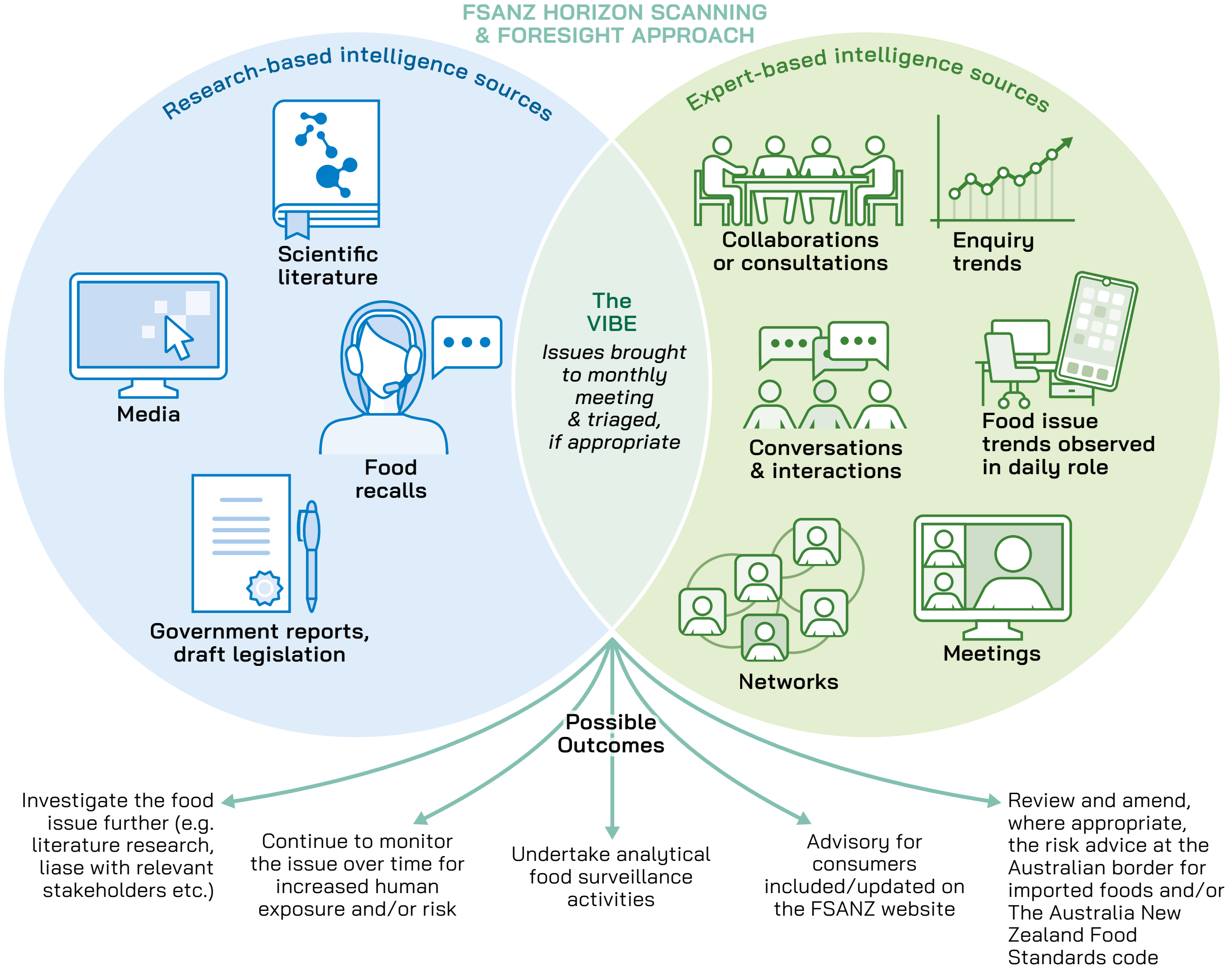
In 2021, FSANZ launched a new in-house approach to horizon scanning and foresight to identify food issues of relevance before they emerge. This approach, referred to as the VIBE (Vigilance and Intelligence Before food issues Emerge), considers a broad range of potential food issues including new technologies, traditional chemical and microbiological hazards and those related to nutritional, labelling and social science issues associated with food. The VIBE collects intelligence from diverse sources, leveraging the expertise within FSANZ and information gained though external networks to identify and address emerging issues (Figure 9). The expertise of FSANZ provides the VIBE with a wide perspective on potential horizon and foresight issues. Along with their national and international networks and stakeholders (e.g. industry, academia, food safety agencies), this approach ensures a cost-effective and comprehensive method to stay informed about emerging food issues. The intelligence gathered in the VIBE is also a valuable tool for the FSANZ Board for strategic planning purposes.

The VIBE meets regularly, with representation from all risk assessment and risk management areas at FSANZ. Each member is a conduit, bringing potential food issues to the VIBE from the broader group they represent. Each issue raised at the VIBE is discussed and the likelihood of the issue eventuating together with the level of risk to consumers also being considered. If determined relevant, the issue is then triaged into one of five categories. The triage categories are:

- visionary
- horizon/foresight
- trending/emerging
- emerged
- established

The triage categories are differentiated based on the level of emergence of the issue and the level of uncertainty driven by the available evidence. The VIBE's primary focus is to capture issues from the first three triage categories (Dator, 2018; Food Standards Australia New Zealand, 2024; Schultz, Crews and Lum, 2025). Food issues triaged in the VIBE may be subjected to further follow-up activities. Activities can range from issue monitoring for updates and/or changes, providing information for consumers, undertaking surveillance and monitoring surveys, to regulatory changes at the Australian border for imported food or amendments to the Australia New Zealand Food Standards Code (Figure 9).

Figure 9. A summary of Food Standards Australia New Zealand's Vigilance and Intelligence Before food issues Emerge (VIBE) framework



Source: **FSANZ.**

5.1 Lessons learned/ways forward

Currently, the VIBE does not routinely use any data mining software *per se* to identify horizon or foresight food issues of relevance. Instead, the intelligence gathered by staff during the course of their daily activities within their areas of expertise, together with a heightened awareness to look for potential issues on a regular basis, are the foundation of the VIBE.

The VIBE has been operational in FSANZ since 2022. In that time, clear overlap in the issues independently identified by the VIBE and international collaborators, many of whom regularly use data mining software, has been recognized. This demonstrates the robustness of an expert-centred approach to horizon scanning and foresight, conducted in a cost-effective way. The VIBE model for intelligence gathering has gained interest from other food safety agencies. FSANZ has shared the model where possible, which has broadened the intelligence network further.

Global cooperation and information sharing between appropriate collaborators have been and will remain essential into the future, regardless of the approach used for horizon scanning and foresight. Many of the issues food regulators are facing are of global consequence, so a collaborative approach grounded in intelligence and judgement remains the pragmatic way forward.

6. Canadian Food Inspection Agency

Similar to other countries, the Canadian Food Inspection Agency (CFIA) uses internal and external data, subject matter expertise and analysis to generate intelligence to inform its activities and assess the food environment in the future. This includes regular environmental scanning using digital tools, such as Environment Scanning Canada and subscription-based platforms. Environment Scanning Canada, part of the Canadian Food Safety Information Network (CFSIN), is a web crawler with machine learning capabilities that scans more than 10 000 information sources, including media reports, scientific publications and journal articles, in nine languages, to help identify food safety issues. Results from environmental scanning and internal data monitoring are categorized, assessed and documented by intelligence analysts to identify "signals", which are defined as an emerging risk or changes in the known risk landscape, and for use in generating intelligence reports. This is done using a variety of methods. For example, CFIA has developed an internal tool that integrates data and identifies trends using statistically based thresholds for hundreds of commodity-hazards of interest. CFIA also routinely monitors internal data (complaints and recalls) using a tool to identify trends and outlier values for commodity-hazard combinations of interest.

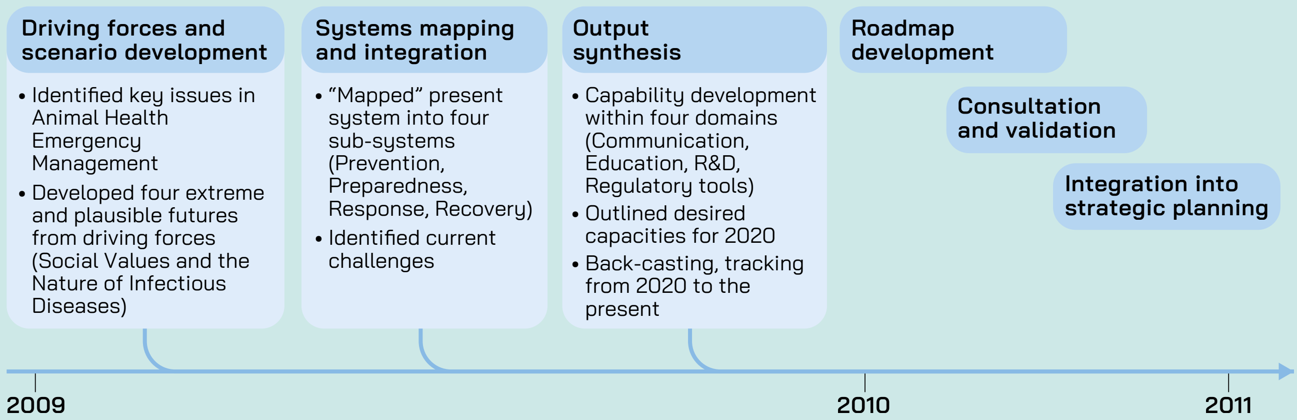
In addition to signals, the CFIA also develops situational awareness, intelligence and foresight reports using multiple sources and types of information (climate change data, industry insights, scientific literature, etc.) which inform its risk management activities and help increase preparedness for and response to emerging food issues. The CFIA has also established a Risk Intelligence Working Group, a multibranch forum to enhance responsiveness and build foresight capacity using available resources and tools and to share intelligence internally and with other federal government departments. The CFIA uses CFSIN and other forums and Memorandums of Understanding to share intelligence with Canadian federal, provincial and territorial government departments. CFSIN was launched in 2020 to provide a platform to facilitate the timely detection of food safety incidents and prevent nationwide emergencies (CFIA, 2022). In addition to providing a platform to share information and connect with food safety experts across Canada, CFSIN hosts laboratory testing data from food surveillance activities of different provincial and federal departments and includes emergency management and coordination capabilities in the event of a crisis or emerging event. The CFIA also exchanges intelligence with other countries through regular meetings to learn from each other and share findings on potential new or changing food risks.

Case study: Fore-CAN project

In response to a series of costly animal health events in Canada in 2008 caused by a range of infectious diseases, the Canadian Food Inspection Agency (CFIA) launched the three-year Foresight for Canadian Animal Health (Fore-CAN) project. The aim of the project was to ensure that the Animal Health Emergency Management (AHEM) system in Canada had the necessary capabilities to maintain the security and health of Canadians (Willis *et al.*, 2011). The AHEM system collects a range of expertise from diverse stakeholders including producer groups, animal health experts, public health experts, academia, federal departments and agencies, provincial governments and international organizations. The project was carried out in partnership with Agriculture and Agri-Food Canada, the Public Health Agency of Canada, the provinces of Ontario and Alberta, Canada's veterinary colleges and the Dairy Farmers of Canada, all key stakeholders in the AHEM system (Vanderstichel *et al.*, 2010).

The overall methodology of the Fore-CAN foresight project included workshops, scenario building, backcasting and roadmapping to help prepare Canada to better manage potential future animal health risks (**Figure 10**). First, a variety of "issues and driving forces" related to animal health were identified as uncertain, yet highly influential, factors expected to challenge the AHEM system in a 10-year time frame. Two of these were used to develop future scenarios, providing a framework for discussions on challenges and requirements for future animal health. Through systems mapping, the relationships between various elements in the scenarios were further analysed. Participants were asked to use their understanding of the current system to provide ideas for a new design that would meet the challenges identified in the future scenarios. Critical capacities to deal with the future scenarios were identified and backcasting was used to explore possible actions to develop these capabilities between now and 10 years later. Finally, steps to integrate the outputs of the foresight project into strategic planning across and within the organizations were elaborated.

Figure 10. The methodology of the Foresight for Canadian Animal Health (Fore-CAN) project led by CFIA



Source: Adapted from **Vanderstichel, R., Van der Linden, I., Renwick, S. & Dubuc, M.** 2010. Foresight: An innovative approach for animal health emergency preparedness. *The Canadian veterinary journal (La revue veterinaire canadienne)*, 51(4): 372–374;

Sources: **Vanderstichel, R., Van der Linden, I., Renwick, S. & Dubuc, M.** 2010. Foresight: An innovative approach for animal health emergency preparedness. *The Canadian veterinary journal (La revue veterinaire canadienne)*, 51(4): 372–374;
Willis, N.G., Munroe, F.A., Empringham, R.E., Renwick, S.A., Van der Linden, I.W.M. & Dunlop, J.R. 2011. Using foresight to prepare animal health today for tomorrow's challenges. *The Canadian veterinary journal (La revue veterinaire canadienne)*, 52(6): 614–618.

7. Singapore Food Agency

In an effort to future-proof Singapore's food safety management, Singapore Food Agency (SFA) continuously explores new initiatives to deal with new emerging risks. SFA applies science-based approaches to assess and manage food safety risks, including horizon scanning to monitor global food safety news with the aim of pre-emptively detecting food safety incidents (Singapore Food Agency, 2024a). As threats to food safety continue to grow, close collaboration between industry and local and international regulatory bodies is considered crucial at SFA. Furthermore, the agency's National Centre for Food Science conducts horizon scanning with the help of selected software for longer term trend analysis (Singapore Food Agency, 2024b). In collaboration with the Nanyang Technological University of Singapore, SFA has designed a project using advanced analytics and machine learning to intelligently predict emerging food safety risks and help in the management of the risks (Singapore Food Agency, 2021).

SFA employs a comprehensive approach to food safety, integrating past analysis, present monitoring, and future planning to ensure a robust and adaptable food safety system for Singapore:

- **Past (rear view mirror) – Root cause analysis:** Analysing past occurrences of foodborne hazards and disease outbreaks is essential for developing strategies to prevent food safety incidents and protect public health. SFA gathers extensive data through monitoring and surveillance of locally produced and manufactured food, imported food, and food from retail food and beverage businesses, as well as investigations of incidents associated with food and food businesses in Singapore. The data, which includes laboratory findings, inspection findings of food safety lapses, and epidemiological data from incident investigations, are systematically organized by food science data analysts to generate insights. Data analysis is complemented by behavioural science to identify root causes of risky behaviours and factors contributing to food safety incidents or pathogen transmission. Key insights from these analyses help SFA implement targeted risk management measures to mitigate risks and safeguard public health in Singapore.

- **Near future (days to months) – Early warning systems:** SFA enhances its food safety monitoring and surveillance through proactive environmental scanning, working with media monitoring companies to gather intelligence from various online sources. This includes surveying digital media from food recall databases, news reports and social media to provide early warning alerts on potential food safety issues and identify adverse events that may impact Singapore's food supply. This approach has proven effective. For instance, following alerts from the Rapid Alert System for Food and Feed, SFA detected aflatoxin contamination in imported peanut powder products. This led to the recall of the affected products, heightened surveillance of similar food products which were imported or used for local manufacturing and improved consumer health protection. Environmental scanning has also enhanced SFA's food sampling and testing plans, improving hazard detection throughout Singapore's food chain. By leveraging this proactive approach, SFA can better anticipate and respond to potential food safety concerns, ensuring a more robust protection system for consumers in Singapore.

- **Long term (years to decades) – Foresight and anticipatory capabilities:** To address long-term food safety threats, SFA collaborates with the food industry and regulatory science communities locally and internationally to enhance its horizon scanning and food safety capabilities. A key initiative is SFA's partnership with the Nanyang Technological University to develop a prototype software that categorizes and summarizes vast amounts of news articles (Lee *et al.*, 2023). This tool uses language models to extract keywords and generate structured metadata, enabling trend analysis and early detection of emerging food safety risks. SFA and Nanyang Technological University are also developing a system to analyse the genetic characteristics of foodborne pathogens from global food safety monitoring systems deposited into the PubMed database. This reference database will aid in comparing pathogen characteristics with those isolated in Singapore, helping SFA better identify the likely sources of foodborne outbreaks. Leveraging these digital advancements, SFA is exploring ways to enhance its foresight and anticipatory capabilities through horizon scanning and predictive analytics. The goal is to improve the identification of emerging trends from weak signals, allowing SFA to better assess potential food safety risks and formulate more effective policies and strategies, ensuring the agency remains ahead of evolving food safety challenges.

Case study: Streamlining food safety – Singapore Food Agency's automated environmental scanning system

To address the challenge of manual data processing, Singapore Food Agency (SFA) has explored incorporating automated data analytics pipelines into its environmental scanning process. This integration has been shown to markedly improve the efficiency and accuracy of analysing information from various online sources, including food recall notifications, safety news and consumer feedback.

The new framework has the potential to enhance SFA's ability to conduct swift risk assessments and prioritize inspection and food sampling and testing activities. Moreover, it can strengthen the agency's capacity to identify and prevent potentially adverse food safety incidents before they occur.

This streamlined approach allows SFA to process and analyse large volumes of data more effectively, enabling quicker responses to emerging food safety concerns and more targeted allocation of resources. By leveraging automation, SFA significantly bolsters its proactive stance in safeguarding public health and maintaining food safety standards in Singapore.

Source: **Lee, N., Vasanthakumar, U., Chen, R., Lee, C., Lam, K.Y., Hui, S.C., Kow, R. *et al.*** 2023. Predictive Food Safety Risk Monitoring. *2023 10th International Conference on ICT for Smart Society (ICISS)*, Bandung, Indonesia, 2023, September 2023 https://doi.org/10.1109/ICISS59129.2023.10291540

8. United States Food and Drug Administration

In 2020, the FDA announced its *New Era of Smarter Food Safety blueprint*, which aims to leverage technology and other tools and approaches to create a safer and more traceable food system (FDA, 2024). The initiative consists of four "core elements," namely to: a) enhance tech-enabled traceability, b) improve predictive analytics for smarter prevention and outbreak response, c) address new business models and retail modernization, and d) foster the development of a stronger food safety culture. "Core Element 2" of the blueprint explores the preventive value of emerging tools for analysing big data relevant to food safety. By implementing novel approaches (including artificial intelligence and machine learning tools) to root cause analysis and predictive analytics, the aim is to increase the likelihood of predicting and mitigating food contamination in the future (FDA, 2024). Predictive toxicology tools can furthermore help identify and characterize food chemical hazards. Together with relevant stakeholders, the FDA aims to develop processes to analyse data from non-traditional data sources, including environmental conditions (rain, temperature, wind, etc.) to enhance foodborne predictive capabilities (FDA, 2020). Customer online reviews, medication sales trends and dining apps are examples of non-traditional data sources that can help detect food safety risks (FDA, 2020).

9. Food Standards Agency (England, Wales and Northern Ireland)

The Food Standards Agency (FSA) foresight programme has a tiered approach to deal with food safety issues and foresight activities (Smith *et al.*, 2019):

- An immediate to near future capability built around surveillance of current and imminent food safety issues, driven by a Signals Prioritisation Dashboard that monitors and collates a broad range of open-source information relating to food safety incidents. Outputs from that are reported within the FSA and more widely as required, with more complex or weak signals monitored on an ongoing basis to identify any developments requiring further action;
- Regular near- to medium-term horizon scanning performed by teams across the FSA within their own particular area of expertise, such as food crime (Food Standards Agency and Food Standards Scotland, 2024), regulatory, and technology developments. Every six months, a horizon scan of the food system as it relates to the remit of the FSA is undertaken, building on the ongoing horizon scanning, combining this with wider information from open source and wider government into an overarching assessment that outlines key developments since the previous assessment, likely emerging issues and their trajectory over a 12 to 18 month time frame, and what the key implications might be for the agency;
- Longer-term foresight and futures activities include a strategic assessment undertaken every two years that looks at a longer timescale to understand the potential and likely changes in the food system that might impact the FSA and its remit, the most recent completed in 2023 (Food Standards Agency and Camrosh, 2023). This strategic assessment feeds into strategy development, as well as identifying areas where further information is required. This has led to more bespoke reporting on topics such as the evolution of personalized nutrition (Strauss, Short and Lotfian, 2022), the future of animal feed (Food Standards Agency, 2023a), 3D printing in the food system (Food Standards Agency, 2023b), the impact of climate change on the food system (Hasnain, 2024), and the use of AI in the United Kingdom of Great Britain and Northern Ireland food system (Zakaria *et al.*, 2024). These research projects are all integrated within the wider research and analysis functions of the FSA, with topics prioritized according to defined areas of research interest. The FSA also uses scenarios for longer-term futures assessment, alongside ad hoc analyses such as pre-mortem and systems thinking-driven approaches. In all these cases, the approach is to integrate the broad range of inputs and knowledge to a coherent systemic view highlighting impacts and meaning for the agency.

The FSA also works closely with others in government and more widely in trying to understand how the future might evolve, and how best to go about considering the future, with close links with the Government Office for Science (making use of and contributing to their futures framework), the Department for Environment, Food and Rural Affairs and academic partners, among others.

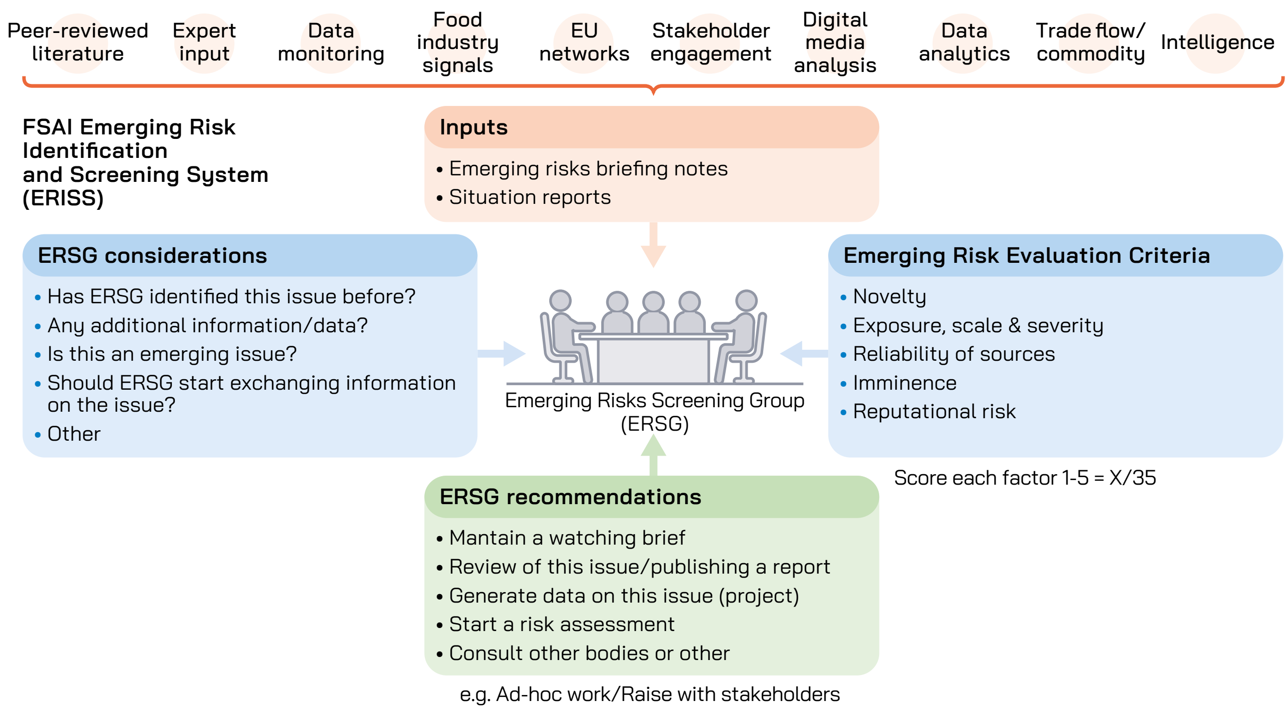
9.1 Lessons identified

- Knowledge and intelligence are distributed across the agency, generally alongside considerable subject matter expertise and ongoing scanning. Integrating these different inputs and analysis is key to ensuring a broad and holistic overview.
- Outputs need to be framed in a way that decision makers across the organization can understand and act on. This means making it clear how the findings impact their area and what it might mean for them.
- Futures and foresight activities tend to be viewed favourably in the abstract, but it can be very challenging to ensure that there is buy-in to specific activities when day-to-day near-term pressures dominate. Understanding the governance and decision-making cycles of your organization and how future and foresight activities can feed into those is key.
- While outputs are important, the process of collaborating is in itself valuable. It can build relationships and connections within and outside an organization, and in many cases gives people "permission" to step back from day-to-day concerns in a way that can be very valuable in its own right.
- Thinking systemically is key – within a food safety context there is a relatively narrow remit, but there are so many relevant drivers of change and impacting trends that a systemic holistic approach is vital. This means that foresight and futures work need to be multidisciplinary and as broad as possible in the scope of who it involves.
- Many foresight techniques involve consultation with experts. Caution is needed when integrating the views of experts so that one field or set of opinions does not unduly dominate. There is also a risk that experts in one area will express (possibly valid and well-informed) opinions on areas outside their area of expertise, and it can be difficult to disaggregate those views according to relevant expertise. A clear explanation of the levels and nature of uncertainty associated with the work is one means to mitigate the risk of bias.

10. Food Safety Authority of Ireland

The Food Safety Authority of Ireland (FSAI) considers emerging risks in food safety as involving new or evolving hazards that have the potential to directly or indirectly impact food safety and/or food security within a period of six months to 20 years. The FSAI Emerging Risk Identification and Screening System (ERISS) considers many sources of information, including changes in food production and processing trends, geopolitical events, changes in policy or regulation, economic impacts, fraudulent activity and shifts in consumer behaviour, among others. For instance, the globalization of the food supply chain has introduced new challenges, such as the spread of foodborne pathogens across borders. Additionally, changing weather patterns have altered the prevalence and distribution of pests, diseases and toxins, introducing a new challenge to the food supply system. However, the list of potential hazards is innumerable, and thus those engaged in emerging risks must keep an open mind to disparate information sources as the next emerging risk could take on many different forms. Continuous monitoring and assessment of potential hazards is crucial to successfully pre-empting emerging risks. FSAI's ERISS system proactively collects and analyses data from various sources, such as scientific literature, industry trends and current affairs (Figure 11). AI literature mining tools, media monitoring platforms, tailored news outlet alerts and trade dashboards all assist in alerting the ERISS to new or emerging signals or hazards, and they help depict a more holistic understanding of the risks at hand. By leveraging these tools, FSAI can be prepared for detected unfolding food safety risks and implement targeted interventions by informing strategies at the risk assessment and risk management phases. FSAI's ERISS is human-centric and collaboration among stakeholders is essential to address emerging risks to food safety and security. The food safety regulators, food business operators, academia and consumers work together to share information, develop best practices and implement pragmatic emerging risk identification strategies.

Figure 11. Illustration of the Food Safety Authority of Ireland's Emerging Risk Identification and Screening System



Source: **Cormac McElhinney**, FSAI.

11. China National Center for Food Safety Risk Assessment

China unveiled a guideline to enhance the country's food safety with a phased plan to build a modern governance mechanism in the field by the State Council (State Council Bulletin, 2019; Xinhua, 2019). By 2035, China should have a world-leading set of food safety standards, a marked drop in illegal practices driven by profit-seeking, and globally advanced risk control capabilities. Utmost efforts should be made in developing standards, conducting regulation, imposing penalties and seeking accountability, the guideline said. The guideline called for joint contribution from all stakeholders including governments, enterprises and consumers. These efforts align with China's broader public health objectives under the Healthy China 2030 initiative, which underscores the critical role of food safety in achieving the SDGs.

In view of future risk assessment challenges, China National Center for Food Safety Risk Assessment (CFSA) has outlined its long-term development strategy to position itself as a world-class high-end think tank and technical resource centre for food safety and applied nutrition. This includes advancing monitoring networks, risk assessment methodologies and database capabilities to address emerging risks such as antimicrobial resistance and chemical contaminants. Looking forward, CFSA aims to integrate cutting-edge digital technologies, such as big data analytics and artificial intelligence, to enhance its risk detection and mitigation capabilities (CFSA, 2023). The platform strengthens scientific cooperation among CFSA, the National Health Commission, the Ministry of Agriculture and Rural Affairs, and the State Administration for Market Regulation through exchanging information and data and to prioritize emerging risks including newly identified underlying drivers. Once emerging risks have been identified, for example from new food ingredients and new food production systems, multisector coordination is activated and CFSA responds through a dedicated platform to the emerging risk following a national monitoring plan, and risk assessment and controls for standard setting follow. Through strengthened international collaboration and the adoption of modern regulatory frameworks, China is working to address both traditional and emerging challenges in food safety (CFSA, 2023).

RESEARCH INSTITUTES AND UNIVERSITIES

12. New Zealand Food Safety Science and Research Centre

A system for identifying emerging food safety risks was established by the New Zealand Food Safety Science and Research Centre (NZFSSRC) in 2021 and is supported by a core group of food industry organizations and in-kind support from the regulatory authority New Zealand Food Safety (a business unit of the New Zealand Ministry for Primary Industries) (King, Thomas and Gautam, 2025). This Emerging Risk Identification System (ERIS) focuses on identifying food safety risks that may impact New Zealand in the coming years. The core purpose of ERIS is to support the food industry to prioritize their current and future food safety research (King, Thomas and Gautam, 2025).

The NZFSSRC learned from existing food safety horizon scanning systems to inform how ERIS could best operate (King, Martin-Neuninger and Brightwell, 2018). In the current system, the ERIS team primarily identify emerging issues through expert networks and manually evaluating published information. Digital tools have not been established to support information scanning. The findings are communicated through briefing notes on emerging issues, regular NZFSSRC meetings, quarterly newsletters, presentations and annual reports (King, Thomas and Gautam, 2025).

12.1 Lessons learned

- ERIS is considered a service rather than a research project, so the outputs must be of value to those investing. To ensure this, the food industry and government stakeholders have become part of the system and have major roles in guiding how ERIS operates, sharing intelligence, debating emerging issues and deciding on actions.
- Bringing in different perspectives is critical. Initially, non-food safety experts were incorporated into the system to draw on a wider range of observations that may have food safety implications. Retention of these experts is difficult if they do not perceive enough benefit from their involvement.
- Connections between people involved in emerging risk detection and foresight is critical for enhancing intelligence and preventing duplication of effort. Regionally, the emerging risk teams in FSANZ, New Zealand Food Safety (Ministry for Primary Industries, New Zealand, 2025) and the NZFSSRC have established regular meetings to share information. The people in these teams also have extended networks, including elsewhere in the world, which improves global connectivity and information exchange.
- An emerging risk/foresight system needs to adapt to the needs of stakeholders and fit within resource constraints. The ERIS team have considered how digital tools might augment some of their activities (King, Martin-Neuninger and Brightwell, 2018). Training a digital tool to look for the unknown (i.e. unrecognized emerging issues) is a challenge. Establishing and validating suitable tools is costly and continued funding is required to maintain their operation (particularly if re-training of ML tools is required).

13. University of Guelph

The University of Guelph conducts various forms of foresight and horizon scanning on food and agrifood system-related topics. The Arrell Food Institute, based at the University of Guelph, aims to transform global agrifood systems through forward-looking research on food security, sustainability and innovation (University of Guelph, 2024). In 2017, the University of Guelph also launched the Food from Thought initiative funded from the Canada First Research Excellence Fund (University of Guelph, 2020). The initiative brings together researchers, industry and decision makers to develop innovative solutions and formulate policies and regulations that address the key sustainability challenges facing agrifood systems. The Food from Thought initiative plans to create next generation information management systems, decision support tools and digital applications that intelligently collect and analyse crop, livestock and environmental data, among others, in an effort to reduce food safety risks, refine agricultural input use, monitor soil and crop health, and track emerging disease threats (University of Guelph, 2020). In association with the Food from Thought initiative, a foresight exercise for five food frontiers was conducted: cellular agriculture, controlled environment agriculture, climate-driven Northern agriculture expansion, entomophagy, and seaweed aquaculture. The foresight methodology used included horizon scanning, literature screening and a feasibility/impact analysis (Glaros *et al.,* 2022).

In partnership with Ambassador Ertharin Cousin and the Chicago Council on Global Affairs, Arrell Food Institute has initiated an 18-month foresighting exercise (Q1 2025 – Q4 2026) to "stress test" the North American Food system. The goal is to (1) identify and explore key stresses the North American food system is likely to experience over the next 20 years; (2) create contingency plans for North America's food system to be ready to prevent problems from cascading into crises; (3) develop a coherent community and established forum to allow smooth and easy communications between key members of the food system in the event of an emerging crisis.

13.1 Lessons learned

The most successful foresight exercises combine a structured approach with flexibility, encouraging diverse participation and using data-driven methods to anticipate future possibilities. The exercise should provide clear, actionable insights while also being adaptable enough to respond to new information and emerging challenges. Combining creativity, ethics, risk assessment and long-term visioning will ensure the desired outcomes from scientific foresight exercises in food safety are achieved.
Below are some key messages for a successful foresight exercise:

1. Conduct meetings in person, not virtually.
2. Gather the right experts with different perspectives and competencies in the room, briefing them on the expectations and the time horizon (e.g. 5, 10, or 20 years).
3. Use a combination of both qualitative and quantitative data to identify trends and uncertainties.
4. Identify key factors that will shape the future (e.g. technological advancements, funding, policy decisions, societal attitudes).
5. Encourage creativity in considering unexpected possibilities.
6. Foster an environment where ideas can cross-pollinate between disciplines and sectors.
7. Conduct a "free for all" brainstorming session sometime during the meeting, making sure that everyone feels comfortable to speak their mind, and encouraging everyone to speak.

Below are some general recommendations on foresight:

1. Develop a framework or metrics on the evaluation and qualification of digital tools (especially AI/ML tools) for use in modern food safety foresight.
2. Set up a working group to discuss any issues related to data protection, interpretability, predictability, and confidence in the outcomes of AI/ML tools.

3. Develop a framework to build strong knowledge partnerships between authorities, international organizations, industry and academia.
4. Develop foresight tools (e.g. a toolbox) that can be used by less developed and developed countries to help them perform foresight exercises, including a user-friendly, interactive, simple, and accessible online food safety risk tool intended to help predict the relative risks from various products/pathogens/processes both in the near and far future.

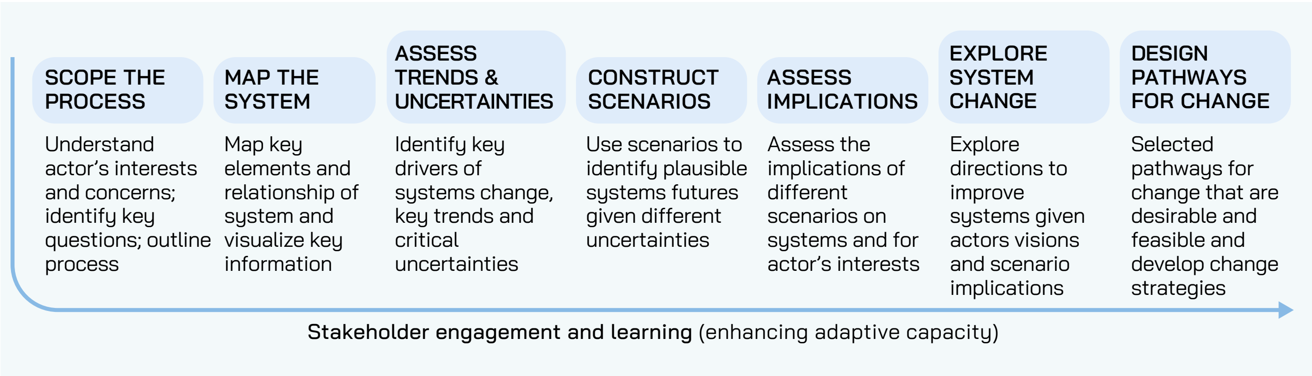
14. International Food Policy Research Institute

CGIAR, formerly the Consultative Group for International Agricultural Research, is a partnership of international organizations engaged in research to support future food security. The International Food Policy Research Institute (IFPRI), a research centre of CGIAR, regularly conducts foresight work as part of its mission to provide evidence-based policy recommendations that help promote sustainability and end hunger in developing countries. IFPRI uses quantitative models that integrate relationships between climate, crop and livestock yields, trade, and different economic sectors to explore how major trends in population, climate and resource availability are likely to affect food security and wellbeing. The International Model for Policy Analysis of Agricultural Commodities and Trade is used to explore long-term challenges to food security (Robinson, Mason-D'Croz and Susler, 2015), whereas the Rural Investment and Policy Analysis system allows users to experiment with policies, investments and economic shocks at the country level (IFPRI, 2025). This approach to foresight is built on analysis of historical data and depends on the validity assumptions underlying that analysis as well as the applicability of the same assumptions to present and future scenarios (Brooks and Place, 2019). While food safety policies and outcomes have not been explicitly incorporated into these models, doing so would be feasible, as related factors such as water availability, temperature, and production intensity are already included.

15. Wageningen University and Research

Wageningen University and Research (WUR) applies various foresight techniques in its research, with a particular focus on systems thinking (and mapping) to identify leverage points for the transformation of agrifood systems, and develops scenarios using modelling and scenario building techniques (Dengerink and Brouwer, 2020). Furthermore, WUR regularly participates in transdisciplinary research projects, including projects that integrate foresight to provide scientific advice to agrifood system-related policies. For example, the Metrics, Models and Foresight for European Sustainable Food and Nutrition Security, or SUSFANS project, was a Horizon 2020 research initiative funded by the European Commission, which was completed in December 2019. The aim of the project was to develop innovative approaches to improving food and nutrition security. For this, several European Union-wide scenarios were developed in collaboration with stakeholders to consider possible drivers of change and analyse future impacts on food and nutrition security (Rutten *et al.*, 2018). More recently, the Foresight for Food Systems Transformation (FoSTr) project, running until June 2025, is using foresight and scenario analysis to support policymakers in five low- and middle-income countries prepare for the future (Foresight4Food, 2024a). The aim is to help policymakers better identify the consequences of existing policies and how to initiate policies that anticipate the future. Figure 12 describes the foresight methodology applied in the FoSTr project.

Figure 12. An overview of the FoSTr foresight methodology for analysing systems change



Source: Adapted from **Foresight4Food.** 2024. Foresight4Food. https://foresight4food.net/foresight-framework

16. Cranfield University

Cranfield University incorporates a Strategic Foresight module in several master's degrees - Sustainability, Future Food Sustainability, and Environmental Management for Business. The module is also offered as a short course for PhD students in natural and social sciences, professionals, government employees and others.

The module looks at the practical example of how the agrifood system might be transformed to be more resilient and sustainable while supplying safe and nutritious food for all (Cranfield University, 2024a). The content focuses on the role of strategic foresight in shaping the future of the agrifood system, including trend research and scenario planning (Cranfield University, 2024b). Students conduct a PESTLE (political, economic, sociological, technological, legal and environmental) analysis (Sakrabani *et al.*, 2023) and learn horizon scanning techniques that can be used to identify new and emerging trends with possible impacts on the future. Using the trends identified through horizon scanning, scenario development is used to study how trends might change the future in different ways. The roles of planning, backcasting, wind-tunnelling and stress-testing are taught, to provide tools to investigate how trends could develop and the potential impacts of anticipatory action (Garnett *et al.*, 2023).

Cranfield University has considerable experience working with organizations, large and small, to design, adopt and apply futures techniques in ways that are in tune with the culture and needs of that organization – and its constituent parts - including in food and food safety (EFSA *et al.*, 2018). Client feedback suggests Cranfield's methods are useful for considering the wider implications of emerging issues and the outputs are useful for leveraging change within the organization, particularly when these are developed (and refined) in stakeholder workshops. Added value comes from provoking learning that leads to strategic insight (moving from information to intelligence), bringing different perspectives and policy "silos" together, and enabling a shift in thinking in organizations where the innovation and creativity of the process transfers to decision-making practice.

Examples include:

- Bringing diverse sectors together to identify and analyse signals, establishing the key drivers for change and the potential benefits to different sectors of the economy. One example is the Foresight into the BCG (Bio-Circular-Green) economy, which identified opportunities associated with the promotion of wellbeing and healthy food (British Council, n.d.).

- Identification and analyses of drivers of change (in sectors or systems), based on evidence review and expert elicitation to describe historic, current and emerging direction(s) of change in topics of interest for policy or research. Examples include shaping environmental policy in the pan-European region through applying foresight methodologies (Geneva Science-Policy Interface, 2024).
- The tools to enable a systematic approach to look ahead, analyse a range of potential futures, react to and use the insights to strengthen and inform strategy, policy and operational goals and approaches. Examples include plausible scenarios for the United Kingdom of Great Britain and Northern Ireland's food and feed system and the water environment in England and Wales (Garnett *et al.*, 2014).
- Structured means to assess risk, uncertainty, emergent trends and technologies, and to identify and work through assumptions (implicit or explicit) and complexity around strategic, policy and implementation challenges. Examples include the EU Environmental Foresight System and foresight projects of the Government Office for Science, United Kingdom of Great Britain and Northern Ireland (European Commission: Directorate-General for Environment et al., 2022; Government Office for Science, 2024a).
- Establishing a framework for the identification, analysis and response to emerging environmental risks in the food supply chain, focusing on the capacities, capabilities, skills and knowledge required in regulatory environments to take anticipatory action in response to issues in the medium and long term.

17. Africa Foresight Academy

The Africa Foresight Academy (AFA) is a network of foresight practitioners at regional, country and continental level, which aims to increase the use of foresight practices in African research institutions and the private sector (FARA Africa, 2024). AFA develops foresight competences, helps interpret the results of foresight exercises, and offers technical support with the aim of enabling the participation of regional and national organizations in foresight initiatives. Among other applications, foresight is applied at AFA to enhance understanding on how innovations can be used to tackle the diverse challenges agriculture faces. For example, in 2022, AFA participated in a foresight training with Foresight4Food researchers and WUR to develop four scenarios for a more climate-resilient Ghana in 2040, focusing on the future of the Ghana agrifood system and its resilience to climate shocks (Foresight4Food, 2024b). The process began with a mapping of the agrifood system's key features, followed by the development of four distinct scenarios based on two identified key uncertainties. Finally, possible actions to ensure climate-resilience in each scenario were explored (Hasnain, 2022).

18. University of Veterinary Medicine Budapest

The University of Veterinary Medicine in Budapest, through its Department of Digital Food Science, engages in cutting-edge activities to identify emerging risks in the food chain. These efforts are aimed at enhancing consumer health protection by leveraging systematic methodologies and advanced data analysis and text mining techniques. The institution has developed a multiphase process for emerging risk identification that involves gathering diverse data sources, filtering issues through expert judgement and algorithms, and assessing potential risks based on predefined criteria (Farkas *et al.*, 2023). The outcomes of these evaluations are then communicated to stakeholders, including regulatory authorities (Hungarian National Food Chain Safety Office, EFSA, etc.), to enable timely mitigation actions.

The university uses innovative data analytical approaches such as media news analysis, rapid alert system trend evaluations, and patent database analysis to detect weak signals and emerging patterns. The emerging risk-related activities encompass all timelines, and connect the short-, medium- and long-term analyses. Between 2020 and 2023, this system identified more than 300 emerging issues and signals across 10 thematic areas, ranging from microbial safety and chemical contaminants to sustainability and climate change-related challenges. The university also participates in various projects in this area, e.g. the HOLiFOOD (Holistic approach for tackling food systems risks in a changing global environment) Horizon Europe project. HOLiFOOD applies AI and big data analytics to develop a systems approach that considers the complexity of the environment in which food is being produced. Such an approach enables the early identification of upcoming known and unknown hazards to human, animal and environmental health along the different selected supply chains and improve the Food Safety Risk Analysis framework in Europe (HOLiFOOD, 2025).

PRIVATE SECTOR

Many businesses in the food and drink industry already use integrated early identification systems that embed smarter horizon scanning and risk anticipation to detect and identify emerging issues relevant to the safety of their products. In food manufacturing, trends are identified by monitoring external and internal information sources, including scientific literature, technology advancements, official surveys, and authority notifications. Other supply chain factors that could lead to increased food safety risks are also considered, such as financial stability, contract recovery, ethical business practices, customs rules, natural disasters, political and labour disputes, and logistics. The hazards and risks identified in this way are evaluated within the business/supply chain context to qualify the relevant trends. This is followed by defining standards and preventative measures, and by identifying mitigation options for associated risks and/or ways to optimize opportunities. Finally, strategies are put in place to prepare for the emerging trends.

A larger pool of data increases the opportunity to uncover valuable insights. Fast-moving consumer goods companies are now actively and willingly collaborating within well-structured frameworks that ensure confidentiality and compliance with antitrust regulations. This approach enables a more profound, impactful understanding and improvement of supply chain performance. Proactive identification of emerging issues relies heavily on data quality and effective data management, using the range of available digital tools and applications, including AI and ML. A comprehensive and effective strategy for identifying emerging food safety risks in the private sector requires collaboration and communication between a wide range of stakeholders across the food supply chain, including ingredient and food producers, farmers, third party and independent laboratories, and national and international authorities. Seizing on the opportunities offered by digital tools and knowledge from various stakeholders enables the collection of an ever-growing amount of complex and diverse information from various sources. In combination with expert analysis, key issues can be identified pre-emptively, and valuable insights can be gathered to ensure food safety and support risk mitigation strategies or business opportunities.

Case study: A collaborative data-driven model to tackle food safety risks in the food supply chain

Major players in the food industry have partnered to introduce an innovative, data-driven approach aimed at enhancing food safety. This new model goes beyond traditional methods such as audits and certifications, shifting the focus to proactive risk management by securely aggregating and analysing confidential data while adhering to confidentiality and antitrust regulations, with the support of a third-party service provider. Initially concentrating on food safety data for ingredients, the model is designed to scale, incorporating new raw materials, data types and additional partners over time. The actionable insights generated from this approach enable companies to benchmark testing strategies, identify risks earlier, enhance supply chain transparency, and adapt their risk management strategies and decision-making processes.

To ensure the model's effectiveness, partners must embrace trust, provide comprehensive data, align with shared safety goals and contribute continuously. By fostering collaboration and innovation, this initiative represents a significant advancement in addressing persistent challenges within the food supply chain. It offers a sustainable and scalable approach to safeguarding public health while generating shared value for all participants.

Conclusions and future opportunities

Foresight is a crucial tool for the early identification of emerging food safety issues. These issues may pose potential risks or offer promising opportunities, influenced by various societal, economic, political, legal, environmental, scientific and technological factors. By incorporating foresight activities and related insights into the development of food safety strategies and policies, governments and stakeholders can address emerging risks with cost-effective and timely interventions. Different approaches exist within the early identification paradigm. Early warning systems, for example, aim to detect immediate hazards and help predict the occurrence of near-future food safety incidents. Foresight broadens the research scope into the farther future, aiming to detect emerging trends and drivers that may influence food safety in the medium to long term, complementing emerging risk identification.

A comprehensive food safety foresight approach that strategically integrates both digital tools and human expertise into existing workflows is essential moving forward. Given the rapid evolution and growing interest in this field, there is also a need to map the landscape of new tools and monitor the continuous evolution of food safety foresight approaches. With recent advances in automation or semi-automation, including AI tools, a unique opportunity is emerging to better manage the ever-growing complexity of agrifood systems. Digital advances offer promising solutions to handle and contextualize the vast amount of available information, enabling the generation of actionable insights and strategies to ensure future food safety.

Presently, AI tools are being applied and leveraged across several key domains, particularly for early warning systems for food safety. These tools support data screening, extraction, structuring, analysis and prediction, with the potential to transform traditional approaches to food safety foresight. However, using digital tools necessitates human scientific and regulatory expertise at various steps throughout the foresight process, for example to define search criteria, monitor the relevance of the data, analyse and conceptualize the outputs, and ensure that appropriate quality measures and feedback are in place. The development of data collection platforms to which digital tools can be applied is another area where human supervision is critical to realizing the potential benefits of these technologies.

In addition to leveraging modern digital tools, there is a recognized need for building strong knowledge partnerships between authorities, international organizations, industry, academia and consumers. Multisectoral collaboration is critical to improving the early identification of food safety issues. A food safety foresight approach should therefore promote open, transdisciplinary and cross-sectoral communication and knowledge sharing between all relevant stakeholders.

This document aims to strengthens the international collaborative effort to establish a global network of expertise and increase foresight capabilities among stakeholders, ultimately supporting the development of effective strategies to safeguard future food safety in an increasingly complex world.

BEST PRACTICES FOR AN EFFECTIVE FORESIGHT APPROACH

Food safety foresight facilitates the proactive identification and assessment of emerging trends and factors that may affect food safety. This enables enhanced preparedness and strategic planning to address potential challenges and capitalize on opportunities. The resources required for an effective foresight approach represent a long-term investment, crucial for shaping a more informed decision-making process that will influence the future status of food safety. However, it is important to note that initiating a foresight exercise does not require extensive personnel or funding. Internal foresight capacity can begin on a small scale and gradually expand over time, depending on evolving needs and available resources.

Effective food safety foresight relies on several key principles and practices derived from lessons learned across various initiatives. Below is a summary of the main insights and know-how shared by specialists in the field:

1. **Rationale and problem formulation:** Successful food safety foresight exercises should begin with clearly defined objectives, timelines, scale and scope. These elements are essential for tailoring the process and methodology. For instance, an exercise may focus on a specific aspect of the food safety domain, such as plant health, food fraud, or feed, or it may provide a broader overview of the entire agrifood system. The design of these exercises should aim to generate actionable insights while remaining flexible to accommodate new information and emerging challenges.

2. **Structured yet flexible approach:** A combination of qualitative and quantitative data, along with the ability to quickly scan a broad range of information sources – not only patents and scientific publications, but also non-scientific inputs about society, the environment and economics, for example – is pivotal for identifying emerging food safety issues, trends, uncertainties, and key factors shaping the future. These factors include technological advancements, funding, policy decisions and societal attitudes. Adopting a holistic, multidisciplinary approach is recommended, considering a broad range of drivers affecting food safety and combining structured data-driven methodologies with human expertise, enabling flexibility, creativity and adaptability.

3. **Human-centred intelligence gathering:** Intelligence gathering, led by subject-matter experts and supported by staff with a strong understanding of foresight requirements, fosters early identification of potential issues in a cost-effective manner. Clearly communicating expectations and a time horizon (e.g. 5, 10 or 20 years) is pivotal for a fruitful outcome. Regular in-person meetings, both formal and informal, improve connectivity and information exchange. Brainstorming sessions must ensure inclusive participation, with no single stakeholder being overrepresented. Engaging experts and stakeholders from outside the food safety sector broadens the scope of perspectives to foresee unexpected or uncommon food safety implications. However, it is essential to cultivate an environment where participants feel motivated and ideas can cross-pollinate between disciplines and sectors.

4. **Integration of digital tools:** Digital tools, including AI, can significantly enhance the speed and efficiency of collecting, scanning and analysing large amounts of data. These tools, even if challenging to train and keep updated, make foresight exercises more time-effective and resource-efficient. However, it is important to carefully consider data needs, access and management, and evaluate digital tools with dedicated metrics, particularly regarding data protection, interpretability, predictability and reliability. Experts should be provided with learning opportunities to use the digital tools and tailor them to the desired outcomes.

5. **Multistakeholder engagement:** Broad communication channels, involving internal and external experts from various disciplines, are essential for strengthening the foresight process, facilitating intelligence sharing, and ensuring a wider pool of insights. Rather than centralizing collection and analysis of available knowledge into a single function, engaging a wide variety of stakeholders ensures diverse perspectives, reduces bias, and enhances objectivity. Stakeholders include *inter alia* governments, national authorities, international organizations, industry, academia and consumers. Expanding the network through ongoing partnerships and international cooperation is crucial, particularly when dealing with global food safety issues. Developing accessible foresight tools can also help extend these benefits globally, catering to both developed and developing countries.

6. **Clear communication and buy-in:** Securing the necessary resources and funding is critical to ensuring the sustainability and effectiveness of the foresight exercise. It is essential to understand the end user organization's governance and decision-making processes and tailor the outputs to specific areas of responsibility, fostering long-term buy-in. Aligning foresight activities with organizational decision-making cycles also ensures continued support and relevance. Foresight outputs should be framed clearly and practically, ensuring that decision makers receive understandable and actionable insights to follow up on the findings. Transparency on the uncertainty associated with foresight exercises is key to building trust in the process, since experts may share insights and ideas outside their remit of expertise.

In conclusion, a successful food safety foresight process equips governments and stakeholders with the capacity to anticipate, prevent, mitigate or exploit future food safety issues, enhancing preparedness and improving participatory decision making. This requires human expertise supported by digital tools, collaboration, and a flexible but structured approach. The introduction of foresight best practices can be accessible, equitable and beneficial for driving food safety improvements worldwide, including for LMICs. By engaging diverse stakeholders, utilizing available digital tools and focusing on practical, actionable outcomes, food safety foresight can effectively prepare decision makers and society for future food safety challenges and opportunities.

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Appendix: List of participants at the FAO Food Safety Foresight Framework Meeting

(FAO headquarters, Rome, Italy, 1–3 April 2025)

EXPERTS

Ákos Jóźwiak, University of Veterinary Medicine Budapest

Angela Parry-Hanson Kunadu, University of Ghana

Angelo Maggiore, European Food Safety Authority

Cormac McElhinney, Food Safety Authority of Ireland

Diego Varela, Chilean Food Safety and Quality Agency

Greg Wasinski, Food Standards Agency

Heather Holland, Canadian Food Inspection Agency

Joanne Chan, Singapore Food Agency

Kate Jones, Cranfield University

Nicola King, New Zealand Food Safety Science & Research Centre *(Chair of the meeting)*

Simone Moraes Raszl, World Health Organization

Vivian Hoffmann, International Food Policy Research Institute

Yongning Wu, China National Center for Food Safety Risk Assessment

Zoe Morosini, Food Standards Australia New Zealand

RESOURCE PERSONS

Aaron O'Sullivan, Danone

Zeina Kassaify, Mars

SECRETARIAT

Markus Lipp, Food safety senior officer, Agrifood Systems and Food Safety Division, Food and Agriculture Organization of the United Nations

Riccardo Siligato, Programme support specialist, Agrifood Systems and Food Safety Division, Food and Agriculture Organization of the United Nations

Maura di Martino, Food safety specialist, Agrifood Systems and Food Safety Division, Food and Agriculture Organization of the United Nations

Jane Feeney, Communication consultant, Agrifood Systems and Food Safety Division, Food and Agriculture Organization of the United Nations

Peijie Yang, Specification and regulatory affairs officer, World Food Programme

Francesco Mascherpa, Food technologist, World Food Programme


Food and Agriculture Organization of the United Nations
Opening remarks:
Zoe Morosini

me Njie
ms and Food Safety Division, FAO
Cormac McElhinney

Glossary: A summary of relevant terminology

FOOD SAFETY FORESIGHT TERMINOLOGY

Agrifood systems

The entire range of actors and interlinked activities that add value in agricultural production and related off-farm activities such as food storage, aggregation, post-harvest handling, transportation, processing, distribution, marketing, disposal and consumption (FAO, 2024d).

Food safety

Assurance that food will not cause adverse health effects to the consumer when it is prepared and/or eaten according to its intended use (FAO & WHO, 2023, p. 7).

TYPES OF CHANGES *WHAT ARE WE LOOKING FOR?*

Drivers

Macro-level factors that derive from a broad spectrum of areas: societal, environmental, technological, political and economic. Drivers can be slow to form, but once in place cause changes with obvious wide-reaching impacts across a range of sectors, spanning different geographic areas and over varying time frames (FAO, 2022a, p. 11).

Trend

A general pattern or direction of change that has been observed over time, which may continue or shift in the future. Trends can be strong or weak, increasing, decreasing, or stable, and are used in foresight to understand the trajectory of developments (UN Global Pulse, 2023).

Emerging issue

An issue that is not yet generally recognized, but could have major impact on sustainable development if not addressed. Although often perceived as risks, emerging issues could also be positive, meaning that there was a need to recognize potential opportunities. There is often an element of newness, but the issue would not necessarily be considered as unheard of or surprising (United Nations Department of Economic and Social Affairs, 2016, p. 2).

Emerging risk (related to food safety)

A risk to human animal and/or plant health resulting from a newly identified hazard to which a significant exposure may occur or from an unexpected new or increased significant exposure and/or susceptibility to a known hazard (EFSA, 2007, p. 1).

Weak signal

Current or past developments with unclear implications for future developments. These may or may not be relevant and are generally difficult to identify. For example, changing public attitudes towards an issue could be considered a weak signal that may change slowly over time (FAO, 2014, p. vi).

Early warning signal

Initial information suggesting that a potential ongoing or emerging food safety hazard or threat is occurring or could occur. Signals can be generated by traditional food safety surveillance systems (e.g. food inspection, laboratory surveillance) or less traditional food safety intelligence (e.g. foresight). Early warning signals may be difficult to detect and analyse, and care must be taken to avoid spurious information (e.g. not indicative of a true food safety threat or adverse event) (FAO, 2015, p. vi).

TYPES OF APPROACHES *HOW?*

Food safety surveillance

The systematic and ongoing collection, analysis, interpretation and dissemination of data on signals of potential food safety threats or adverse events. Incorporates both food chain surveillance (primarily an agrifood agency activity that includes the identification, monitoring, and surveillance of hazards or threats along the food chain) and *public health surveillance* (primarily a public health agency activity that includes routine monitoring for food-borne illnesses in people) (FAO, 2015, p. vii).

RETROSPECTIVE

Foodborne illness outbreak environmental assessment

The systems-based component of a foodborne illness outbreak response that fully describes how the environment contributed to the introduction and/or transmission of agents that cause illness or could cause illness. Environment is everything external to the host, including air, food, water, animals, plants, climate, etc., as well as people and the social and built environments (Selman and Guzewich, 2014, p. 98).
Environmental assessments (root cause analysis) determine the contributing factors and environmental antecedents that led to the outbreak and/or to support the epidemiological investigation as needed (ibid., p. 98).

IMMEDIATE TO NEAR FUTURE

Early warning system

In the context of food safety, early warning systems include various tools, technologies, processes, and resources used to monitor, detect, and verify early warning signals, analyse data and information arising from such signals, and disseminate and communicate alerts to stakeholders at appropriate levels for the purpose of informing risk management actions and decision making (FAO, 2015, p. vi).

MEDIUM-TERM TO LONG-TERM FUTURE

Foresight

A collection of forward-thinking methodologies that are generally applied to improve institutional planning or policy making for potential future situations, hazards or opportunities (FAO, 2014, p. v).

Systems thinking

A system is a regularly interacting or interdependent group of items forming a unified whole – more than a collection of its parts.
Systems thinking is a set of synergistic analytic skills used to improve the capability of identifying and understanding systems, predicting their behaviors, and devising modifications to them in order to produce desired effects. These skills work together as a system (Arnold and Wade, 2015).

Systems mapping

The creation of visual depictions of a system, such as its relationships and feedback loops, actors and trends. Systems mapping is intended to provide a simplified conceptual understanding of a complex system that, for collective action purposes, can get partners on the same page (Gray and Bloch, 2020).

Horizon scanning

The systematic examination of potential threats, opportunities and likely future developments which are at the margins of current thinking and planning. Horizon scanning may explore novel and unexpected issues, as well as persistent problems or trends (DEFRA, 2002).

Delphi survey

A structured questioning tool, used to gather opinion from a panel of subject matter experts by using multiple rounds of questionnaires. It is a systematic and qualitative method that relies on experts to highlight the future issues they think could be important (Government Office for Science, 2024b).

Scenarios and scenario building

A scenario is a story, told in words and numbers, concerning the manner in which future events could unfold and offering lessons on how to direct the flow of events towards desirable pathways and away from undesirable ones (Gallopín *et al.*, 1997).
Scenarios do not attempt to forecast or predict the future; instead, they envision several plausible pathways along which the future may develop and thereby account for critical uncertainties (Kahn and Weiner 1967; Kok, Biggs and Zurek, 2007).

ARTIFICIAL INTELLIGENCE

Artificial intelligence (AI)

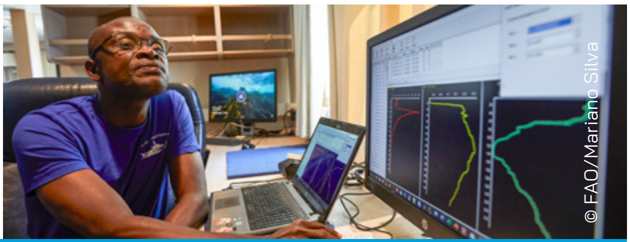
An AI system is a machine-based system that, for explicit or implicit objectives, infers, from the input it receives, how to generate outputs such as predictions, content, recommendations, or decisions that can influence physical or virtual environments. Different AI systems vary in their levels of autonomy and adaptiveness after deployment (OECD, 2024, p. 4).

Machine learning (ML)

Machine learning is a set of techniques that allows machines to improve their performance and usually generate models in an automated manner through exposure to training data, which can help identify patterns and regularities rather than through explicit instructions from a human. The process of improving a system's performance using machine learning techniques is known as "training" (OECD, 2024, p. 8).

Natural language processing (NLP)

Natural language processing refers to computer programs and tools that automate natural language functions by analysing, producing, modifying, or responding to human texts and speech (OECD, 2023, p. 14).



DIGITAL ERA

Digitization

The process of converting something to digital form (Merriam-Webster, 2025a).
The action or process of digitizing; the conversion of analogue data (esp. in later use images, video, and text) into digital form (Oxford English Dictionary, 2024).
To put information into the form of a series of the numbers 0 and 1, usually so that it can be understood and used by a computer (Cambridge Dictionary, 2025a).

Digitalization

The process of converting something to digital form (Merriam-Webster, 2025b).
The adoption or increase in use of digital or computer technology by an organization, industry, country, etc. (Oxford English Dictionary, 2023).
To start to use digital technology such as computers and the internet to do something (Cambridge Dictionary, 2025b).

Digital transformation

Digital transformation covers both the integration of digital technologies […] and the impact on society of new technologies, such as the Internet of Things (IoT), cloud computing, innovative digital platforms and blockchain technologies (Negreiro and Madiega, 2019, p. 2).

Digital transformation is a process of integration of digital (ICT) technologies by […] enterprises and citizens and the ongoing impact of such technologies on the economy and society (Lomba, Jančová and Fernandes, 2022, p. 2).

SUMMARY COMPARISON

TERM	FOCUS	SCOPE	IMPACT
Digitization	Converting analogue data to digital format	Limited to data conversion	Improves accessibility and storage
Digitalization	Enhancing organization processes with digital tools	Broader, affecting organization processes	Enhances efficiency and decision making
Digital transformation	Integrating digital technologies into all aspects of an organization	Holistic, encompassing entire organization model and culture	Fundamental change in operations and strategy

Foresight approaches in food safety enable the proactive identification and management of emerging issues – including both risks and opportunities – over the medium to long term. These approaches are most effective when human expertise is complemented by emerging digital tools and supported by strong knowledge partnerships among stakeholders. This publication outlines best practices and guiding principles for an effective food safety foresight approach, designed for policymakers, regulators, researchers and industry professionals. It supports timely, informed decision making to strengthen preparedness across agrifood systems.

As global agrifood systems undergo rapid transformation, driven by factors such as climate change, urbanization, global trade and technological innovation, the complexity of food safety challenges continues to grow. This publication explores how foresight techniques can be used to prepare for emerging issues and inform science- and evidence-based risk assessments. It highlights the importance of multisectoral collaboration and knowledge sharing, drawing on insights from a global network of experts – from governments, international organizations, research institutes, universities, and the private sector – convened by FAO in 2025.

The FAO Food Safety Foresight Programme proactively identifies, assesses and prioritizes emerging trends and drivers shaping agrifood systems that may have implications for food safety. Effective food safety foresight begins with clear objectives and a flexible, structured approach that combines qualitative and quantitative data. It relies on expert-led intelligence gathering, supported by digital tools to identify emerging risks and opportunities. Inclusive stakeholder engagement across sectors enhances insight and objectivity. Success depends on strong communication, institutional buy-in and alignment with decision-making processes. Even with limited resources, foresight capacity can start small and grow over time. This approach empowers stakeholders to anticipate and respond to future food safety challenges, supporting resilient agrifood systems and proactive policy making worldwide.

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ISBN 978-92-5-140096-8

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CD6798EN/1/09.25