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Vulnerability analysis report and data base

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1 Preface

HOLiFOOD aims to develop a holistic assessment framework, including but not limited to the development of an emerging risk identification tool based on the use of a broad range of data sources and Artificial Intelligence (AI). Emerging risks include risks from known hazards to which exposure has started to increase due to, for example, shifts in dietary preferences and/or new or altered production methods. In addition, risks can come from previously unknown hazards which have been revealed recently, owing to scientific progress. New risks can emerge from new hazards being introduced in the food supply chain, such as a new strain of a particular pathogen, or the introduction of new products and processes. In a holistic approach towards emerging risk identification, changes within the influential sectors within and surrounding the food production environment are considered to have a possible impact on the introduction and behaviour of hazards within the food supply chain. Trends within these sectors may therefore finally turnout to be major drivers for the occurrence of hazards and their development into risks. Monitoring driver-related data on a continuous basis (*e.g.* scouring the Internet using AI) should help to identify hazards with the potential to become emerging risks and to contain them. The research described in this report is performed in the course of Task 5.2, and sets out to find and prioritise the likely drivers of emerging risks in the food chain. This will help other work packages (WPs) within HOLiFOOD to use these drivers and implement the emerging risk identification tools.

The document is made up of the following consecutive parts:

- An introduction describing the background of the research featured, such as the HOLiFOOD project, and the subjects of the research featured in this report, including past food incidents, the Green Deal, and climate change.
- The methodology and outcomes of the two strands of research reviewing literature with the aim to identify drivers of emerging hazards within the food supply chain:
    - Retrospective research (grey literature, *e.g.* from food safety authorities) on past food safety incidents and the commonalities shared amongst them in terms of underlying trends and drivers that led to these incidents (task 5.2.1).
    - Prospective research (scientific literature) on the possible impact of climate change and environmental "green" policies on food safety (task 5.2.2).
- The method and outcomes of the prioritisation by invited international food safety experts (residing in Europe) of a set of 15 pre-identified drivers likely to lead to the emergence of hazards in the near future (selected from the literature reviews).
- A discussion of these results, putting them into perspective, followed by conclusions and recommendations.
- An Annex with detailed results of the various research activities.

2 Summary

The research summarised in this report has been carried out in the frame of the EU-funded HOLiFOOD project. One of the aims of this project is to develop AI-powered tools for emerging risk identification in food production. As input for such a tool, it is imperative to have data on drivers related to climate change and green policies driving the emergence of hazards within the food supply chain. Drivers have thus been identified through the research described in this report. It followed a two-pronged research approach, I) looking prospectively into the food safety items that might be brought about by climate change and green, environmental policies, and II) retrospectively into the commonalities amongst past food safety incidents.

The prospective research was performed to assess the effects of changes by the European Green Deal and climate change on emerging food risks. Very little information regarding the European Green Deal and its possible effects on food safety risks was obtained. Climate change and its possible effect on food safety risks, however, have been described in multiple articles and reviews. A list of drivers and corresponding effects and indicators were extracted from all relevant literature. An overview of the results is presented in this report. Furthermore, due to the high degree of complexity caused by related drivers and effects, all relations have been visualised in a flow scheme.

As regards the food safety incidents, a widely varying range of incidents occurred, stretching a wide range of geographies and time periods. Yet, several commonalities could be found amongst the incidents reported, as far as related to causes and drivers. Generally, there are contamination and adulteration events that resulted in the contamination of food products. Examples include the purposeful or accidental substitution of ingredients with cheaper, contaminated ones, mingling of grain with co-harvested toxic seeds, infestation of harvested or stored produce with mycotoxin-producing fungi, etc.

Based on careful consideration of the drivers shared in common by the various hazards considered, a selection of the list of drivers was then prepared as input for a mini-Delphi survey amongst invited food safety experts. This ultimately resulted in a list of 14 prioritised drivers related to climate change, economics and the green deal. Amongst these drivers, the highest-scoring was increasing temperatures and rainfall, which could eventually give rise to growth of moulds on crops and harvest, and the formation of mycotoxins by these moulds..
Results of this Deliverable report will be used in other WPs, mainly WP1, for further exploration of related indicators and the data sources that can be used to monitor for changes in these indicators.

3 Introduction

3.1 Background

3.1.1 The HOLiFOOD project

The overall objective of HOLiFOOD is to improve the integrated food safety risk analysis (RA) framework in Europe. With the results of this project, involved stakeholders from the food production and processing sector will be able to meet future challenges arising from Green Deal policy driven transitions, in particular in relation to climate driven changes. The results of the project will therefore contribute to the United Nations' sustainable development goals and support the realisation of a truly secure and sustainable food production system.

HOLiFOOD takes three supply chains into consideration, specifically cereals [maize], legumes [lentils], and poultry [chicken]. A system approach will be applied to these supply chains, which takes the whole environment into account in which food is being produced. This means that not only the supply chain itself will be analysed but economic, environmental and social aspects will also be taken into consideration.

Within HOLiFOOD, multiple systems and methods will be developed for integrated food safety RA. Firstly, tools and methods will be developed for targeted and non-targeted hazard detection. Secondly, early warning and emerging risks prediction systems for known and unknown food safety hazards will be developed using Artificial Intelligence (AI) and big data. Lastly, new holistic risk assessment methods will be developed in which food safety risk management will be embedded in a comprehensive cost-benefit analysis of the food system including positive and negative health, environment, and economic dimensions.

Finally, an effective impact pathway will be developed and implemented through integration of the HOLiFOOD outputs into the legal framework associated with the food risk analysis process. The impact pathway will be supported by an electronic data and knowledge sharing platform. The aim of the platform is the full digitalization of food (safety) systems, supporting transparency and impact for all stakeholders. In order to align with stakeholder priorities, preferences and user requirements, the HOLiFOOD innovations will be designed and tested in a multi actor approach (i.e., Living Lab) involving all stakeholders (*e.g.*, authorities, food producers and citizens).

3.1.2 Climate change and environmental policies

On the 11th of December 2019, the European Green Deal was presented by the President of the European Commission. The European Green Deal is a package of policy initiatives that should aid the European Union (EU) with the green transition, the final goal being to reach climate neutrality in 2050. The package contains initiatives covering areas such as the climate, the environment, energy, industry, and agriculture.

An example of such an initiative is the Fit-for-55 package, which aims to translate the climate ambitions of the Green Deal into law. For instance, a reduction target has been set to 40% for greenhouse gas emissions in 2030 compared to 2005 in concerned sectors. A second example is the 'Farm to Fork' strategy. This strategy aims to shift the current EU food system towards a sustainable model. Policies included in the 'farm to Fork' strategy are, for instance, promoting more sustainable food consumption and healthy diets, and aiming to reduce the overall use of chemical pesticides by 50% by 2030. Another example is the biodiversity strategy which aims to help recover Europe's biodiversity by 2030. Extending protected land and sea areas in Europe are part of this strategy. Finally, another legislative initiative, is the European climate law regulation. The climate law regulation provides a legal obligation to reach climate neutrality by 2050.

As becomes clear from these initiatives, climate change is a key challenge that the EU is trying to overcome. Climate change is a global problem posing multiple risks. One of the major risks being the effect of climate change on food safety.

3.1.3 Past food incidents

Food poisoning was probably accountable for some recorded historic adverse events (*e.g.,* illness, death). However, it was not until the 19^{th} century that institutions dealing with the quality and safety of food became widely established. Knowledge and awareness continued to grow and legislation and inspections evolved concurrently throughout the 20^{th} century. Also, the monitoring of foodborne illnesses and the execution of major food recalls started to evolve by the early 1970s. Moreover, the Hazard Analysis Critical Control Points (HACCP) approach had originally been developed for food used during spacefare in the USA in the 1960s, but its adoption was accelerated in the 1990s. This acceleration followed after a number of major food safety incidents, such as the bovine spongiform encephalopathy (BSE) crisis in Europe, as well as the dioxin crisis and a major food infection outbreak in the United States of America (USA). Another major development by the start of the 21^{st} century was the inauguration of the European Food Safety Authority (EFSA) for independent scientific advice, and that of the Rapid Alert System for Food and Feed (RASFF) for centralised reporting of food safety issues of relevance to other European community members (European Commission, 2023, IFT, 2022, Jukes, 2023, Weinroth et al., 2018).

The fact that food safety events are recorded, make them also amenable to retrospective analysis with the aim of learning lessons from the past for future food safety management [*e.g.*, (Warmate and Onarinde, 2023)]. Several studies have already been undertaken for this purpose and we wanted to extend this to the current topics within HOLiFOOD through the analysis of past incidents to find commonalities in the causes and drivers underlying them. This will help us understand how these risks can be prevented from occurring, and which prevention and mitigation measures can be put in place.

3.2 Driver identification within HOLiFOOD Task 5.2

Taking into consideration the described factors above, task 5.2 focused on assessing existing and emerging food safety risks linked to changes in the food supply chain associated with the European “Green Deal” and related to climate change. The project takes three supply chains under consideration, namely; lentils (legumes), maize (cereals), and chicken (poultry). To achieve this task, two sub-tasks were performed. The first sub-task focused on performing a holistic assessment of earlier food crises, further referred to as the retrospective research. This research provided lessons learned from the past, mainly on the causes and drivers of these past incidents, which can provide input for development oftools for emerging risk identification. The second task took a prospective approach and used a literature study to assess the effects of changes caused by the Green Deal and climate change on emerging food safety risks. This task is further referred to as the prospective research. Both strands of research resulted in a list of drivers that are likely to drive the emergence of safety hazards in the food supply related to the Green Deal and climate change in the near future. These drivers have been ranked according to their priority by invited experts. This output will be used in the next step within the HOLiFOOD project (in particular Work Package 1) in the development of models for early detection of emerging food safety risks.

4 Methods

4.1 Retrospective research

For the retrospective search of food crises, first, a query was developed for a Google's advanced search to analyse grey literature sources. Google was chosen as often information related to food safety crises is not easily gathered from academic literature databases, as well as the ability to use Google's search functions such as for specific file types or searching within URLs. The query is listed below, containing several concepts on the product groups, emerging risks, and crises, as well as an operator for the filetype .pdf for documents such as reports and papers.

The query, as listed below consists of 4 short concepts, which are as follows:

<u>Product categories:</u>
(cereal* OR poultry OR pulse*)

<u>Impact on food safety:</u>
("emerging risk" OR "food contamination" OR "food hazard" OR "food safety" OR "food-borne zoonosis")

<u>General food/feed terms:</u>
(feed OR food OR health)

<u>Food crises or incidents:</u>
(crises OR crisis OR disease OR incident OR outbreak OR zoonosis)

Google advanced search query:
(cereal* OR poultry OR pulse*) ("emerging risk" OR "food contamination" OR "food hazard" OR "food safety" OR "food-borne zoonosis") (feed OR food OR health) (crises OR crisis OR disease OR incident OR outbreak OR zoonosis) filetype:pdf

This Google search yielded 62 results, which were screened for their relevance and used for data extraction. Further results were gathered using "snowballing", where additional relevant sources were taken from references in the Google search results.

The combined Google advanced search and snowballing results yielded in total 128 results. Data were extracted from these search results, such as; 1) year of the crisis, 2) causative agent, 3) affected food products, 4) country or region where the crisis took place, 5) if it involved food products consisting of or containing cereals, poultry, or pulses, and 6) the type of crisis (*e.g.*, contamination of foods, food adulteration, intentional poisoning, or other causes). Results were further analysed to evaluate if any trends existed that the different crises have in common and to establish drivers of emerging food risks. Extracted data and results were documented in Microsoft Excel.

4.2 Prospective research

A prospective literature search has been performed to assess the possible effects of changes by the European Green Deal and climate change on emerging food safety risks. For this prospective search, a search query for Scopus was synthesised using different concepts embedded in the aim of the search. These included the following keywords: green deal, climate change and the impact on food safety. Synonyms were added and various trial queries were entered in Scopus. The final concepts were as follows:

<u>Green deal or climate change:</u>
"Green deal" OR (farm W/1 fork) OR (fit W/1 55) OR (europe* W/2 policy) OR "global warming" OR ((effect OR result OR impact OR chang*) W/1 climate))

<u>Impact on food safety:</u>
((food OR feed) W/1 safe*) W/5 impact OR result OR prediction OR influenc* OR impl* OR risk OR hazard

This resulted in the <u>final query:</u>
TITLE-ABS-KEY("Green deal" OR (farm W/1 fork) OR (fit W/1 55) OR (europe* W/2 policy) OR "global warming" OR ((effect OR result OR impact OR chang*) W/1 climate)) AND TITLE-ABS-KEY(((food OR feed) W/1 safe*) W/5 impact OR result OR prediction OR influenc* OR impl* OR risk OR hazard)

This query resulted in a total of 270 hits in Scopus. All hits were judged on relevancy. Exclusion criteria included, amongst others: books, articles not available in English, symposium summaries, and articles that included the concept “farm to fork” but were not specifically related to green deal policy or climate change. Ultimately, this resulted in 52 relevant articles and 218 articles judged as not relevant.

The 52 relevant articles were downloaded. Information from the retrieved papers was extracted and summarised in Excel. General relevant parameters included the food matrix, product category, hazard (group), the topic of the article (green deal or climate change), and the country or region under investigation. For each article a summary was written down concerning: the risks described, the causes (drivers), the effects, and indicators. The indicators were either specifically mentioned in the article or derived from the information in the article. If an article was about modelling, the data sources used, and the applied model were also noted. Finally, to provide an overview and the relations between drivers and hazards, a flow scheme was made in Microsoft Visio.

4.3 Delphi

A miniaturised version of the Delphi survey method was used in order to gauge a group of experts on the relative importance they attached to pre-defined drivers of the emergence of food risks. Mini-Delphis can take two or three rounds of questioning and interim summarizing. This kind of survey requires less resources than full-fledged ones yet can provide more reliable information than single-round surveys (Uncertainty Project, 2023). One of the main reasons for choosing this format for the current research was to avoid repetitiveness with other surveys carried out within the HOLiFOOD project with similar groups of stakeholders (*e.g.,* potentially causing respondents' fatigue) and the limited time window.

4.3.1 Background

Delphi is a method originally developed by the RAND company in the early 50s of the last century. It aims to obtain group-based consensus on topics for which empirical evidence is still lacking and has been used particularly much in medical sciences (2/3rd of the publications) and to a lesser but still substantive part in life science & technology, and in social science. The process is aimed at reaching group consensus. Particular features of the process are anonymity of the participants (avoiding group dynamics), iterative rounds of questioning the participants, gathering additional participant feedback, and statistical processing of the response. Participants can be asked, for example, to express their agreement or disagreement with postulates, such as commonly done within a traditional Delphi. In the follow-up rounds, participants will be presented the overall outcome (anonymised) and asked if they want to change their own answers and comment on the joint outcome. After a given number of rounds have been executed or consensus has been reached, the Delphi can then be completed and its outcome presented (Khodyakov, 2023).

There are many variants to this process with regards to the goals of the survey, the questions, posed, and homogeneity of participants invited. The various types of Delphi surveys include, for example (Paré et al., 2013):

- The aforementioned “traditional Delphi”, which is a fact-finding exercise aiming to spot the areas of consensus amongst a large group of unbiased experts who respond by indicating their agreement or disagreement with postulates.
- The “policy Delphi”, which engages a broad range of participants representing different stakeholder groups so as to analyse and describe the different views they hold regarding the possible effects of policy changes and how they rate the relevance and impact of these effects.
- The “decision Delphi”, in which groups with a high participation by decision makers discuss how a certain decision can be implemented.
- The “ranking-type” Delphi, in which a limited number of experts brainstorm, select, and rank issues with the aim of guiding agendas for business actions or research.

4.3.2 Methodology followed for this study

The Delphi method followed is a variant to the ranking-type Delphi. The results of the retrospective and prospective research served as input for this Delphi. After collecting the drivers, a selection of 14 drivers in total was made and categorised, as shown in Table 1. These were used as input for the miniaturised Delphi survey. In this survey, important drivers were selected based on expert feedback, after consultation with international food safety experts residing in Europe.

Table 1 Drivers selected from retrospective and prospective research as input for the Delphi study.

Economic incentives	Environmental and climate change related	Societal, Green Deal and circular economy related drivers
Opportunity for financial gain by using cheaper / illegal / undeclared / unknown ingredients (replace added value ingredients)	Biomass & waste incineration causing contaminant deposition in primary production areas	Change to plant-based diets (which can result in enhanced exposure to various contaminants)
Use of cheaper, lower quality ingredients because current ingredients are too expensive	Higher temperature and rainfall	Circular use of side-streams (which can result in accumulation of contaminants/hazards)
Opportunity to maintain high yield, by use of banned pesticides / veterinary drugs	More frequent extreme weather events & natural disasters leading to e.g. spread of contaminants (*e.g.* dioxins)	Reduced pesticide use (which can lead to increased contamination of harvest with weed seeds (*e.g.* alkaloids), as well as use of alternatives to pesticides without record of safe use)
Illegal / dubious practices (*e.g.* drug dumping)	Higher sea temperature and agricultural run-off (leading to e.g. harmful algal blooms, producing natural toxins)	Shift from synthetic to natural fertilizers (*e.g.* composted bio-waste) (which can increase exposure to (zoonotic) pathogens or contaminants if not properly composted)
Improper food handling / processing	Geographical shifting favourable conditions for pests and zoonotic vectors	

Experts as subjects for this mini-Delphi were recruited from three different groups:

- Internal food safety experts within Wageningen Research
- Food safety experts within the HOLiFOOD consortium
- Experts in the area of Emerging food safety risks (with residence in Europe) attending an FAO expert workshop on emerging risks related to new developments (technological, societal) within food systems

Prospective participants received an invitation via email with statements regarding their rights under GDPR as well as an attached Excel file containing the 14 selected drivers. Experts were asked to divide 100 points over these drivers, by assigning more points for drivers they deem important. After receiving the results from the experts, the drivers were ranked based on the assigned points. The mean ranking with standard deviation was then sent out to the same group of experts, asking if they agree to this ranking of drivers and if they would like to redistribute points if they do not agree. The goal was to observe a reduction in standard deviation of the assigned points to the drivers, hereby approaching consensus between the experts.

5 Results

5.1 Retrospective research

A retrospective analysis was conducted by searching grey literature, using Google's advanced search, for past food crises. A total of 128 different food crises were reported (Annex A, Table A1), consisting of incidents concerning food products contaminated with microbial or chemical hazards, cases of food adulteration, as well as intentional food poisoning, as well as various incidents beyond these categories. Of the 128 food crises, 44 cases concerned food products consisting of or containing cereals, poultry, or pulses (Annex A, Table A1).

The majority of these 44 cases concerned products consisting of or containing cereals (26/44 cases), with the main causes of the crises being toxins of fungal (11/26) or plant (5/26) origin. For instance, mycotoxins originating from *Claviceps purpurea* (ergot), *Aspergillus flavus* or *Fusarium sp.* were frequently found to be causative agents of food poisoning. These contaminations were often associated with weather events, such as harvesting during heavy rainfall, but also improper storage conditions. Plant toxins often found their way into cereal products when seeds of toxic weeds, such as *Datura sp.*, were accidentally co-harvested with the grains.

Thirteen of the identified cases concerned food crises related to contaminated poultry products, with the majority of causative agents being chemicals (9/13), such as dioxins, polychlorinated biphenyls (PCBs), and banned veterinary drugs (*e.g.*, fipronil and nitrofuran).

In 5 instances, products consisting of or containing pulses were identified to be associated with a food crisis. One such a crisis concerned microbial contamination of pulse products (*e.g.*, beansprouts contaminated with *E. coli* O104:H4). Another crisis was linked to products containing high levels of iodine (*e.g.*, soy milk blended with high iodine containing seaweeds for flavour). Consumption of large amounts of grasspeas causing lathyrism, a neurological disorder, also caused a food crisis.

A further analysis was performed to determine if trends can be elucidated between different food crises and to identify drivers of these crises (Table 2). In particular, cases related to contamination (*e.g.*, with chemical or microbial agents) and food adulteration were investigated in this manner. as intentional food poisoning cases are difficult to categorise further due to their personal nature.

For both food adulteration and contamination, trends have been identified where there exists an economic driver. For instance, increasing the value of a food product in case of food adulteration can entail the modification of organoleptic properties, such as using minerals and dyes to influence the colour, enhancement of flavour, or dilution of the product. Additionally, these actions can be hidden, for example in the case of dilution of milk (a scandal in 2008 in China), where melamine was added to make it appear that the milk still had a higher protein content, in order to pass quality control tests based on nitrogen content determination (*i.e.,* unable to identify melamine as the source of nitrogen).

Table 2 Identified drivers and trends in retrospective research of food crises.

Crisis Type	Drivers	Trends
Food adulteration	Economic	Value increase (*e.g.*, appearance, flavor enhancement, dilution of product)
		Cheaper ingredients and hiding of its use
		Use of illegal growth stimulants (*e.g.*, clenbuterol)
		Substitution of product with inferior options (*e.g.*, inferior meats)
		Accidental use of toxic compounds when committing food fraud
Contamination	Economic	Cheaper alternatives to lower costs during food processing
		Use of (banned) antibiotics for livestock, subsequent transfer to food product
		Use of (banned) pesticides
		Accidental use of impure industrial grade food components during processing
	Environmental	Contamination of harvested product with pesticides
		Presence of toxic weeds in harvested crops
		Spread of toxicants into the environment due to illegal practices, or accidents
		Transmission of pathogens to food products (*e.g.*, from manure fertilizer, or during processing)
		Fungal growth due to weather events, or improper storage
	Incidents	Improper food handling
		Contamination of river water used for irrigation or fishing (*e.g.*, with heavy metals from mining waste)
		Contamination of feed with dioxins from waste incineration, or use of contaminated additives

Other identified drivers were environmental effects leading to food contamination, such as accidental presence of pesticides, toxic weeds, and pathogenic microbes, associated with agricultural practices. Environmental factors also include the transfer of toxic compounds due to illegal practices such as waste burning and dumping, leading to contamination with toxicants such as dioxins. Another example of such environmental factors is the presence of mycotoxins in foods due to climatological conditions and improper food storage, leading to fungal growth and toxin formation.

The final identified driver was named “incidents”, this group contains examples of improper food handling, as well as contaminated drivers used as source of irrigation water and for fishing, and contaminated feed due to precipitation of pollutants from the flue of waste incineration facilities onto agricultural land or to the use of contaminated feed additives. The latter two examples concerned the presence of dioxins in feed, which could be traced back to waste incineration near a farm in one instance, and in another to the use of clay in animal feed as an additive, where the clay was shown to contain dioxins.

5.2 Prospective research

A prospective search was conducted aiming to find drivers for emergence of food safety risks, as related to climate change and the European Green Deal. The query, with 270 hits in Scopus, resulted in 52 relevant articles. All relevant information was extracted and summarised in Excel. This information includes a general summary of the article on general relevant information, drivers for climate change and/or the European Green Deal and indicators (either extracted from the article or identified by the writers of this report). An overview of all drivers with corresponding indicators and effects of these drivers of change can be found in Table 3.

Table 3 Overview of drivers, corresponding effects and indicators retrieved from literature.

Drivers	Indicators	Effects

Elevated temperatures
 	
Related drivers:
• Increased seawater temperature
• Increase of cyanobacterial blooms
• Spread and increase in pest populations
• Volatilization of pesticides
• Increase in pesticide use
• Increased bioaccumulation of heavy metals in rice and the aquatic chain
• Accelerated permafrost thawing
• Thawing of ice caps
• Heat stress in livestock
• Changes in timing or length of seasons
• Milder winters
• Increase of number of extreme weather events
• Increased intensity of hurricanes
	Related to elevated temperatures:
	• Average temperature
	• Average temperature over flowering period
	• Daily (between days) change in temperature over harvest period
	• Higher average temperature
	• Mean maximum monthly temperature
	• Mean minimum monthly temperature
	• Minimum temperature
	• Maximum temperature
	• Number of days in month with maximum temperature ≥ 32 °C
	• Number of days in month with maximum temperature ≤ 0 °C
	• Number of days in month with minimum temperature ≤ 0 °C
	
	Related to increased seawater temperature:
	• Seawater temperature
	• Seawater temperature variability
	
	Other relevant indicators:
	• Soil evaporation
	• Potential evaporation from a moist bare soil surface – monthly average
	• Water evaporation
	• Potential evaporation from a free water surface – monthly average
	• Plant transpiration
		Elevated temperatures can lead to:
		• Affected handling and processing of food at end of the product supply chain, increasing the risk of consuming contaminated food (Anas et al., 2021, EFSA, 2020)
		•
		• Reduced chilled storage life (2-3 °C rise reduces chilled storage life by half) leading to increased food spoilage and poisoning (Duchenne-Moutien and Neetoo, 2021)
		• Increased Salmonellosis cases (5-10% increase for every one degree Celsius rise in temperature per week when ambient temperatures exceed 5 °C) (Anas et al., 2021)
		• Potential spread and increase in pest populations, *e.g.* the European corn borer (Chhaya et al., 2022)
		  ○ Increased pest attack on *e.g.* cereals, potentially leading to increases in fungal contamination and increased mycotoxin production levels (Chhaya et al., 2022)
		  ○ Outbreaks of a wider variety of insects and pathogens will result in an increased pesticide use and changes in their application timings (Kasuga, 2022)
		• In combination with rising carbon dioxide levels and direct sunlight exposure, a dilution and increased volatilization of pesticides and fungicides can occur, lowering the concentration and thus reducing their efficiency against pests and pathogens (Duchenne-Moutien and Neetoo, 2021)
		  ○ Volatilization of pesticides can lead to their deposition in remote areas such as the Arctic, where thawing permafrost releases them back into the environment, and possibly into the food chain (Guerin, 2022)
		• Proliferation of animal diseases (Kasuga, 2022)
		  ○ Increased use of veterinary drugs
		    ▪ Possibly leading to an increased release in the environment
		    ▪ Increased residue levels of veterinary drugs in foods of animal origin pose an increased concern of antimicrobial resistance
		• Expansion of Datura plant (Fusco et al., 2020)
		  ○ Carryover of tropane alkaloids in *e.g.* feed
		• Rise in prevalence of antimicrobial resistance (Duchenne-Moutien and Neetoo, 2021)
		• Increased bioaccumulation of arsenic from soil by rice (Duchenne-Moutien and Neetoo, 2021)
		• Decrease in grain yield (temperature rise of 2-3 °C can result in about 20-25% decrease in grain yield) (Nji et al., 2022)
		• Translocation of Escherichia coli towards the leaf and tightly bind to the leaf, disabling the possibility to wash E. coli away (Samut et al., 2023)
		
		Increased seawater temperature can lead to:
		• More frequent occurrence of cyanobacterial blooms (Anas et al., 2021, Tirado et al., 2010)
		• Emergence and proliferation of *Vibrio parahaemolyticus* (Kniel and Spanninger, 2017)
		
		Milder winters can lead to:
		• Increased survivability of a range of Campylobacter vectors, including common houseflies (Duchenne-Moutien and Neetoo, 2021)

Drivers	Indicators	Effects

	• Potential evapotranspiration from a crop canopy – monthly average
	• Changes in timing or length of seasons
		Increased intensity of hurricanes can lead to:
		• Increased coral mortality (Duchenne et al., 2021)
		  ○ New platform unto which *Gambierdiscus toxicus* can grow and colonize
		
		Accelerated permafrost thawing can lead to:
		• Release of trapped inventories of *e.g.* heavy metals into fresh-water systems (Guerin, 2022)
		  ○ Methylation of mercury can result in bioaccumulation of methylmercury in the aquatic food chain
		  ○ The uptake of methylmercury by fish and mammals has been found to increase by 3-5% for each degree Celsius rise in water temperature (Herrera et al., 2016)
		
		Heat stress in livestock can lead to:
		• Higher vulnerability to diseases (Herrera et al., 2016)

Increased greenhouse gas levels	• CO_2 levels • CH_4 levels • NO/N_2O levels • O_3 levels	**Increased greenhouse gas levels can lead to:** • Increased atmospheric temperature (Duchenne-Moutien and Neetoo, 2021) **Increased CO_2 levels can lead to:** • Increased polycyclic aromatic hydrocarbon (PAH) levels in soil (Ai et al., 2018) ○ Has been linked to a shift in soil microbial community structure and function • Changed plant susceptibility to fungal attacks (Chhaya et al., 2022) • Ocean acidification (Miraglia et al., 2009)
Changes related to the ocean These could include: • Increased ocean acidity • Changed ocean salinity • Sea level rise	• Ocean acidity • Ocean salinity • Sea level rise	**Ocean acidification can lead to:** • Proliferation of Vibrio spp. (Duchenne et al., 2021) ○ The selection of strains that can survive in an acidic medium is enabled

Changes in rainfall
Related drivers:
• Increase in number of floods
• Increase in number of droughts
• Changes in patterns of rainfall
• Heavy precipitation
• Changes in lengths of seasons
	• Aridity index
	• Humidity
	• Average humidity over flowering period
	• Changes in intensity of precipitation
	• Increased precipitation
	• Minimum rainfall
	• Maximum rainfall
	• Relative humidity
	• Total precipitation
	• Total month precipitation
	• Precipitation span
	• Precipitation intensity
		Flooding can lead to:
		• Increased incidence and transfer of waterborne diseases (Duchenne-Moutien and Neetoo, 2021)
		• Increased mold contamination in damaged silos (Chhaya et al., 2022)
		  ○ Increased risk on mycotoxins
		• Accumulation of untreated human sewage (Duchenne et al., 2021)
		  ○ Increased risk of enteric virus contamination in fresh produce and molluscan shellfish
		• Water contaminated with bacterial pathogens from animal feeding operations entering the sea (Duchenne et al., 2021)
		  ○ Increased risk of foodborne diseases from seafood
		• Contamination of irrigation water with antibiotic-resistant bacteria or antibiotic residues (Duchenne-Moutien and Neetoo, 2021)
		• Wet paper labels on canned food, possibly harboring dangerous bacteria and molds (Duchenne-Moutien and Neetoo, 2021)
		  ○ Can result in foodborne disease outbreaks
		
		Droughts can lead to:

Drivers	Indicators	Effects

	• Changes in rainfall patterns
	• Days of precipitation with precipitation ≥ 0.1 inch
	• Days of precipitation with precipitation ≥ 1 inch
	• Days of precipitation with precipitation ≥ 0.5 inch
		• Increased incidence and transfer of waterborne diseases (Anas et al., 2021)
		
		Unusual patterns of rainfall can lead to:
		• Contamination of irrigation wells by manure run-offs from nearby farms of livestock animals (Duchenne et al., 2021)
		
		Heavy precipitation can lead to:
		• Increased levels of bacteria in the air in agricultural fields (Duchenne et al., 2021)
		• Leaching of herbicides into groundwater or runoff (Duchenne-Moutien and Neetoo, 2021)
		  ○ Herbicides become too diluted to exert any effects
		  ○ Herbicides being present in water bodies
		• Overwhelmed water-filtration plants (Kniel and Spanninger, 2017)
		  ○ Increased risk of human exposure to waterborne pathogens through direct exposure to water or through consumption of contaminated seafood
		
		Changes in lengths of seasons can lead to:
		• Affected crop phenology and changing crop planting seasons (Chhaya et al., 2022)

Changes related to water flow These could include: • Overflowing of sewages • Changes in groundwater levels • Changes in drinking water distribution systems	• Study of changes in water flow, sewage, surface and groundwater supplies • Distribution of drinking water • Levels of organics in rivers and coastal waters • Sediment, nutrients, dissolved organic carbon, pathogens, pesticides, toxic metals and salts in water • Groundwater level	**Limited water supply can lead to:** • Reuse of wastewater (Kniel and Spanninger, 2017) ○ Has the potential to introduce pathogens into the environment
Increased number of climatic events	• Number of climatic events such as droughts and heatwaves	
Change in biodiversity	• Biodiversity, *e.g.* focused on local insects • Number of houseflies (vector of Campylobacter) • Presence of nonnative species	
Globalization	• Import and export routes	**Globalization can lead to:** • Accelerated spread of dangerous pathogens and contaminants in food (Cheftel, 2011)

Drivers	Indicators	Effects
Changing farm practices	• The use of agrichemicals • Yearly plant growth regulators use • Yearly pesticides use • Yearly herbicides use • Yearly insecticides use • Yearly fungicides use • Yearly rodenticides use	**Changing farm practices can lead to:** • A move towards high intensity farming could increase the reliance upon feed concentrate and hence potential amounts of mycotoxins consumed, as well as carry-over of mycotoxins into the animal products (Kniel and Spanninger, 2017) • Changes in crop types, cultivation methods, farming environment and in atmospheric transport may lead to an increased use of dichlorodiphenyltrichloroethane (DDT) due to an increased need for malaria control (Kasuga, 2022)
Overuse of nitrogen in fertilizer	• Nitrogen levels in soil	**The overuse of nitrogen in fertilizer can lead to:** • Emissions of NO_x and ammonia and compromised air quality (Qiu et al., 2021) ○ Elevated concentrations of NOx in the air can cause or aggravate respiratory health problems • Decreased water quality when these compounds leak into groundwater and surface water, causing formation of poisonous nitrates and eutrophication in lakes and rivers (Qiu et al., 2021) • Reduced soil quality when nitrate surpluses lead to accelerated acidification or when surpluses of phosphate and nitrate interact negatively with micronutrients (Qiu et al., 2021)
Increased life expectancy and proportion of elderly people	• Life expectancy • Proportion of elderly people to population	**Increased life expectancy and proportion of elderly people can lead to:** • Higher vulnerability to foodborne diseases (Cheftel, 2011)
Changes in food composition motivated by consumer health Related drivers: • Demand for fresh and less processed food • Demand for organic food • Demand for less chemicals in food • Reduction of sodium in food	• Social media complaints about *e.g.* food poisoning	**Changes in food composition motivated by consumer health can lead to:** • Food containing less salt, sugar or anti-microbial agents, which may enhance microbial growth (Cheftel, 2011) • Increased presence and illnesses caused by pathogens such as *Listeria monocytogenes*, *Campylobacter* spp., and *Salmonella* spp. in food (Rivera et al., 2018)
Circular economy: reintroduction of side-streams in food production		

Most articles focused on food safety in relation to climate change and very few articles were found regarding the European Green Deal and its effects on food safety. Several literature reviews provided an excellent overview of the different effects of climate change on food safety. One of the most discussed subjects was the increased occurrence and spread of mycotoxins, followed by the spread and persistence of foodborne and waterborne diseases. Two main overarching drivers are increased temperatures and changes in rainfall, as is also visible in the flow scheme in appendix B.

Several other drivers and effects are more indirectly related to those two main drivers. For instance, changes in rainfall, and in particular more heavy rainfall in short time periods, can subsequently cause flooding, possibly resulting in the contamination of irrigation water, which could result in antimicrobial resistance due to the transfer of *e.g.* antibiotic-resistant bacteria or antibiotic residues (see Figure B1 in Annex B). Elevated temperatures could lead to volatilisation of pesticides, subsequently leading to a reduced efficiency of pesticides and fungicides, which could lead to an increase in pesticide use, dose and frequency (depicted visually in Figure B1 in Annex B). In other words, these are dependent variables resulting in a high degree of complexity. As such, besides summarising in Table 2, an attempt was made to visualise this complexity in the flow scheme.

5.3 Delphi

A total of 14 potential drivers of change were shared with experts (Table 1) to gauge which of these they deem most impactful for the emergence of food safety risks. After the first round of ranking these 14 drivers, the overall score was calculated by averaging all awarded points for each driver (Table 4). The most important drivers after round one according to the experts are climatological drivers, such as higher temperatures and rainfall and geographical shifting of favorable climatological conditions, as well as the circular use of side streams.

This overall ranking was shared with the experts with the question if they agree with this score and experts were given the opportunity to redistribute assigned points. Of the participants 12 out of 14 participants responded in round two of the survey. Of these twelve participants, four participants agreed with the overall ranking from round one, six participants made minor adjustments to the ranking but largely agreed with it, and two did not agree and preferred their original scoring or made significant changes. The final overall ranking (Table 4) is largely similar to the round one scores, albeit with reduced standard errors. This reduction in standard error is indicative of convergence towards consensus among respondents on the assigned ranking. As with round one, particularly climatological/geological drivers are deemed to have an important potential impact on food safety. Based on the results from both rounds of the survey, the three most impactful drivers related to climate change and the green deal, according to the consulted experts, are: 1) higher temperature and rainfall, 2) geographical shifting of favourable conditions for pests and zoonotic vectors, and 3) circular use of side-streams.

Table 4 Ranking of most impactful drivers for food safety, based on expert opinions. The average and standard deviation of the assigned points is shown.

Driver	Ranking Round 1 (N=14)	Ranking Round 2 (N=12)
Higher temperature and rainfall favoring fungal growth, mycotoxin production	17.2 (±7.8)	16.3 (±3.2)
Geographical shifting favorable conditions for pests and zoonotic vectors	11.9 (±7.1)	11.4 (±1.2)
Circular use of side-streams can result in accumulation of contaminants/hazards	11.4 (±8.7)	10.1 (±2.8)
Higher sea temperature and agricultural run-off leading to harmful algal blooms, producing natural toxins	9.7 (±6.8)	9.5 (±2.2)
Opportunity for financial gain by using cheaper/illegal/undeclared/unknown ingredients (replace added value ingredients)	6.8 (±8.3)	8.0 (±3.1)
Reduced pesticide use can lead to increased contamination of harvest with weed seeds (e.g. alkaloids), as well as use of alternatives to pesticides without record of safe use	7.4 (±6.5)	7.7 (±1.4)
Shift from synthetic to natural fertilizers (e.g. composted bio-waste) can increase exposure to (zoonotic) pathogens or contaminants if not properly composted	6.7 (±6.8)	7.2 (±1.3)
More frequent extreme weather events & natural disasters leading to spread of contaminants (e.g. dioxins)	7.0 (±7.1)	7.0 (±1.4)
Use of cheaper, lower quality ingredients because current ingredients are too expensive	5.8 (±5.4)	6.0 (±1.2)
Improper food handling/processing	5.3 (±6.6)	5.4 (±3.5)
Opportunity to maintain high yield, by use of banned pesticides/veterinary drugs	4.1 (±4.5)	4.6 (±2.6)
Illegal /dubious practices (e.g. drug dumping)	2.1 (±3.1)	2.8 (±1.6)
Change to plant-based diets can result in enhanced exposure to various contaminants	2.7 (±3.8)	2.4 (±0.8)
Biomass & waste incineration causing contaminant deposition in primary production areas	2.0 (±3.1)	1.6 (±1.4)

6 Discussion

Two different strands of retro- and prospective data and information mining research have been performed within WP5 of the HOLiFOOD project, with the aim of identifying drivers – related to climate change and the Green Deal - that are likely to drive the emergence of risks to food safety in the near future. In particular, the prospective search took stock of changes brought about by climate change and/or green environmental policies (*e.g.,* rising sea water temperatures). This is all in the context of the influential sectors within and surrounding the food system, and how these would ultimately impact the food production chain and, particularly, the emergence of food safety risks. In addition, a retrospective study was carried out, exploring what underlying causes influenced the occurrence of food safety incidents in the past. Multiple incidents can have a similar underlying cause. Consequently, commonalities could be drawn from the cases as drivers of these events.

A number of conspicuous observations have been made. In a number of cases, climate-change-related hazards and drivers identified in the prospective analysis had an impact on both chemical and biological hazards, and on plant and animal production. For example, migration of pests and zoonotic diseases (including those transmitted by vectors) could eventually lead to more pesticides being used in crops to ward off these pests (counteracting the Green Deal goal of reducing riskfull pesticides usage). This would result in higher likelihood of residue formation of pesticides, and to disease pressure of zoonotic agents leading to the use of veterinary drugs (giving rise to residues) in livestock animals. The hazards and drivers thus identified largely overlapped with those featuring in reports of FAO and WHO on the impact of climate change on food safety (FAO, 2020, WHO, 2018), as well as a literature study carried out by (EFSA, 2020).

Within the retrospective analysis, the observed hazards were of a widely varying nature (chemical contaminants, pathogens). A distinction could be made between the hazards that were introduced purposefully (*i.e.,* adulteration) and unwantedly (contamination). A common feature of such events are the financial/economic factors underlying the use of cheaper sources of lower-quality or even toxic food ingredients to replace more expensive ones. This could be for fraudulent reasons where the motive is to make financial gains or in good faith where the aim is to keep the product affordable for buyers.

The selection of 14 drivers and their subsequent prioritisation by experts through the Mini-Delphi showed that experts' agreed that climate- and geography-related drivers are of importance, accounting for 3 out of the 4 best scoring ones, including:

- Changed climatic conditions that might give rise to mycotoxin formation,
- Changing conditions favoring the migration of zoonotic diseases and plant pests towards different geographies,
- Higher sea water temperatures and runoff from land ultimately resulting in the proliferation of harmful algal blooms producing toxins

The remaining driver amongst the four highest-scoring drivers included:

- The sourcing of feed materials from side streams of "circular" processes, which may lead to accumulation of contaminants

Also, drivers related to the replacement, either fraudulously or for economic reasons, of valuable food and feed ingredients with cheaper, potentially hazardous counterparts, scored relatively well.

The selected drivers will be used by developers of the emerging risk identification tools within HOLiFOOD (WP1) as the starting point to identify one or more indicators per driver, as well as relevant datasources for each indicator. In consecutive research, the prioritised drivers will be evaluated first, for indicators and datasources, followed by the lower prioritised drivers. In the end, not only the priority of the driver but also the availability of measurable indicators with high quality datasources is relevant for the continuation of the HOLiFOOD project.

7 Conclusions and recommendations

The prospective and retrospective analyses have drawn on data from the scientific and grey literature, respectively. A number of drivers were thus selected and further prioritised. These drivers are considered to potentially lead to emergence of chemical and biological food safety hazards in the near future under the influence of climate change and/or green policies, or for economic reasons. The top-ranking drivers included: higher temperature and rainfall; the sourcing of "circular" ingredients for animal feed production; shifts in the geographical spread of plant pests and zoonotic pathogens, and; circular use of feed ingredients. The highest-ranking driver(s) received high scores from all experts surveyed in the Mini-Delphi. In particular, rising temperatures and rainfall potentially giving impetus to mycotoxins, stood out as the highest-scoring driver. This is not surprising as these phenomena are also discussed in many other expert fora and scientific literature, as well as the occurrence of recent incidents. As regards subcategories, drivers related to climate change scored particularly well. This information should help partners from HOLiFOOD to develop emerging risk identification tools and to implement these tools with the purpose of safeguarding society against the emergence of any risks instigated by these drivers if this were to happen.

Contrary to the impact of climate change and economics on food safety, the literature search indicated that there is still a scarcity of literature on the interrelationship between green environmental policies and food safety. The consulted experts' feedback indicates, though, that policies towards, *e.g.,* greater circularity and changed pest management are seen as potentially giving rise to food safety issues in future. This would therefore appear to be worthy of further investigation.

Recommendations

- For HOLiFOOD WP1 partners, to employ the drivers selected and prioritised in this study, and to explore which corresponding indicators can be accommodated into the emerging risk identification tools that they develop.
- For research policy in general, to promote research into the relationship between green environmental policies and the food safety issues that may arise from them, but also the interrelationship and effects between climate change and green environmental policies.

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10 Annex A: Retrospective research results

A retrospective research study was performed to generate an inventory of food crises, using Google's advanced search. The responsible causative agents, and other characteristics such as year of the crisis, and food products concerned were gathered. These crises are listed in Table A1, which contains all these gathered characteristics as well as the source URL.

Table A1 Retrospective research grey literature results

Year	Crisis	Country/region	Cause	Food product	Source of contaminant	Category	Source- URL
Middle ages	Grain infected with ergot fungi	Europe	Ergot	Flour	Contamination of flour with fungi	Contamination	https://pubmed.ncbi.nlm.nih.gov/7641960/#:~:text=Epidemics%20of%20ergotism%20occurred%20frequently,with%20the%20fungus%20claviceps%20purpurea.
1850s	Swill milk scandal in New York	New York	Other	Milk	Food adulteration	Adulteration	https://en.wikipedia.org/wiki/Swill_milk_scandal
1857	Adulteration of bread with alum in London, causing rickets	London	Alum	Bread	Food adulteration of bread	Adulteration	https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=fba0144153562c647308e88e44643d1339ce9e08
1857	Esing Bakery incident: poisoning of bread with arsenic in Hong Kong	Hong Kong	Arsenic	Bread	Inconclusive (intentional poisoning or accidental)	Inconclusive	https://openaccess.city.ac.uk/id/eprint/14522/1/Caution!%20Revised%20article%20for%20JICH,%20August%202014.pdf
1858	Sweets poisoned with arsenic in Bradford, England	Bradford, UK	Arsenic	Peppermint candy	Food adulteration (accidental use of arsenic trioxide instead of powdered gypsum (daff) as substitute for sugar)	Adulteration	https://en.wikipedia.org/wiki/1858_Bradford_sweets_poisoning
1888	Contaminated wine in France	France	Arsenic	Wine	Contaminated wine	Contamination	https://onlinelibrary.wiley.com/doi/full/10.1111/j.1757-837X.2012.00129.x
1900	1900 English beer poisoning	England	Arsenic	Beer	Lowering of costs, use of invert sugar contaminated with arsenic.	Contamination	https://en.wikipedia.org/wiki/1900_English_beer_poisoning
1900s-49	Neurological disorders due to bread flour bleached with agene	UK	MSO	Flour	Flour bleaching using agene	Adulteration	https://www.sciencedirect.com/science/article/pii/S0306987798900676
1910-45	Cadmium from mining waste contaminated rice irrigation water in Japan	Japan	Heavy metals	Rice	Irrigation of rice fields with contaminated river water	Contamination	https://web.archive.org/web/20141006194252/http://www.iwaponline.com/wst/02511/wst025110149.htm
1920	Bread contaminated with naturally occurring pyrrolizidine alkaloids	South Africa	Alkaloids	Bread	Contamination of flour with flower heads and seeds of Senecio spp.	Contamination	https://www.hindawi.com/journals/jt/2010/313280/

Year	Crisis	Country/region	Cause	Food product	Source of contaminant	Category	Source- URL
1924	Contaminated cider in the USA	USA	Arsenic	Cider	Contaminated cider	Contamination	https://onlinelibrary.wiley.com/doi/full/10.1111/j.1757-837X.2012.00129.x
1930s	An epidemic of OPIDN organophosphate poisoning occurred during the 1930s Prohibition Era.	various	TOCP	Medicinal alcohol substitute	Food adulteration	Adulteration	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1037779/
1931-1947	Contaminated wheat in Russia	Russia	Mycotoxins	Wheat	Contaminated over-wintered wheat, with Fusarium	Contamination	https://onlinelibrary.wiley.com/doi/full/10.1111/j.1757-837X.2012.00129.x
1942	Hundreds of prisoners were suffering from lathyrism	Ukraine	Grasspea	Grasspea	Consumption of exclusively grasspea	Other	https://en.wikipedia.org/wiki/Lathyrism
1950s	Mercury poisoning in fish in Japan	Japan	Heavy metals	Fish	Contaminated fish	Contamination	https://link.springer.com/chapter/10.1007/978-81-322-1922-4_25
1951	1951 Pont-Saint-Esprit mass poisoning	France	Ergot	Flour	Contamination of flour with fungi or fungicide	Contamination	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2069953/
1955	Morinaga Milk arsenic poisoning incident	Japan	Arsenic	Milk	Use of low purity disodium phosphate additive containing arsenic	Contamination	https://archive.unu.edu/unupress/unupbooks/uu35ie/uu35ie09.htm
1957	Millions of chickens died after eating dioxin-contaminated feed	USA	Pentachlorophenol	Feed	Contamination of feed containing tallow from treated cow hides	Contamination	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1474955/
1959	Moroccan oil poisoning disaster	Morocco	TCP	Cooking oil	Adulteration of cooking oil withTCP containing oils	Adulteration	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1008817/
1965	Mass poisoning resulting from contamination of flour	Epping, UK	MDA	Flour	Contamination of flour during transport	Contamination	https://www.atsdr.cdc.gov/ToxProfiles/tp122.pdf
1968	Mass poisoning resulting from contaminated rice bran oil	Japan	Dioxins	Rice bran oil	Contamination of rice bran oil during heating with PCBs used as the heating medium	Contamination	https://pubmed.ncbi.nlm.nih.gov/11386736/
1971	1971 Iraq poison grain disaster	Iraq	Heavy metals	Grain	Contamination of grains treated with mercury as a fungicide	Contamination	https://www.nytimes.com/1972/03/09/archives/mercury-poisoning-in-iraq-is-said-to-kill-100-to-400.html

Year	Crisis	Country/region	Cause	Food product	Source of contaminant	Category	Source- URL
1973	Michigan PBB contamination incident	USA	PBB	Feed	Accidental mixing of feed with FireMaster BP-6 flame retardant instead of magnesium oxide feed precursor	Contamination	http://greatlakesecho.org/2010/06/04/poisoning-michigan-an-author-revisits-the-most-widespread-contamination-30-years-later/
1974	Contaminated maize	India	Mycotoxins	Corn	Contaminated corn	Contamination	https://onlinelibrary.wiley.com/doi/full/10.1111/j.1757-837X.2012.00129.x
1974-76	Widespread poisoning in Afghanistan	Afghanistan	Alkaloids	Wheat	Contamination of wheat with charmac (Heliotropium popovii. H Riedl)	Contamination	https://www.hindawi.com/journals/jt/2010/313280/
1975	Contaminated pearl millet	India	Ergot	Pearl Millet	Contaminated pearl millet, with ergot	Contamination	https://onlinelibrary.wiley.com/doi/full/10.1111/j.1757-837X.2012.00129.x
1976	Seveso disaster	Italy	Dioxins	Various	Contamination of a large area with dioxins after a large industrial accident	Contamination	https://ehp.niehs.nih.gov/doi/10.1289/ehp.6573
1978	Contaminated barley	Ethiopia	Ergot	Barley	Contamination of barley with ergot containing oats	Contamination	https://onlinelibrary.wiley.com/doi/full/10.1111/j.1757-837X.2012.00129.x
1978	Adulterated oranges	Netherlands	Heavy metals	Oranges	Adulterated oranges from Israel	Adulteration	https://onlinelibrary.wiley.com/doi/full/10.1111/j.1757-837X.2012.00129.x
1979	Spoiled potatoes	UK	Alkaloids	Potatoes	Spoiled potatoes	Other	https://onlinelibrary.wiley.com/doi/full/10.1111/j.1757-837X.2012.00129.x
1979	Dioxin-contaminated cooking oil	Taiwan	Dioxins	Rice bran oil	Contamination of rice bran oil during manufacture	Contamination	https://doi.org/10.1016/j.envres.2012.09.003
1981	"Spanish toxic oil syndrome" outbreak	Spain	Organophosphate	Tomatoes probably, but also rapeseed oil named	Contaminated salad, probably tomatoe with high levels of pesticide, but official statement blames contaminated rapeseed oil	Contamination	https://www.theguardian.com/education/2001/aug/25/research.highereducation
1983	Spoiled potatoes	Canada	Alkaloids	Potatoes	Spoiled potatoes	Other	https://onlinelibrary.wiley.com/doi/full/10.1111/j.1757-837X.2012.00129.x

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1984	Rajneeshee bioterror attack	USA	Salmonella	Water and salad dressing	Spiked water and salad dressing	Intentional poisoning	https://culteducation.com/group/1108-osho-rajneesh/17627-ore-town-never-recovered-from-scare-.html
1984-85	An outbreak of thyrotoxicosis	USA	Bovine thyroid hormone	Ground beef	Contamination of ground beef with thyroid tissue during the process of "gullet trimming"	Contamination	https://pubmed.ncbi.nlm.nih.gov/3561455/
1985	An outbreak of pesticide food poisoning concerning watermelons	USA	Aldicarb	Watermelons	Contamination of watermelons with Aldicarb pesticide residue	Contamination	https://www.scientificamerican.com/article/toxic-pesticide-banned-after-decades-of-use/
1985	Adulteration of Austrian wines	Austria	Diethylene glycol	Wine	Adulteration of wine with diethylene glycol, to make wines appear sweeter	Adulteration	https://www.latimes.com/archives/la-xpm-1986-04-09-mn-3528-story.html
1985	California listeriosis outbreak in cheese	USA	L. monocytogenes	Cheese	Contaminated Mexican-style cheeses from one particular manufacturer	Contamination	https://www.cdc.gov/mmwr/preview/mmwrhtml/00000562.htm
1986	Adulteration of Italian wines	Italy	Methanol	Wine	Adulteration of cheap wine with methanol	Adulteration	https://www.latimes.com/archives/la-xpm-1986-04-09-mn-3528-story.html
1987	Bread contamination	India	Mycotoxins	Bread	Bread contaminated with mouldy wheat	Contamination	https://onlinelibrary.wiley.com/doi/full/10.1111/j.1757-837X.2012.00129.x
1987	Selling of artificially flavored sugar water as apple juice	USA	Other	Apple juice	Food fraud, sale of articially flavored water as apple juice	Adulteration	https://www.washingtonpost.com/archive/politics/1987/11/14/beech-nut-guilty-in-juice-fraud/aed8287d-6c41-4e09-bb27-dd70a234074a/
1989	Lead in animal feed	UK	Heavy metals	Feed	Animal feed containing lead contaminated rice bran	Contamination	https://onlinelibrary.wiley.com/doi/full/10.1111/j.1757-837X.2012.00129.x
1993	Jack in the Box E. coli outbreak	USA	E. coli	Beef	Contaminated beef products	Contamination	https://www.foodsafetynews.com/2017/12/jack-in-the-box-e-coli-outbreak-25th-anniversary/
1993	Contaminated rice	China	Mycotoxins	Rice	Heavy rainfall during harvest resulted in contaminated rice	Contamination	https://onlinelibrary.wiley.com/doi/full/10.1111/j.1757-837X.2012.00129.x

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1994	Contaminated paprika in Hungary	Hungary	Heavy metals	Ground paprika	Adulterated ground paprika with red lead	Adulteration	https://lead.org.au/lanv3n3/lanv3n3-6.html
1994-95	National outbreak of Salmonella senftenberg associated with infant food	UK	Salmonella	Infant cereal	Contamination of infant food with Salmonella	Contamination	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2809380/pdf/9593480.pdf
1995	Contaminated sorghum and maize	India	Mycotoxins	Corn	Contaminated sorghum and maize	Contamination	https://onlinelibrary.wiley.com/doi/full/10.1111/j.1757-837X.2012.00129.x
1996	Odwalla E. coli outbreak	USA	E. coli	Apple juice	Contaminated unpasteurised apple juice	Contamination	https://www.acpjournals.org/doi/10.7326/0003-4819-130-3-199902020-00005
1996	Japan E. coli O157:H7 outbreak in Osaka	Japan	E. coli	White radish sprouts	Contaminated white radish sprouts	Contamination	https://academic.oup.com/aje/article/150/8/787/101485?login=false
1996	Wishaw, Scotland E. coli outbreak	UK	E. coli	Meat products	Contaminated meat products (stewed steak, puff pastry, roast turkey, baked ham, and cooked meat)	Contamination	https://www.theguardian.com/news/1999/feb/10/food.foodanddrink
1998	Adulteration of curry	Japan	Arsenic	Curry	Alduterated curry	Adulteration	https://onlinelibrary.wiley.com/doi/full/10.1111/j.1757-837X.2012.00129.x
1998	Meat and milk were found with elevated dioxin concentrations	Germany and the Netherlands	Dioxins	Meat and milk	Contamination of meat and milk with dioxins from citrus pulp that was neutralised using dioxin containing lime	Contamination	https://doi.org/10.1016/S0045-6535(99)00352-5
1998	Delhi oil poisoning	India	Other	Mustard oil	Adulteration of mustard oil with Argemone mexicana seed oil	Adulteration	https://www.sciencedirect.com/science/article/pii/S0304416504003162?via%3Dihub
1999	Meat, dairy, and egg contamination with dioxin in Belgium	Belgium	Dioxins	Meat, dairy, and eggs	A mixture of polychlorinated biphenyls (PCBs) contaminated with dioxins was accidentally added to a stock of recycled fat used in the production of animal feeds	Contamination	https://www.sciencedirect.com/science/article/abs/pii/S0013935101942744?via%3Dihub

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1999-2000	Over 100 deaths due to pyrrolizidine alkaloid poisoning	Afghanistan	Alkaloids	Wheat	Inconclusive, probably consuming charmac (Heliotropium popovii. H Riedl) seeds mixed with wheat or drinking milk from goats which graze on charmac may be the cause of the disease	Contamination	https://reliefweb.int/report/afghanistan/health-talks-afghanistan-sep-2001
2001	Spanish olive pomace oil contamination	Spain	PAHs	Olive oil	Contamination of pomace oil with PAHs during production	Contamination	https://web.archive.org/web/20131108073405/http://www.food.gov.uk/multimedia/faq/olivepomoilqa/
2002	Chloramphenicol in honey	Canada	Chloramphenicol	Honey	Presence of chloramphenicol antibiotic in honey imported from China	Contamination	https://www.canada.ca/en/health-canada/services/drugs-health-products/veterinary-drugs/factsheets-faq/chloramphenicol-honey-factsheet.html#a4
2002	Nitrofurans in chicken	UK	Nitrofuran	Chicken	Presence of nitrofuran drugs in imported chicken products	Contamination	https://www.reading.ac.uk/foodlaw/news/uk-02035.htm
2002	Nitrofurans in prawns	UK	Nitrofuran	Prawns	Presence of nitrofuran drugs in imported prawns and shrimps	Contamination	https://www.fao.org/3/y5723e/y5723e0u.htm
2002	Poisoned food from a breakfast shop	China	Rat poison	Bread, cakes and rice balls	Intentional poisoning of food at a restaurant by a rival food trader	Intentional poisoning	http://news.bbc.co.uk/2/hi/asia-pacific/2325623.stm
2003	Dioxin in animal feed	Germany and the Netherlands	Dioxins	Feed	Contamination of animal feed originating from use of bakery waste dried on an open fire of waste wood	Contamination	https://edepot.wur.nl/172323
2003	Nitrofurans in chicken	Portugal	Nitrofuran	Chicken	Presence of nitrofuran in chickens, due to illegal use of these drugs on poultry farms	Contamination	https://www.reading.ac.uk/foodlaw/news/uk-03018.htm
2004	Chloramphenicol in honey	Canada	Chloramphenicol	Honey	Presence of chloramphenicol antibiotic in honey labelled as "Product of Canada"	Contamination	https://www.canada.ca/en/health-canada/services/drugs-health-products/veterinary-drugs/factsheets-faq/chloramphenicol-honey-factsheet.html

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2004	EHEC O104:H4 outbreak in South Korea	South Korea, Europe	E. coli	Ground beef	Contamination of ground beef with EHEC	Contamination	https://eymj.org/DOIx.php?id=10.3349/ymj.2006.47.3.437
2004	Toxic levels of iodine in soy milk	New Zealand	Iodine	Soy milk	High levels of iodine in soy milk, of which the source was kelp which was added for flavour	Contamination	https://doi.org/10.1111/j.1467-842X.2005.tb00240.x
2004	Cornflour contaminated with lead	New Zealand	Lead	Cornflour	Contamination of corn onboard the ship used to transport the product from China	Contamination	https://web.archive.org/web/20130210094004/http://foodsafety.govt.nz/elibrary/industry/Source_Lead-Nzfsa_Confident.htm
2004	Aflatoxin-contaminated maize in Kenya	Kenya	Mycotoxins	Corn	Contamination of maize with Aspergillus flavus S strain	Contamination	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1314920/
2004	Nitrofurans in chicken	UK	Nitrofuran	Chicken	Presence of nitrofuran in chickens, due to illegal use of these drugs on poultry farms	Contamination	https://web.archive.org/web/20101019053515/http://www.food.gov.uk/multimedia/pdfs/publication/fsanews43.pdf
2005	Mabini food poisoning incident	Phillipines	Carbamate	Cassava	Contaminated cassava roots, probably with carbamate pesticide	Contamination	https://www.cbsnews.com/news/pesticide-eyed-in-bohol-poisonings/
2005	Farmed salmon in British Columbia containing banned fungicide	Canada	Malachite green	Salmon	Farmed salmon containing the fungicide malachite green, a carcinogenic substance	Contamination	https://web.archive.org/web/20120510000155/http://www.focs.ca/news/050604.asp
2005	Worcester sauce containing banned food colorant	UK	Other	Chilli powder	Contamination of chilli powder with Sudan I dye, which was used to manufacture Worcester sauce	Contamination	https://web.archive.org/web/20101210002120/http://www.food.gov.uk/news/newsarchive/2005/feb/worcester
2006	Clenbuterol in pork	China	Clenbuterol	Pork	Adulteration of feed with additives, such as clenbuterol, to shorten growth time of pigs	Adulteration	https://www.thepigsite.com/news/2008/11/outbreak-of-clenbuterol-food-poisoning-1#:~:text=During%20September%202006%2C%20a%20series,suffered%20from%20clenbuterol%20food%20poisoning.

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2007	Pet food recalls	North America, Europe, South Africa	Melamine	Pet food	Adulteration of wheat gluten for use in pet food from China with melamine and cyanuric acid	Adulteration	https://academic-accelerator.com/encyclopedia/2007-pet-food-recalls
2008	Contaminated wheat flour	Afghanistan	Alkaloids	Wheat flour	Contaminated wheat flour, contaminated with the seeds of the Heliotropium plant	Contamination	https://doi.org/10.1155%2F2010%2F313280
2008	Irish pork crisis of 2008	Ireland	Dioxins	Feed	Contamination of animal feed with dioxins and PCBs	Contamination	https://www.theguardian.com/uk/2008/dec/09/irish-pork-dioxins-food-scare
2008	Dioxin was found in buffalo milk	Italy	Dioxins	Milk	Contamination of buffalo milk with dioxins, due to illegal burning or dumping of toxic waste, which contaminated pastures	Contamination	https://archive.nytimes.com/thelede.blogs.nytimes.com/2008/03/21/italys-mozzarella-makers-fight-dioxin-scare/
2008	Canadian listeriosis outbreak	Canada	L. monocytogenes	Cold meat products	Contaminated cold cuts meat products with Listeria	Contamination	https://www.canada.ca/en/news/archive/2009/07/report-independent-investigator-into-2008-listeriosis-outbreak.html
2008	United States salmonellosis outbreak	USA	Salmonella	Jalapeño peppers	Contaminated jalapeño peppers imported from a farm in Tamaulipas, Mexico	Contamination	https://en.wikipedia.org/wiki/2008_United_States_salmonellosis_outbreak
2008	Baby milk scandal, in China	China	Melamine	Milk and infant formula	Adulteration of milk and infant formula with melamine	Adulteration	https://www.straitstimes.com/asia/east-asia/chinas-lethal-milk-scandal-reverberates-a-decade-later#:~:text=The%20deadly%20milk%20scandal%20of,to%20artificially%20boost%20protein%20levels.
2008	Adulteration of wine	Italy	Strong acids	Wine	Adulteration of wine with sugar, sulphuric and hydrochloric acid	Adulteration	https://timesofmalta.com/articles/view/20080404/world/italian-wine-under-investigation-for-adulteration.202817

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2008	Report of an International Outbreak Investigation into a Multi–country Outbreak of Salmonella Agona, Europe, 2008	Europe	Salmonella	Ready to eat products	Contamination of ready to eat products with Salmonella	Contamination	https://www.hpsc.ie/a-z/gastroenteric/salmonellosis/surveillancereports/outbreaks/File,12549,en.pdf
2008	Listeriosis outbreak	Canada	L. monocytogenes	ready-to-eat meat products (a variety of turkey, smoked meat and roast beef products)	Contamination of ready to eat products with Listeria	Contamination	https://doi-org.ezproxy.library.wur.nl/10.1159/000342770
2008-09	Peanut Outlook Impacts of the 2008-09 Foodborne Illness Outbreak Linked to Salmonella in Peanuts	USA	Salmonella	Processed peanuts (*e.g.* King Nut peanut butter)	Contamination of processed peanut products with Salmonella	Contamination	https://www.ers.usda.gov/webdocs/outlooks/37835/8684_ocs10a01_1_.pdf?v=7326
2009	Pork, in China, containing the banned chemical clenbuterol	China	Clenbuterol	Feed	Adulteration of feed with additives, such as clenbuterol, to shorten growth time of pigs	Adulteration	http://archive.boston.com/news/world/asia/articles/2011/01/24/skinny_pigs_poison_pork_china_battles_farm_drugs/
2009	Iodine in Bonsoy-brand Soymilk in Australia	Australia	Iodine	Soy milk	High levels of iodine in soy milk, of which the source was Kombu seaweed which was added for flavour	Contamination	https://onlinelibrary.wiley.com/doi/abs/10.5694/j.1326-5377.2010.tb03972.x
2009	Hola Pops from Mexico contaminated with lead	USA	Lead	Lollypops	Contamination of lollypops from Mexico with lead	Contamination	https://www.claimsjournal.com/news/west/2009/05/04/100181.htm
2010	Snakes in China were contaminated with clenbuterol	China	Clenbuterol	Snakes	Snakes being fed frogs that had been given clenbuterol	Adulteration	https://meatfreemondays.com/clenbuterol-use-of-chinas-lean-meat-drug-conti/
2011	Meat, eggs and egg products in Germany contaminated from animal feed (incl. poultry)	Germany	Dioxins	Meat, eggs, and egg products	Contamination of animal feed due to the use of fats containing dioxin, probably fatty acids that were intended for the industrial production of lubricants	Contamination	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3050964/

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2011	German E. coli O104:H4 outbreak	Germany	E. coli	Fenugreek seeds	Contaminated fenugreek seeds from Egypt	Contamination	https://www.efsa.europa.eu/en/news/efsa-publishes-report-its-task-force-e-coli-o104h4-outbreaks-germany-and-france
2011	Vinegar from China contaminated with ethylene glycol	China	Ethylene glycol	Vinegar	Vinegar contaminated with ethylene glycol due to storage in plastic barrels that used to contain antifreeze	Contamination	http://www.chinadaily.com.cn/imqq/china/2011-08/23/content_13171392.htm
2011	United States listeriosis outbreak	USA	L. monocytogenes	Cantaloupes	Contamination of cantaloupes from a farm in Colorado with Listeria monocytogenes	Contamination	https://www.cdc.gov/listeria/outbreaks/cantaloupes-jensen-farms/index.html
2011	Alcohol poisoning in India	India	Methanol	Liqour	Inconclusive, contamination of illegal alcoholic drinks (hooch) with methanol or ammonium nitrate due to improper production, or adulteration of illicit liquor with methanol to increase alcohol content	Inconclusive	https://www.bbc.co.uk/news/magazine-16197280?print=true
2012	Herbs treated with an apparently organic plant growth strengthener	Germany	DDAC	Herbs	Contamination of herbs due to the use of plant strengthener Vi-Care, containing DDAC	Contamination	https://www.freshplaza.com/europe/article/98608/Germany-1-million-pots-of-organic-herbs-destroyed/
2012	"excessive levels" of the poisonous chemical dioxin in eggs	Germany	Dioxins	Eggs	Contamination of eggs with dioxin	Contamination	https://www.feednavigator.com/Article/2012/06/21/Eggs-recalled-in-Germany-over-dioxin-contamination
2012	Multiple American Licorice Company black licorice products recalled	USA	Lead	Licorice candy	Contamination of black licorice with lead	Contamination	https://web.archive.org/web/20120826003006/http://www.americanlicorice.com/2012/08/red-vines-black-licorice-recall-notice/
2012	Frozen Chinese strawberries contaminated with norovirus	Germany	Norovirus	Strawberries	Outbreak of norovirus traced back to a consignment of frozen strawberries from China	Contamination	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3753465/#:~:text=During%20September%2FOctober%202012%2C%20a,for%20the%20presence%20of%20norovirus.

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2013	Taiwan food scandal	Taiwan	Chlorophyllin	Olive oil	Adulteration of olive oil with cottonseed oil and use of chlorophyllin as coloring agent	Adulteration	https://en.wikipedia.org/wiki/Food_safety_incidents_in_Taiwan
2013	Coliforms in almond cakes	China	Coliforms	Almond cakes	Contamination of almond cakes with coliform bacteria	Contamination	https://www.foodnavigator.com/Article/2013/03/06/IKEA-cake-wihdrawn-due-to-possible-human-waste-contamination
2013	Bihar school meal poisoning incident	India	Monocrotophos	Cooking oil	Toxic levels of monocrotophos pesticide in meals prepared with cooking oil which was stored in a container that used to contain organophosphate pesticide	Contamination	https://www.bbc.com/news/world-asia-23390972
2013	European aflatoxin contamination	Europe	Mycotoxins	Corn	Maize intended for feed contaminated with aflatoxin B1	Contamination	https://brill-com.ezproxy.library.wur.nl/view/journals/wmj/8/5/article-p641_641.xml
2013	Halal Lamb Burgers contained samples of Pork DNA	UK	Other	Lamb meat	Contamination of Halal meat with pork	Contamination	https://www.theguardian.com/education/2013/may/09/pork-school-halal-lamb-burgers
2013	Lettuce contaminated with rat poison	Germany	Rat poison	Romaine lettuce	Romaine lettuce imported from Italy contaminated with rat poison	Contamination	https://www.thelocal.de/20130309/48433
2013	Horse meat scandal	UK and Ireland	Other	Beef	Adulteration of beef with horse meat, imported into the UK and Ireland from France, originally from Romania	Adulteration	https://www.theguardian.com/uk/2013/feb/15/horsemeat-scandal-the-essential-guide
2013	Rat, and other small mammal meat, sold as lamb	China	Other	Lamb meat	Adulteration of lamb meat with rat or other inferior meats, and sale of fake meat products consisting of only such illegal meat sources	Adulteration	https://www.scotsman.com/news/world/china-rat-meat-sold-as-lamb-in-latest-food-scandal-1576659
2014	Taiwan food scandal	Taiwan	Other	Cooking oil	Adulteration of cooking oil with waste oil and animal feed oil	Adulteration	https://en.wikipedia.org/wiki/Food_safety_incidents_in_Taiwan

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2015	Mozambique funeral beer poisoning	Mozambique	Bongkrekic acid	Beer	Contaminated pombe beer due to presence of Burkholderia gladioli which produced bongkrekic acid	Contamination	https://academic.oup.com/cid/article/66/9/1400/4636543?login=false
2015	United States E. coli outbreak	USA	E. coli	Rotisserie chicken salad	Outbreak of E. coli O157:H7 linked to contaminated rotisserie chicken salad, precise ingredient source unknown	Contamination	https://www.cdc.gov/ecoli/2015/o157h7-11-15/
2015	Listeria in ice cream	USA	L. monocytogenes	Ice cream	Contamination of ice cream products at a creamery facility	Contamination	https://www.cdc.gov/listeria/outbreaks/ice-cream-03-15/index.html
2015	Lead contamination in Nestlé's Maggi brand instant noodles	Nepal	Lead	Instant noodles	Contamination of instant noodles with lead and excessive levels of monosodium glutamate	Contamination	https://kathmandupost.com/miscellaneous/2015/06/04/maggi-noodles-banned-in-nepal
2015	Caraga candy poisonings	Phillipines	S. aureus	Durian candy	Durian candies contaminated with S. aureus	Contamination	https://www.gmanetwork.com/news/topstories/regions/523454/poisonous-durian-candies-test-positive-for-staphylococcus-bacteria/story/
2015	Contaminated milk tea	Phillipines	Oxalic acid	Milk tea	Intentional addition of oxalic acid to milk tea	Intentional poisoning	https://www.gmanetwork.com/news/topstories/metro/485374/bleaching-substance-found-in-remains-of-ergo-cha-milk-tea-poisoning-victims/story/
2016	Punjab sweet poisoning	Pakistan	Chlorfenapyr	Laddu confections	Intentional addition of the insecticide chlorfenapyr to laddu confection	Intentional poisoning	https://www.independent.co.uk/news/world/asia/pakistani-sweetshop-owner-admits-killing-30-people-with-poisonlaced-sweets-a7017236.html
2016	Over 400 frozen food products recalled due to listeria	USA and Canada	L. monocytogenes	Frozen vegetable products	Contamination of frozen vegetable products with Listeria	Contamination	https://www.cdc.gov/listeria/outbreaks/frozen-vegetables-05-16/index.html
2016	Mars Chocolates contamination incident	Britain, France, the Netherland	Other	Snickers bar	Red plastic, originating from protective cover material, inside Snickers bar	Contamination	https://www.theguardian.com/lifeandstyle/2016/feb/23/mars-chocolate-product-recalls-

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		s and Germany					snickers-milky-way-celebrations-germany-netherlands
2017	Fipronil eggs contamination	Netherlands	Fipronil	Eggs	Contamination of eggs due to use of banned insecticide fipronil against poultry mite	Contamination	https://www.rechtspraak.nl/Bekende-rechtszaken/fipronil-eieren
2017-18	South African listeriosis outbreak	South Africa	L. monocytogenes	Cold meat products	Contamination of processed cold meat products, such as polony, with Listeria	Contamination	https://www.timeslive.co.za/news/south-africa/2018-05-18-death-toll-from-listeria-outbreak-rises-to-more-than-200/
2018	Australian rockmelon listeriosis outbreak	Australia	L. monocytogenes	Rockmelons	Contamination of rockmelons with Listeria, caused by dust storms	Contamination	https://www.abc.net.au/news/2018-10-12/listeria-rockmelon-report-finds-outbreak-caused-dust-storms/10365636
2018	Australian strawberry contamination	Australia	Other	Strawberries	Intentional addition of sewing needles to strawberries by disgruntled ex-employee	Intentional poisoning	https://www.abc.net.au/news/2018-09-12/strawberry-investigation-after-sewing-needles-found-inside/10237954
2019	Widespread lead chromate adulteration of turmeric	Bangladesh	Lead	Turmeric	Adulteration of turmeric with lead chromate to enhance its yellow color	Adulteration	https://news.stanford.edu/2019/09/24/lead-found-turmeric/
2019	Dioxin contamination of eggs	Indonesia	Dioxins	Eggs	Contamination of eggs with dioxin due to the burning of plastic as fuel in the vicinity of the farm	Contamination	https://www.nytimes.com/2019/12/19/world/asia/indonesia-dioxin-plastic-tofu.html
2019	Returning of contaminated ice cream to shelves of retailer	USA	Other	Ice cream	Contamination of ice cream by individuals who lick or poke the product and place it back on the shelves	Intentional poisoning	https://www.delish.com/food-news/a31248041/viral-ice-cream-licking-video-jail-time/
2019	Laboratory investigations into the cause of multiple serious and fatal food poisoning incidents in Uganda during 2019	Uganda	Alkaloids	Super cereal	Contamination of Super cereal, fortified blended food, with tropane alkaloids originating from Datura seeds	Contamination	https://pureadmin.qub.ac.uk/ws/portalfiles/portal/227196892/WFP_Analytical_Methods_QUB_Revision_Food_Control_Update_31082020.pdf

Year	Crisis	Country/region	Cause	Food product	Source of contaminant	Category	Source- URL
2020	Fermented corn noodles contaminated with bongkrekic acid	China	Bongkrekic acid	Homemade noodles	Consumption of fermented noodles that were frozen for nearly a year, contaminated with bongkrekic acid	Contamination	https://www.independent.co.uk/news/world/asia/family-china-killed-noodles-die-bongkrekic-acid-heilongjiang-jixi-b1201859.html
2020	Ethylene glycol contamination in brazilian craft beers produced in Minas Gerais	Brazil	Ethylene glycol	Beer	Contamination of beers with ethylene glycol, probably caused by the use of contaminated water	Contamination	https://www.foodsafetynews.com/2020/01/more-poisonings-in-brazil-linked-to-beer-officials-urge-extreme-caution/#:~:text=More%20than%2020%20people%20are,by%20Backer%20should%20be%20consumed.
2020	Sesame seeds contamination	Europe	Ethylene oxide	Sesame seeds	Contamination of sesame seeds imported from India with ethylene oxide pesticide	Contamination	https://food.ec.europa.eu/safety/acn/acn-incidents/ethylene-oxide-incident-sesame-seeds_en
2021	Turkey meat suspected of plastic contamination	USA	Other	Ground turkey meat	Contamination of ground turkey meat with blue plastic particles	Contamination	https://edition.cnn.com/2021/10/14/business/butterball-turkey-recall/index.html
2022	Recall of Similac baby formula	USA	Cronobacter sakazakii	Infant formula	Contamination of baby formula with Cronobacter sakazakii	Contamination	https://www.fda.gov/food/outbreaks-foodborne-illness/fda-investigation-cronobacter-infections-powdered-infant-formula-february-2022
2022	Bassar produced snacks for dental care contaminated with ethylene glycol	Brazil	Ethylene glycol	Pet food	Contaminated pet food, probably due to the use of propylene glycol containing ethylene glycol	Contamination	https://www.petfoodindustry.com/news-newsletters/pet-food-news/article/15469146/dog-deaths-prompt-brazil-to-recall-stop-bassar-pet-food

9 Annex B: Flow scheme related to the prospective study

In this annex, a simplified version of the flow scheme summarizing the relations between drivers and their effects, with related indicators, can be found. Then, there will be zoomed in on specific parts of the flow scheme, where all details are provided.

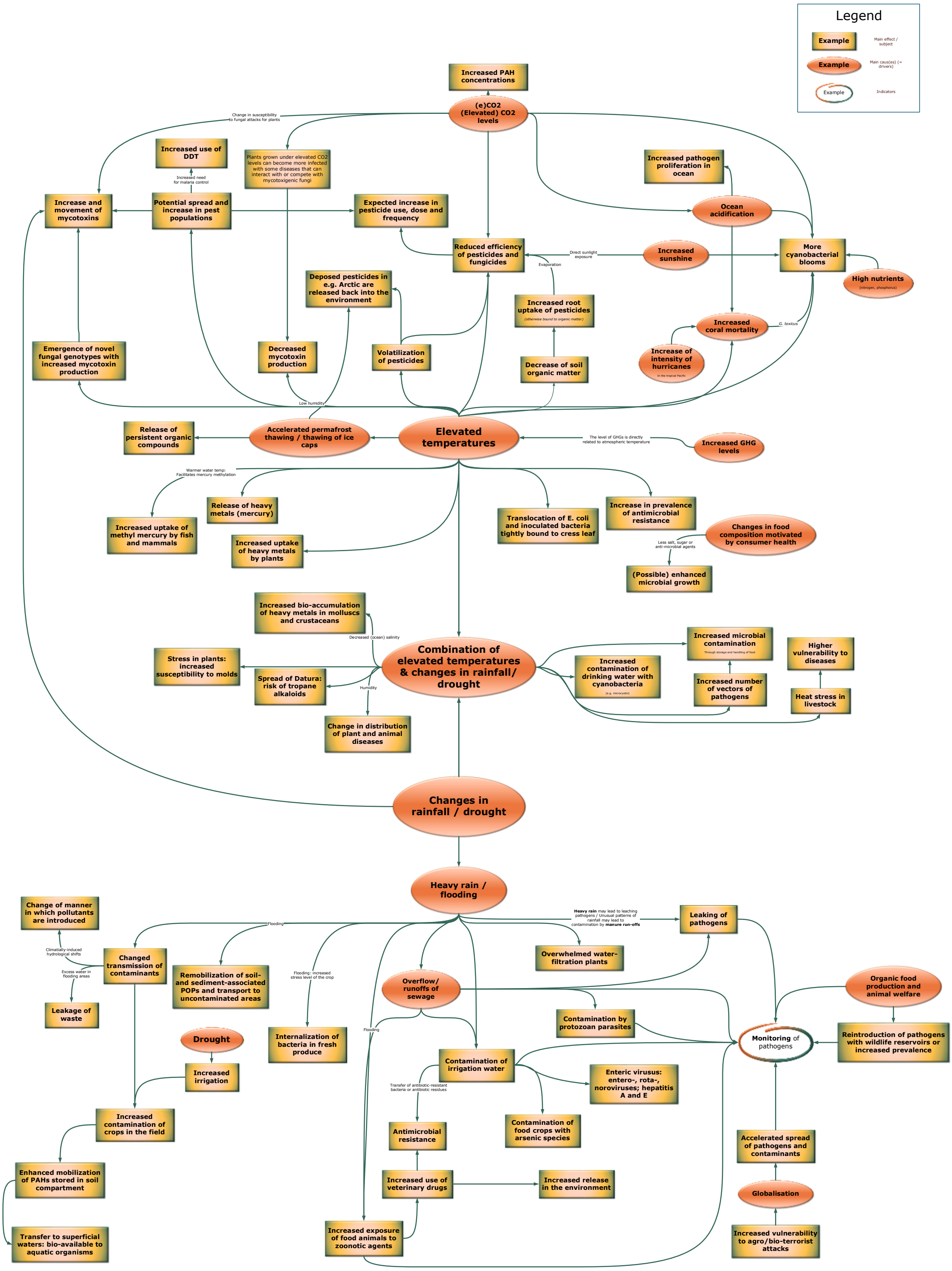

Figure B1 Simplified flow scheme (made with Microsoft Visio) summarizing the relations between drivers, corresponding effects and indicators from literature

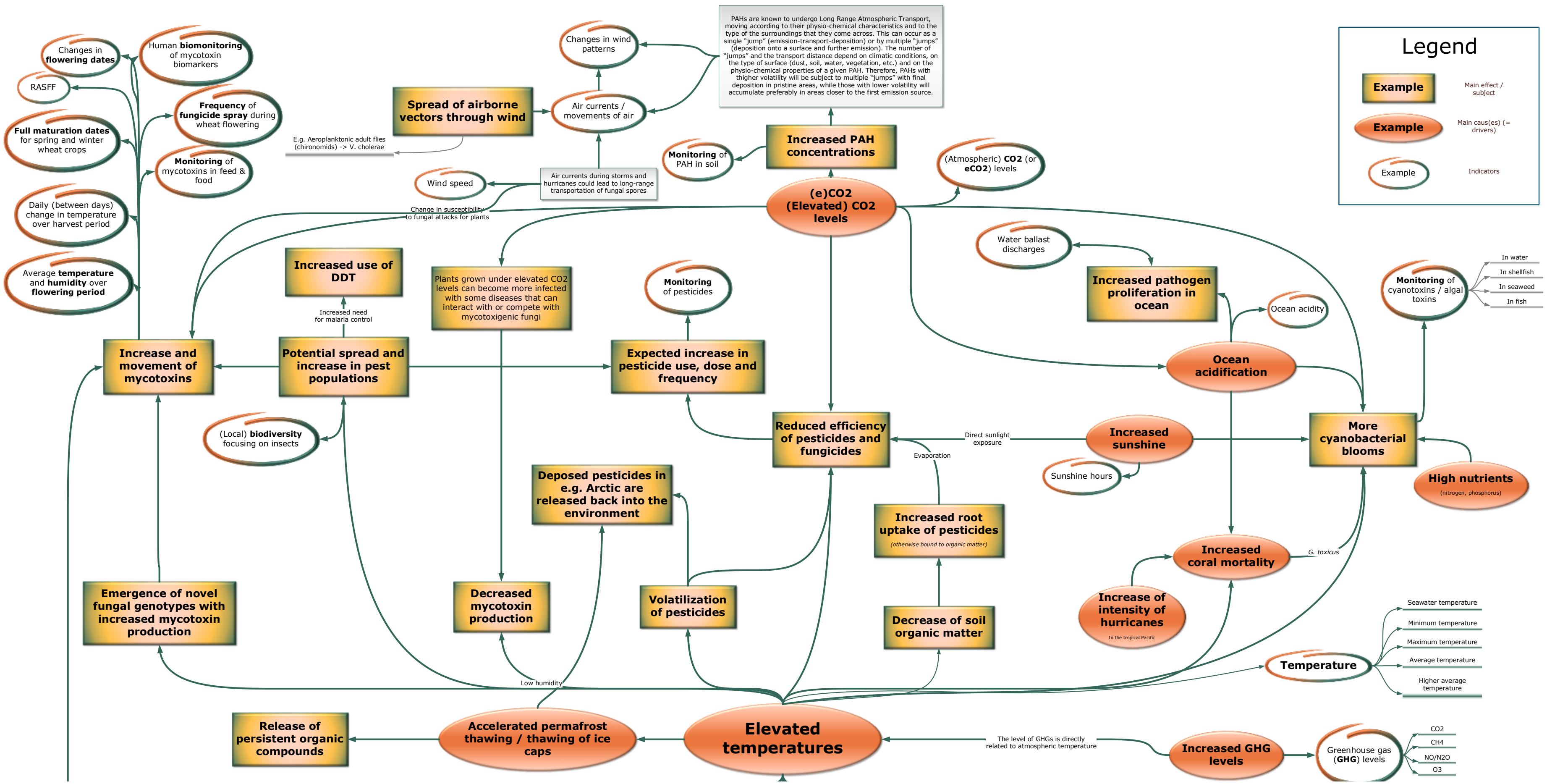

Figure B2 Extended flow scheme (made with Microsoft Visio) summarizing the relations between drivers, corresponding effects and indicators from literature – upper part

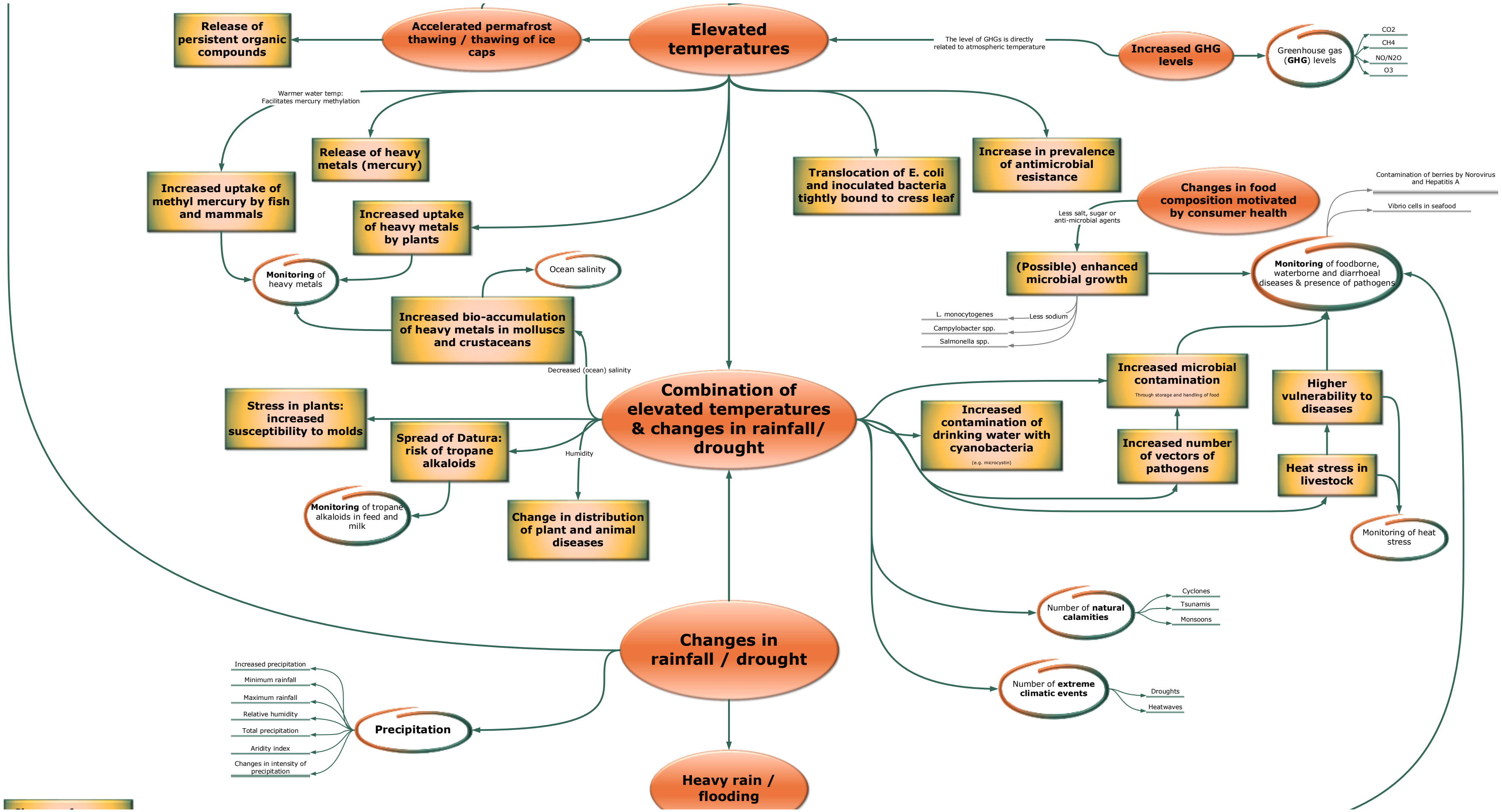

Figure B3 Extended flow scheme (made with Microsoft Visio) summarizing the relations between drivers, corresponding effects and indicators from literature – middle part

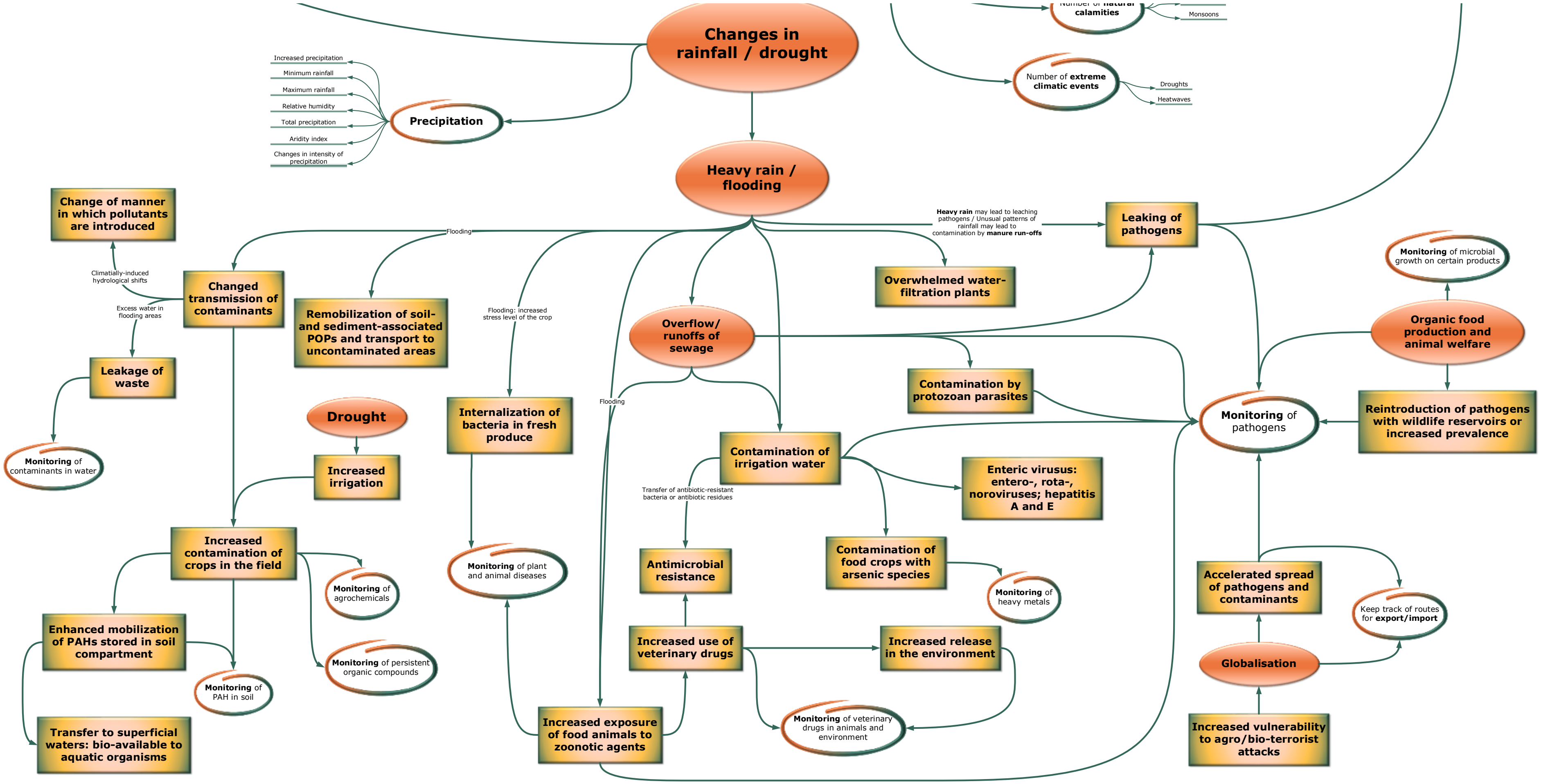

Figure B4 Extended flow scheme (made with Microsoft Visio) summarizing the relations between drivers, corresponding effects and indicators from literature – lower part

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