APPROVED: 11 June 2020

doi:10.2903/sp.efsa.2020.EN-1881

Climate change as a driver of emerging risks for food and feed safety, plant, animal health and nutritional quality

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Abstract

Climate change constitutes a relevant driver of emerging risks. While a broad range of forward-looking studies and reports examine the impact of climate change on food security, future challenges for food and feed safety, plant and animal health and nutritional quality are usually not investigated in depth.

The CLimate change and Emerging risks for Food SAfety (CLEFSA) project has explored the possibility of: (a) using the specific driver, climate change, for long-term anticipation of multiple emerging risks, using scenarios of climate change; (b) using crowdsourcing and text mining to collect a broad range of signals from a variety of information sources; (c) using a knowledge network of experts from international organisations; (d) designing a Multi-Criteria Decision Analysis tool for characterising signals through a participatory process, in which expert knowledge is used to identify relevant issues from the vast and often incomplete information; (e) developing methodologies and indicators for the analysis of the information available, addressing uncertainty.

Climate change and its implications for food safety demand complex scientific study, given the number and diversity of hazards to be considered, the large uncertainties involved and the interconnections between the different areas. The effects of climate change are characterised by a multidisciplinary nature (human–plant–animal health and environmental sciences) and go beyond the recognition of specific emerging risks. CLEFSA has identified numerous issues that are driven by climate change and that may affect food safety in Europe. Climate change has the potential of causing, enhancing or modifying the occurrence and intensity of some food-borne diseases and the establishment of invasive alien species harmful to plant and animal health. It has an impact on the occurrence, intensity and toxicity of blooms of potentially toxic marine and freshwater algae and bacteria, on the dominance and persistence of various parasites, fungi, viruses, vectors and invasive species, harmful to plant and animal health. Climate change is likely to drive the (re)emergence of new hazards, increase the exposure or the susceptibility to known hazards and change the levels of micronutrients and macronutrients in food and feed items. By the very nature of the challenge, this list is inevitably incomplete, and undoubtedly unanticipated surprises await us in the future.

Key words: climate change, emerging risks, identification, characterisation, uncertainty, impacts, likelihood of emergence

Requestor: EFSA

Question number: EFSA-Q-2020-00075

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Acknowledgements: EFSA wishes to thank the following people for the support provided to this scientific output: Stefano MESSORI (OIE), Andrea TORETI (JRC), Hans-Martin FÜSSEL (EEA), Elisa BERDALET (UNESCO-IOC – SCOR GlobalHAB programme), Jan C. SEMENZA (ECDC), Jessika GIRALDI (JRC), Jorge DIOGÈNE (EuroCigua project), Cristina TIRADO (University California Los Angeles), Marco BINDI (Florence University), Kim PETERSEN (WHO), Keya MUKHERJEE (FAO), Federica ROSSI (CNR), Pinya SARASAS (UNEP), Robert STEFANSKY (WMO); the following EFSA Staff members: Aleksandra Lewandowska, Angeliki Konsta, Yves Van der Stede, José Tarazona; all the experts listed in Appendix A of this report as well as the following members of the EFSA Uncertainty Working Group: Andrew Hart, Ullrika Sahlin, Wopke van der Werf and Peter Craig.

Suggested citation: EFSA (European Food Safety Authority), Maggiore A, Afonso A, Barrucci F, De Sanctis G, 2020. Climate change as a driver of emerging risks for food and feed safety, plant, animal health and nutritional quality. EFSA supporting publication 2020:EN-1881. 146 pp. doi:10.2903/sp.efsa.2020.EN-1881

ISSN: 2397–8325

Summary

A series of complex and interlinked disruptive changes could put the European food system under severe stress. These include population growth, globalisation, climate change, resource and energy scarcity, decreasing agricultural productivity, price volatility, modification of diet trends, new technologies and the emergence of antimicrobial resistance. Therefore, food and feed safety, plant and animal health and nutritional quality cannot be taken as granted. Activities need to be undertaken to ensure preparedness for future food safety and risk assessment challenges.

A key requirement for ensuring food and feed safety in the future is a holistic approach, which assesses major drivers of change in the food system, to support the identification of emerging risks. This would support the long-term anticipation of future food safety challenges and risk assessment needs (consistent data, knowledge, risk assessment methodologies) and even preventing safety issues. Climate change constitutes a relevant driver of emerging risks for food and feed safety, plant and animal health (including terrestrial and aquatic species) and food nutritional quality.

The CLEFSA project (CLimate change and Emerging risks for Food SAfety) aims at developing and testing new methodologies for the identification, characterisation and analysis of emerging risks linked with climate change. This is a challenging task, given the number and diversity of hazards to be considered and the large uncertainties involved. The project provides a list of emerging issues/risks potentially linked to climate change and characterises these issues/risks in terms of potential impact, likelihood of emergence, other qualifying criteria, indicators of the effects of climate change and the associated uncertainty.

While the anticipated effects of climate change on food security are well documented, numerous gaps remain in the understanding of how climate change can affect food safety. This report by no means strives to be fully comprehensive on this aspect. Rather than providing in-depth information on individual issues, it attempts to illustrate the bigger picture, proposing possible solutions for identifying pertinent and relevant issues from vast and incomplete weak signals with high uncertainty.

The CLEFSA project has explored the possibility of (a) using the specific driver, climate change, for long-term anticipation of multiple emerging risks, using scenarios of climate change; (b) using horizon scanning and crowdsourcing to collect a broad range of signals from a variety of information sources; (c) using a knowledge network of experts from international organisations in the European Union and the United Nations; (d) designing a Multi-Criteria Decision Analysis (MCDA) tool for characterising signals through a participatory process, in which expert knowledge is used to identify relevant issues from vast and often incomplete information; and (e) developing methodologies and indicators for the analysis and visualisation of the information collected during the characterisation and for addressing uncertainty in a data-poor environment.

An interdisciplinary CLEFSA network has been created, constituted by experts from international intergovernmental organisations and coordinators of large EU projects involved with climate change. The task of this network is to support the identification of emerging issues, design the MCDA tool for characterisation purposes and to support the building of the characterisation group. The criteria to identify emerging issues potentially affected by climate change have been defined based on those used in the EFSA emerging risks identification process and adapted to the specific driver under analysis. A survey has been launched to collect a broad range of issues potentially affected by climate change, including weak signals, in all EFSA's areas. More than 600 people responded, providing over 240 issues. The issues identified in the survey have been complemented by literature search, using online searching tools developed by other EU institutions, the EFSA Emerging Risks Networks (Emerging Risks Exchange Network – EREN and the Stakeholders Discussion group) and information stemming from EFSA's activity related to the subject. The identified issues have been filtered and clustered according to specified criteria. The list can be reviewed and revised based on updated knowledge and new emerging hazards. The adopted procedure to identify emerging issues/risks guarantees responsiveness to changes in scientific knowledge.

In the data-poor situations typical of emerging risks, decisions are most dependent on expert judgement and so it is in these situations that it is often most worthwhile to use the best methods for representing and eliciting expert judgements. A multi-criteria approach has been defined in a participatory fashion with the experts of the CLEFSA network to characterise the identified issues and potentially support the decision-making process. Two of them, impacts and likelihood of emergence, are associated with a

scoring system. The other eight criteria provide useful information for deciding what kind of follow-up is suitable and by whom (risk assessors, risk managers, researchers, etc.). All these criteria have been defined to the extent possible, in consideration of the different nature of the areas and issues for which they were designed to be applied and the limited knowledge available on the identified issues.

Climate change scenarios were drafted from the climate data store provided by the Copernicus C3S platform implemented by the European Centre for Medium-Range Weather Forecasts (ECMWF) on behalf of the European Commission. They are used to characterise the identified emerging issues against the established set of criteria. A CLEFSA app has been designed, coded in R programming language and launched on the Open Analytics server. The app serves the purpose of structuring the characterisation exercise and facilitating the following statistical analysis and visualisation of the results.

The characterisation has been performed by a group of 60 experts identified by the CLEFSA network and the relevant EFSA's Panel and working groups. It is based on the assessment of the criteria mentioned above. The objective of the characterisation is to identify, based on expert knowledge and expertise, relevant issues from the vast and often incomplete information retrieved in the survey. A tool for the analysis and visualisation of the characterisation results for the different issues in the impact/likelihood domain was built. It includes an assessment of the cumulative uncertainty (= expert confidence level + spread of scores across different experts). This tool constitutes a pilot to test innovative visualisation methodologies.

The CLEFSA project has characterised and statistically analysed over 100 emerging issues for food and feed safety, plant and animal health and nutritional quality. Some of them have been characterised for their impacts on both human and animal health. The analysis indicates that climate change may increase severity, duration and/or frequency of the potential effects of the hazard considered in the identified issue. However, it indicates a more pronounced effect on the likelihood of emergence.

It is difficult to draw a general conclusion applicable to all EFSA's areas. Focusing on the parameter with the highest confidence level, likelihood of emergence, most of the EFSA's areas include issues distributed along all ranges. However, under the climate change scenario, plant health shows a gathering of its issues at the highest ranges of likelihood of emergence, followed by contaminants issues (within this group, marine biotoxins show the highest likelihood of emergence). This may rather be a reflection of the current state of knowledge than an objective representation of comparative risk.

Crowdsourcing and 'unsupervised' expert elicitation and characterisation were used to widen the scope of the exercise to several areas and capture possible interlinkages across them. The limited evidence base confers high uncertainty and broad descriptions to each individual issue. The wide variety of issues identified and characterised in this report emphasises the need for policymakers and other relevant players in the food system to consider adjusting surveillance and monitoring to prepare for emerging risks caused by climate change.

Climate change considerations can impact the assessment of the risks to human, plant, animal health and to the environment. So, for risk assessment to remain relevant, climate change needs to be accounted for. Holistic approaches to deal with multiple stressors, including climate change, should be increasingly explored in the food and feed safety area. In the EFSA's risk assessments, climate change scenarios could be considered in the problem formulation phase and when characterising the hazard, evaluating trends in prevalence or incidence and assessing fate and distribution in the environment.

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1. Introduction

1.1. Background and Terms of Reference

According to the EFSA's Founding Regulation (EC, 2002) No. 178/2002 (Article 34), EFSA is required to establish procedures for the screening and analysis of information with a view of identifying emerging risks in the fields within its mission. The main objectives are to: (i) identify, assess and disseminate information on emerging issues and ensure coordination with relevant networks and international organisations; (ii) promote the identification of data sources and data collection and/or data generation in prioritised emerging issues and (iii) evaluate the collected information and identify emerging risks. The final aim of the emerging risks identification process is to anticipate and possibly prevent food safety and risk assessment challenges, thus contributing to preparedness.

Emerging issues identification tends to focus on the short- and medium-term time horizons whereas the long-term anticipation of future food safety challenges and risk assessment needs (data, knowledge, methodologies) may be based on the identification of drivers. They are natural or anthropogenic factors causing complex and interlinked changes having the potential to directly or indirectly drive or modulate the emergence of an issue. One important characteristic of drivers is that they may act as modifiers of effect on the onset of emerging risks and can either amplify or attenuate the severity, duration and/or frequency of the potential effects of the hazard considered or the likelihood of emergence of the risk.

Rather than focusing on single food safety issues, it is possible to develop a process for grouping food safety issues based on the drivers underpinning their emergence. A commonly used classification for drivers categories is the STEEPLE framework (Social, Technological, Economic, Environmental, Political, Legal and Ethical). Drivers include population growth, globalisation, resource and energy scarcity, slowing agricultural productivity, increasing concentration of the supply chain, price volatility, changing diet trends and the emergence of antimicrobial resistant strands. These can cause complex and interlinked changes that could put the European food system under severe stress.

The world around us is changing very rapidly. There is a need for the best possible understanding of these changes and the way they interact with the food system to predict, control and possibly prevent future risks. Monitoring and modelling drivers can help to anticipate future risks and to strengthen control measures. More important, intervening directly on these underlying drivers can diminish the likelihood of emergence and reduce the associated human and economic costs. Drivers' analysis has already been used in previous EFSA's works (EFSA, 2014; Richardson et al., 2016). In these works, it was evident how the drivers interact with each other and cannot be separated. Climate change constitutes a relevant driver of emerging risks for food safety. As a first step toward a more comprehensive analysis, CLEFSA uses climate change for long-term foresight, considering the several emerging issues it drives. The climate change driver is characterised by using scenarios.

A broad range of forward-looking studies and reports examines the impact of climate change on health (through its social and environmental determinants such as clean air, safe drinking water and extreme weather events), farming (EEA, 2019) and food security (by addressing the question of food production for a growing human population and the effects of undernutrition on infants) (Hoegh-Guldberg et al., 2019). Reduced food availability at 2.0°C of global warming is projected for many regions including the Mediterranean and central Europe (Hoegh-Guldberg et al., 2019).

However, future challenges for food safety (WHO, 2018a) and nutrition quality are not specifically studied, although food safety and food security are strongly intertwined. Food safety constitutes a fundamental pillar of food security in all its four dimensions (availability, access, utilisation and stability), its 'utilisation' component. Achieving food security is not possible without considering food safety. Likewise, if food supplies are insecure, food tends to be consumed disregarding its safety and nutritional value. The sensitivity of pathogens (including bacteria, viruses and parasites), potentially toxigenic microorganisms and various pests to climate factors suggests that climate change has the potential of causing, enhancing or modifying the occurrence and intensity of some food-borne diseases and the establishment of invasive alien species harmful to plant and animal health. Climate change may therefore affect food safety and nutrition, through impacts occurring at all stages of the food chain as food moves from production to consumption, or from 'farm to table' (see Figure 1).

(taken from https://health2016.globalchange.gov/)

Figure 1: The potential interactions of rising CO_2 and climate change on food safety and nutrition from 'farm to table'

Consideration of climate change is becoming more and more relevant in almost all areas in the EFSA's remit. Climate change poses challenges to future risk assessment, for which the EFSA's strategy 2020 outlines the need to be prepared[1]. The CLEFSA project (CLimate change and Emerging risks for Food SAfety) aims at developing and testing new methodologies for emerging risks identification and characterisation and to produce a list of emerging issues/risks in EFSA remit potentially affected by climate change. This report is aimed at a broad audience, including all the relevant players in the food safety arena, from risk assessors, risk managers, researchers, to the general public.

1.2. The EFSA emerging risks identification process

Article 34 of the EU Food law (EC, 2002) requests EFSA to draft monitoring procedures with respect to systematically searching for, collecting, collating, and analysing information and data with a view to the identification of emerging risks in the fields within its mission (Afonso et al., 2019).

The emerging risks identification (ERI) procedure currently in place in EFSA is based on three main steps:

1) Identification of priority emerging issues.
2) Identification of data sources and data collection.
3) Evaluation of emerging risks.

The difference between an emerging 'issue' and an emerging 'risk' is therefore the amount and quality of available data.

A definition for emerging risk was developed and agreed by EFSA Scientific Committee in 2007 and updated in 2019 while a working definition of emerging issues was applied in 2012:

> 'An emerging risk to human, animal and/or plant health and environment is understood as a risk resulting from a newly identified hazard to which significant exposure may occur or from an

[1] https://www.efsa.europa.eu/sites/default/files/151008.pdf

> unexpected new or increased significant exposure and/or susceptibility to a known hazard (EFSA, 2007[2]).'
>
> 'Emerging issues are identified at the beginning of the ERI process as issues that may merit further investigation and additional data collection. Emerging issues can include specific issues as well as general issues such as drivers of change (EFSA, 2012a).'

In this definition, the concept of 'significant' referred to the exposure includes a consideration of the magnitude of the effects. The term 'unexpected' implies the emergency and novelty of the issue. A revision of the definitions was proposed by the EFSA Standing Working Group on Emerging risks (EFSA et al., 2018b) and endorsed by the EFSA Scientific Committee in 2019[3]. The revised emerging risks definition includes risks to the environment as one of the outcomes to be considered when identifying emerging risks relevant to EFSA remit:

> 'An emerging risk to human, animal and/or plant health and the environment is understood as a risk resulting from a newly identified hazard to which significant exposure may occur or from an unexpected new or increased significant exposure and/or susceptibility to a known hazard.'

Emerging issues can include specific hazards (e.g. specific chemical substances or pathogens), as well as general issues such as drivers of change. Due to the global nature of the latter, many are interrelated (e.g. climate change, globalisation, competition for key resources). The procedure is focusing on the identification and characterisation of issues from weak signals arising from surveillance activities, scientific publications screening or media monitoring. Automatic identification tools such as text (MediSys and the TNO Emerging Risk Identification System – ERIS) or data mining (Bitsch et al., 2016) are being used. Issues are identified by EFSA networks of knowledge: EREN, Emerging Risk Stakeholders Discussion Group (StaDG-ER), EFSA Scientific Committee, Panels or scientific support units, and other EU institutions or international parties. They give access to diverse expertise in all fields related to EFSA remit (EFSA, 2015).

In the EFSA ERI process, a defined set of criteria (Novelty, Soundness, Imminence, Severity and Scale) (EFSA 2012b, 2015) are used for the 'characterisation' of the identified issue through an iterative process with a vast range of stakeholders. Additional information on the nature of the hazard identified, or associated drivers and trends is also included. No action is undertaken if the issue is deemed as not compliant with the definition of emerging issue/risk and relevant criteria. The process of characterisation of emerging issues is often based on limited and ambiguous data and expert knowledge with high levels of uncertainty and low reproducibility.

The characterisation of the identified emerging issues/risks supports decisions on possible follow-up activities either in the area of data generation/collection or formal risk assessments. They include:

- recommendation to perform additional research when data gaps are identified;
- recommendation for future detailed risk assessment;
- recommendation to continue monitoring and collect information;
- recommendation for specific risk management options;
- additional discussions with knowledge networks.

The ERI procedure aims to raise awareness and to improve preparedness to future food/feed safety challenges as well as to identify future data and methodological issues for risks assessment. It aims at identifying risks pro-actively before they have any impact or at an early stage of development. It has, therefore, a predictive and anticipatory nature (EFSA, 2012b). ERI is distinct from the detection of known risks leading to emergency (or crisis) conditions. Crisis management and early warning systems have, generally, different aims, tools and principles. They generally result from a lack of compliance with existing regulations and are dealt with through specific Commission procedures[4]. They are reactive systems designed to collect, analyse and interpret data from hazard or disease surveillance programmes

[2] https://www.efsa.europa.eu/sites/default/files/scientific_output/escoemriskdefinition.pdf
[3] https://www.efsa.europa.eu/sites/default/files/event/20191205_m.pdf
[4] Corrigendum to Commission Decision No. 2004/478/EC of 29 April 2004 concerning the adoption of a general plan for food/feed crisis management. OJ L 212/60, 12 June 2004, pp. 60–68.

after they have occurred. These systems are useful to support decision makers in implementing control and mitigations measures (EFSA, 2012b).

1.3. Present weaknesses and opportunities leading to the CLEFSA project

The Standing Working Group on Emerging risks[5] has revised the EFSA ERI process (EFSA et al., 2018b) identifying strengths, weaknesses, opportunities and threats of the current procedure. It was concluded that a systematic approach to the identification of emerging issues based on experts' networks is the major strength of the procedure. However, some weaknesses were identified (Afonso et al., 2019). Those which have triggered the development of the CLEFSA project are listed below:

- Focus on single issues at short and medium term, identifying new risks that are in the process of emerging.
- Limited capacity for carrying out exploratory scans based on 'open searches', implying a reduced capability of capturing a broader range of issues.
- No consistent weighting, ranking and prioritisation of the identified issues.
- Poor representation of certain stakeholder groups (e.g. citizens).
- Lack of close collaboration between the various institutions responsible for food and feed safety.
- The application of the EFSA Guidance on uncertainty (Benford et al., 2018) to the area of ERI is difficult due to data scarcity.

One of the areas proposed for further development was the implementation of a food system-based approach in the ERI to understand the complex interactions and dynamics that exist between players and the drivers operating in the food system environment over different time horizons.

[5] The Standing Working Group on Emerging Risks (SWG-ER) is a Scientific Committee group whose main objective is to provide scientific advice to support EFSA to draft procedures for the screening and analysis of information with a view of identifying emerging risks in the fields within its mission.

2. Data and Methodologies

The CLEFSA project addresses the weaknesses identified in the ERI process (see Section 1.3) and contributes to reviewing the ERI process by the following actions:

Emerging issues identification:

- Enhance foresight capability, using driver analysis and scenarios of change as tools contributing to the implementation of a food system and holistic approach to food safety.
- Improve the understanding of (a) interactions and dynamics between the food system and food safety, with global megatrends acting as potential drivers of change; (b) a broad range of signals, including weak signals and issues at medium- and long-time frames.
- Improve horizon scanning capacity through collaboration with wider audiences than the EFSA Emerging Risks Networks (whole EFSA staff, EFSA panels, Scientific Committee) and networking with other EU institutions and international organisations.
- Explore the potential of citizen science capacity for ERI.
- Test media monitoring and text mining tools by strengthening a world-wide cooperation with Agencies and Institutions already active in this sector.
- Implement search protocols (i.e. data retrieval systems) that capture and combine structured and unstructured data from a variety of data sources.

Emerging issues characterisation:

- Develop a Multi-Criteria Decision Analysis (MCDA) system for issue characterisation, accompanied by a transparent and guided scoring system to ensure reproducibility.
- Enlarge the pool of experts to characterise emerging issues. A specific network (CLEFSA network) for characterisation of emerging issues is proposed. The network includes experts from different scientific fields of expertise (biological and chemical hazards, impact on human, animal, plant health and environment). Participatory characterisation ensures that the issues are deemed relevant to the priorities and policies of EFSA's audience.
- Explore methodologies for handling the uncertainty in probability estimates for various criteria.
- Develop visualisation approaches to make sense of the vast amount of information retrieved through an easily communicable expert assessment.
- Implement effective characterisation in multilateral, international cooperation involving different stakeholders.

Figure 2 represents the overall CLEFSA procedure, designed for emerging issues identification, characterisation and analysis, consisting in the following steps:

1) setting up the CLEFSA network
2) emerging issues identification
    a) definition of identification criteria
    b) identification of emerging risks issues for characterisation
3) emerging issues characterisation – MCDA
    a) definition of characterisation criteria
    b) design of methods and tools for the characterisation of emerging issues
    c) characterisation of emerging issues
4) analysis of results and reporting.

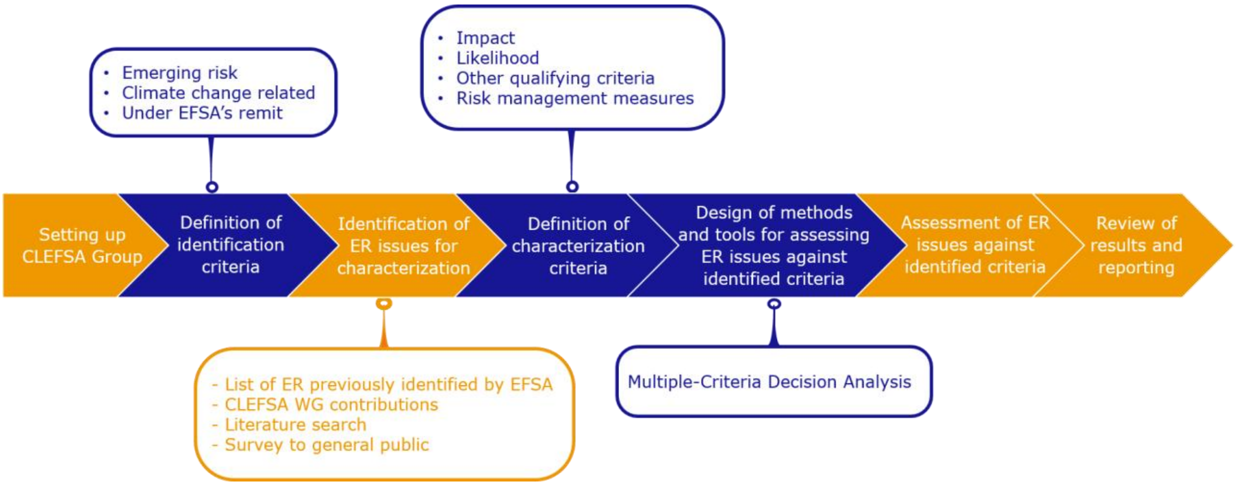


Figure 2: CLEFSA workflow

2.1. CLEFSA network

A network of 14 experts involved with climate change and its effects on food/feed safety, plant, animal health and nutritional quality was created (Table 1), covering a wide range of expertise in different aspects related to impacts of/adaptation to climate change. The experts belong to academia, government agencies and international bodies. This network has contributed to the identification, characterisation and analysis of emerging issues.

These experts were identified from:

- international intergovernmental organisations with relevant expertise (OIE, JRC, FAO, WHO, WMO, UNEP, EEA, UNESCO-IOC, ECDC, Intergovernmental Panel on Climate Change (IPCC));
- coordinators of relevant international projects (EuroCigua[6]) and programmes (the IOC-UNESCO programme on HABs- GlobalHAB[7]).

Table 1: CLEFSA network composition

Organisation/project	Contact point
World Organisation for Animal Health	Stefano Messori
European Centre for Disease Prevention and Control	Jan Semenza
Joint Research Centre	Andrea Toreti; Jessika Giraldi
European Environment Agency	Hans-Martin Füssel
EuroCigua project	Jorge Diogène Fadini
UNESCO-IOC – SCOR GlobalHAB programme	Elisa Berdalet
University California Los Angeles (UCLA), Lead Author of the IPCC Assessment Report Health Chapter	Maria Cristina Tirado
Florence University, Lead Author of IPCC Assessment Report	Marco Bindi
UNESCO-Intergovernmental Oceanographic Commission	Henrik Enevoldsen
Food and Agriculture Organisation	Keya Mukherjee
World Health Organisation	Kim Petersen
World Meteorological Organisation	Robert Stefansky
CNR Institute Bioeconomy	Federica Rossi
UN Environment Programme	Pinya Sarasas

The group has:

[6] http://www.aecosan.msssi.gob.es/AECOSAN/web/ciguatera/home/aecosan_home_ciguatera.htm
[7] http://www.globalhab.info/

- supported the exchange of data, information and methods;
- supported the definition of the criteria for identification and characterisation;
- assisted in the identification of emerging risks to human, plant, animal health and nutrition;
- assisted in the development of a characterisation methodology;
- facilitated the discussions held to score the identified issues according to the predetermined criteria using the established procedures;
- supported the analysis and visualisation of identified issues;
- supported the identification of relevant conclusions and recommendations;
- assisted in the identification of research needs;
- shared information about work programmes to avoid duplication of effort.

2.2. Identification criteria

The criteria for identification of emerging issues potentially affected by climate change are based on the definition of emerging risk/issue (Section 1.2). They reflect the way in which climate change may affect food and feed safety, plant and animal health and nutritional quality, namely:

- driving the emergence of new biological, chemical or physical hazards;
- increasing the exposure to a known biological, chemical or physical hazard;
- increasing the toxicity/pathogenicity of a known hazard or the susceptibility to a known hazard;
- changing the micronutrient and macronutrient composition of environmental matrices and food products;
- affecting other drivers, like the amount and type of pesticides/veterinary products or fluctuations in trade volumes and prices.

The resulting criteria for identification are therefore the combination of the following (A), (B) and (C) aspects:

(A):

- newly identified hazard to which a significant exposure may occur

  or
- known hazard with an unexpected new or increased significant exposure

  or
- known hazard with new or increased toxicity, pathogenicity or susceptibility in the host population

  or
- changed composition of environmental matrices (soil, water, air) and food products potentially leading to changed intake of micro/macronutrients

  or
- interconnected driver.

(B) Affecting:

- human health via food

  or
- plant health via the environment (including vectors)

  or
- animal health via feed chain and the environment (including vectors)

  or
- nutritional quality via food.

and

(C):

- linked with climate change or its interconnected drivers.

These criteria are illustrated in Figure 3 below. The geographic scope of the issues identified in the CLEFSA project includes regions outside of Europe if evidence or modelling suggest that they may potentially pose a risk, at some point, to Europe. Species not currently present in Europe (like the glassy winged sharpshooter for plant health) may still be relevant, if the experts involved in the assessment consider that they may appear in a future climate change scenario. Potential emerging risks arising in Europe because of import of contaminated food items from EU non-European territories (e.g. oversea territories) will not be considered. The scope within which issues are identified covers all areas within EFSA's mission.

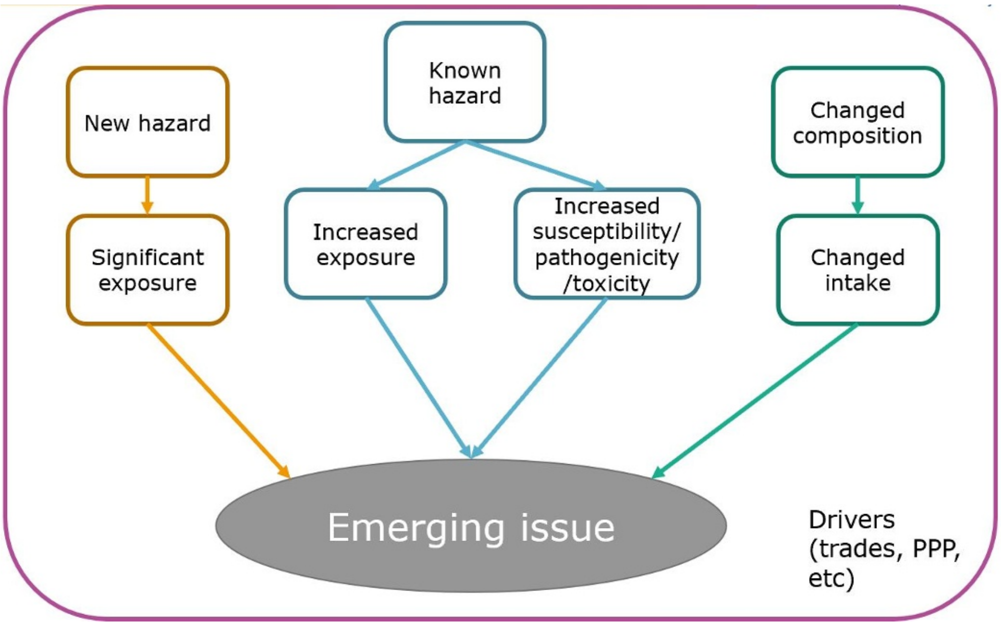


Figure 3: Criteria for the identification of emerging issues

2.3. Emerging issues identification

Information about signals of change in the food and feed system, plant, animal health and nutritional quality potentially affected by climate change, was collected through:

- crowdsourcing survey aimed at the general public
- literature search
- text mining tools analysing social media and scientific literature (Tools for Innovation Monitoring (TIM)/EMM/MediSys tool)
- EFSA's past work related to climate change
- EREN
- StaDG-ER
- TIM/EMM/MediSys tool
- CLEFSA network

2.3.1. Survey

Traditional data sources may not be enough to generate insights into the dynamics of change. New and non-traditional sources of data are required to develop forward-looking assessments based on horizon scanning and other foresight approaches. Horizon scanning can be used in the ERI process to anticipate medium to longer-term issues, by analysing observable trends or patterns within a vast but often incomplete and disconnected information and data retrieved from a wide variety of information sources (e.g. blogs, trade or business publications, magazines, newspapers, news alerts, social media), beyond traditional sources of evidence (e.g. academic journals, reports, conferences, specialised scanning systems).

When analysed through a specified frame or connected with other data such as those emerging from a more targeted search of the scientific literature or via media monitoring (Palomino et al., 2013), these data can support the identification of larger pattern informing about the possibility of future food safety issues. The main aspects of horizon scanning that differentiates it from other foresight approaches are its ability to distinguish between different forms of change (i.e. constant, incremental, volatile or rapid change), focus on weak signals[8], as well as persistent problems or trends and including issues at the margin of current thinking (low probability, high impact incidents). However, in order to be coherently applied across food and feed safety, animal health, plant health and nutritional quality, horizon scanning needs to be conducted in a systematic and harmonised fashion.

The ability of horizon scanning to capture weak signals can be enhanced by ensuring that a wide and diverse range of insights and information sources is gathered. To this end, the involvement of 'citizens' – usually members of the public – 'crowdsourcing' (the practice of obtaining information or input into a task or project by enlisting the services of a large number of people, typically via the internet) or social media analysis could extend the data provision and increase the local resolution (in the sense that citizens are more sensitive to local problems or local climate conditions). The idea behind citizen science is that citizens produce data and monitor issues that affect them in order to carry out change and provide inputs, despite not being formally trained experts or professionals in the topic of study (Fritz et al., 2019). Citizen science has already been used in studies on the impacts of climate change, in particular for monitoring progress towards Sustainable Development Goal 13 ('Take urgent action to combat climate change and its impacts') (Fritz et al., 2019).

The type of citizen contribution could vary widely: from direct identification of emerging risks connected to climate change to observing and reporting how climate change is impacting their daily lives[9]. The public has developed a strong interest in health and food safety and, now more than ever, they are looking for meaningful ways to contribute to scientific research, risk assessment and decision-making processes (Naydenova et al., 2019).

Within CLEFSA, an online survey (EU survey: https://ec.europa.eu/eusurvey/runner/ClimateChange_Survey_2018) aiming at the collection of a broad range of horizon scanning issues was launched on 6 February 2018 and lasted until the 7 March 2018.

The survey was addressed to anybody with an insight on this topic – from the broader scientific community (including the CLEFSA network) with an interest/expertise in climate change to the general public. In particular the addressees of the survey were:

- whole EFSA staff;
- EFSA Panels (BIOHAZ, CONTAM, NDA, PLH, AHAW);
- EFSA Scientific Committee;
- EFSA working group members, Network members, external experts/partners and their circles;
- Emerging Risks Networks;
- EFSA registered stakeholders;
- Art. 36 organisations;
- EFSA Advisory Forum and Focal Points;
- CLEFSA network;

[8] Weak signals are past or current change with ambiguous interpretations of their origin, meaning and/or implications (http://wiwe.iknowfutures.eu/what-is-a-weak-signal/)

[9] https://www.iseechange.org/

- European Commission: DG-SANTE, DG-ENV, DG-CLIMA, DG-AGRI, DG-RTD;
- UN Organisations: FAO, IPPC, IPCC, WHO, WMO, UNESCO-IOC;
- INFOSAN;
- Euro-Mediterranean Centre on Climate Change (CMCC);
- Istituto Superiore Protezione e Ricerca Ambientale (ISPRA);
- Istituto Ricerca sulla Acque (IRSA-CNR);
- Bologna University;
- Instituto Português do Mar e da Atmosfera (IPMA);
- Coordinators of relevant international project (EuroCigua, SafeFoodTomorrow).

The following communication channels were used:

- EFSA website: https://www.efsa.europa.eu/it/news/climate-change-and-food-safety-complete-efsa-survey-0 ;
- emails;
- global cooperation newsletter;
- weekly highlights newsletter;
- stakeholders newsletter;
- newstory (for Focal Point members);
- social media channels (https://twitter.com/EFSA_EU/status/964433689953341440; https://twitter.com/MurielSuffert/status/964436505438584833; https://www.linkedin.com/feed/update/urn:li:activity:6370203952998289408);
- internal communication for ESFA staff (Portal news with link to survey: https://portal.efsa.europa.eu/portal/server.pt?CommunityID=640&parentname=Login&control=SetCommunity&parentid=4&in_hi_userid=546860&PageID=0&cached=false&space=CommunityPage);
- slide on the EFSA screen to advertise the opening of the survey;
- participation in internal events like the RASA watch the week and REPRO Wrap-up;
- IPPC website: https://www.ippc.int/en/news/european-food-safety-authority-efsa-survey-on-climate-change-and-emerging-risks-for-food-safety-including-plant-and-animal-health-clefsa/;
- EEA Climate-ADAPT website: https://climate-adapt.eea.europa.eu/news-archive/european-food-safety-authority-survey-on-climate-change-and-risks-for-food-safety;
- European and Mediterranean Plant Protection Organization (EPPO) social media: https://twitter.com/MurielSuffert/status/964436505438584833.

The survey was accompanied by a note providing background information, objectives of the consultation and timeline. The survey website included a list of emerging issues which have already been considered by EFSA and potentially linked with climate change, inviting submitters to exclude them and propose new issues. This is the list:

- occurrence of ciguatoxic fish in European marine waters;
- more frequent and more intense cyanobacteria blooms in freshwater reservoirs;
- increased occurrence of β-methylamino-L-alanine (BMAA) producing cyanobacteria and diatoms;
- increased potential for growth of marine bacteria producing tetrodotoxins;
- increased norovirus contamination of coastal waters;
- increased risk of contamination of mycotoxins in maize, wheat and rice;

- increased area of potential establishment and spread of *Bemisia tabaci* and the viruses it transmits;
- northwards expansion of wild boar, reservoir of pathogens such as the African Swine Fever virus.

The template used for the survey (see Figure 4) included the following information:

- a short title with the key aspects of the proposed emerging issue;
- area(s) in the EFSA's remit;
- short description of the identified issue;
- criterion for considering it as an emerging risk;
- information source, including date of publication and the attached document, when possible.


* 1 - OTHER EMERGING ISSUE FOR FOOD SAFETY POTENTIALLY RELATED TO CLIMATE CHANGE

Please insert a short title with the key elements of the proposed emerging issue. Please make sure not to insert issues that are already present in the list above.

* AREA(S) IN THE EFSA'S REMIT

- [x] plant health
- [x] animal health
- [ ] contaminants
- [ ] biological hazards for human health
- [ ] nutrition
- [ ] pesticides
- [ ] GMOs
- [ ] FEED
- [x] FOOD INGREDIENTS AND PACKAGING

* DESCRIPTION

Please insert a short description of the identified issue. Relevant web links can be included here.

aaa

* WHY DO YOU CONSIDER IT AN EMERGING ISSUE FOR FOOD SAFETY, INCLUDING PLANT AND ANIMAL HEALTH?

Please explain why you think this issue may harm human, animal and/or plant health through the food chain for humans, through the feed chain and the environment for animals and through the environment for plants

- new hazard
- new or increased exposure to a known hazard
- new or increased susceptibility to a known hazard
- other

* INFORMATION SOURCE

- [ ] Specialised scanning systems
- [ ] Scientific publications
- [ ] Reports
- [ ] Blogs
- [ ] Conferences
- [ ] Trade or business publications
- [ ] Magazines
- [ ] Newspapers
- [ ] Social media
- [ ] other

Date of publication

DD/MM/YYYY

If possible, please upload the relevant document

The maximum file size is 1 MB

Select file to upload

Figure 4: CLEFSA survey template

The number of hits received by the survey website from 1st February to 31st March is illustrated in the Figure 5 below.

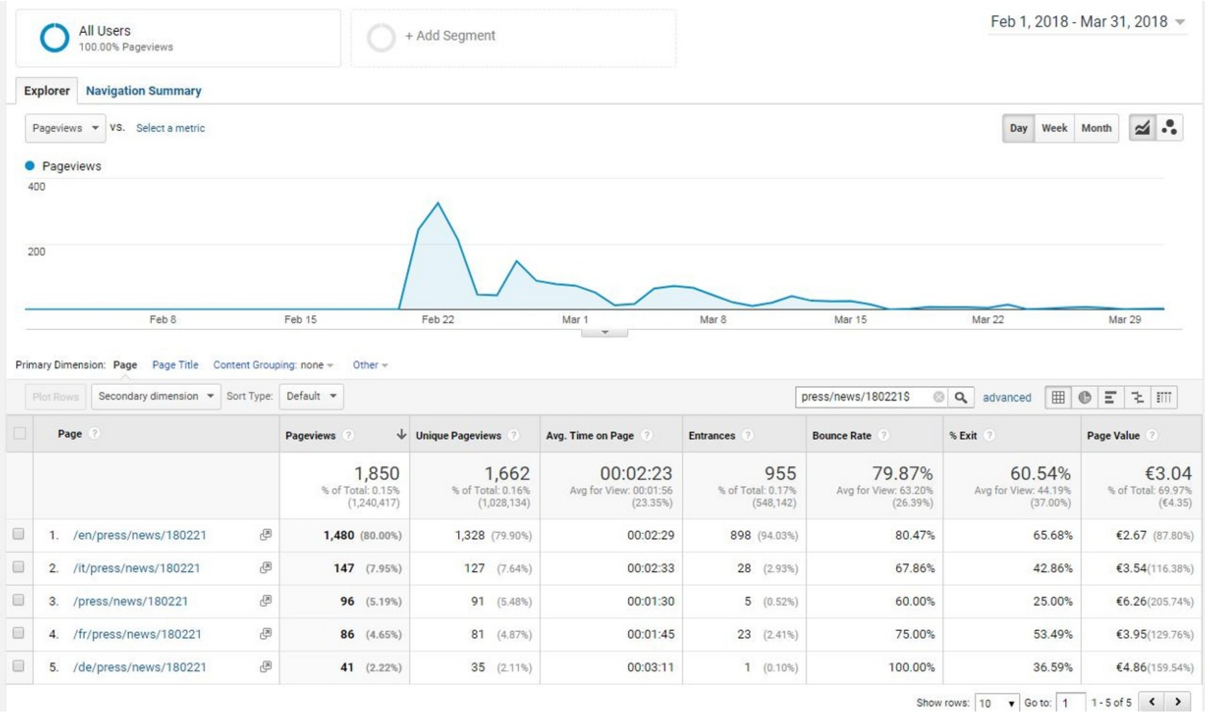


Figure 5: Number of hits received in the survey

Taking into consideration just the English version for easiness, it was in the top 10 most viewed news in the EFSA's website in the timeframe 1 February to 31 March (see Figure 6).

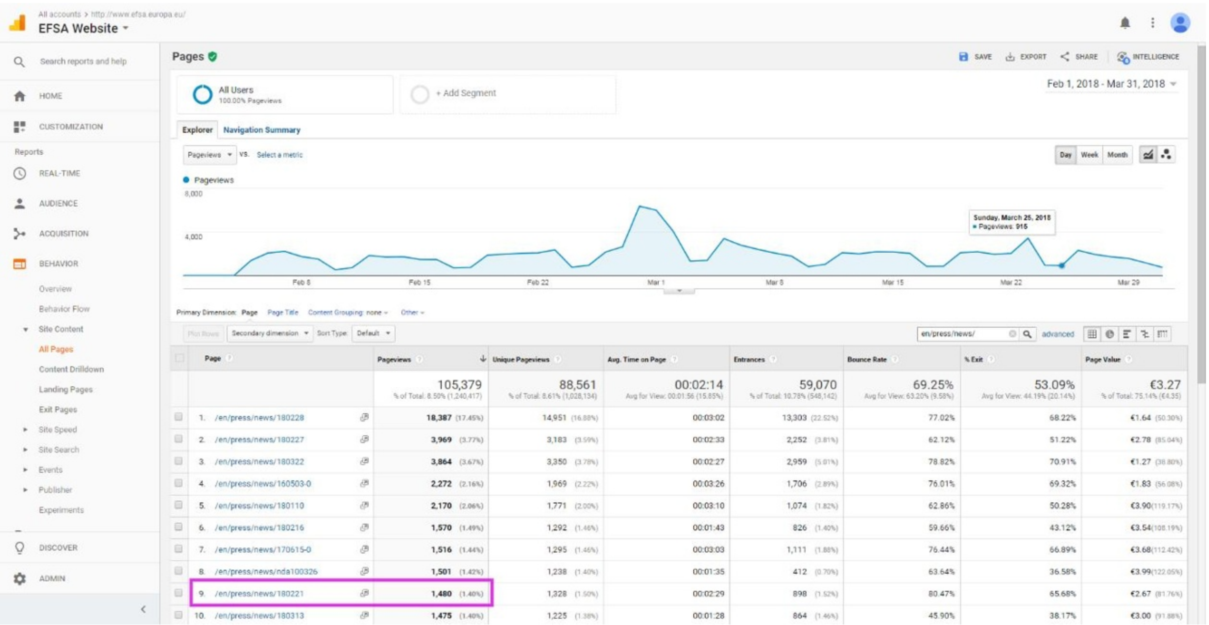


Figure 6: Top 10 most viewed news in the timeframe 1 February to 31 March in the EFSA's website

It is important to note that involving a large group of participants with diverse backgrounds in a survey creates several challenges: appropriate processes must be put in place to ensure that crowdsourced issues are relevant, and information provided is reliable. This challenge is handled through the characterisation process described in Section 2.6. Despite being open to lay people, most of the respondents were indeed professionals in the fields of EFSA's interest. The issues received in the survey were screened by the EFSA secretariat supported by the CLEFSA network, through the following steps:

- Elimination of the issues not matching the identification criteria or outside the EFSA's remit.
- Attribution of the correct EFSA's areas.
- Separation of generic (low granularity) issues or drivers[10], not identifying a specific hazard but a wide category. These issues have not been characterised. They are listed and discussed in Section 4.3 and in the Appendix D.
- Splitting issues containing more than one agent in as many issues as the number of agents (supported by the CLEFSA experts if needed).
- Linking issues related to the same agent.
- Asking for clarification to the issue submitter when unclear.

Non-food-borne zoonotic diseases (vector-borne zoonosis, for example diseases brought by ticks biting humans) were excluded from the following steps of characterisation and analysis. The documents or links provided for the issues as supporting information have been complemented by literature search when needed.

2.3.2. EFSA's past work related to climate change

Since the 2008 Joint EFSA-FAO-WHO Europe seminar on 'Climate change and its health impacts on food/water safety and nutrition[11]', EFSA has been committed to providing climate change considerations in its assessments. Table 29 in Appendix G summarises the scientific work conducted by EFSA related or potentially related to climate change, categorised per EFSA's remit and type of organism. An informative note has been published on the EFSA website, including the activities conducted in the areas of plant health, animal health, biotoxins and biological hazards potentially affected by climate change[12].

2.3.3. EFSA Emerging Risks Networks

A retrospective search has been held to collect the issues that have been identified through the EFSA Emerging Risks Networks (EREN, and StaDG-ER) meetings and are connected to climate change. The search covered the documents of secretary notes, briefing notes, short and mini issues from the beginning of networks creation. The keywords used were: 'climate', 'climat*', 'weather', 'temperature' and 'environment'.

2.3.4. Literature search

Considering the limited resources available, a simplified process has been developed to retrieve literature on emerging issues associated with climate change. While most of the published literature focuses on the effects of climate change on specific food safety aspects (biotoxins production, invasive species, abundance and geographic distribution of disease vectors etc.), the literature search conducted in the context of CLEFSA has been based on previous efforts covering the effects of climate change on food safety in general:

- FAO, 2008 and FAO, 2020
- Miraglia et al., 2009
- Tirado et al., 2010
- Barange et al., 2018
- WHO, 2018a

[10] The generic low granularity issues are not going to be characterised.
[11] https://www.efsa.europa.eu/it/events/event/climate-change-and-its-health-impacts-foodwater-safety
[12] https://www.efsa.europa.eu/en/topics/topic/climate-change-and-food-safety

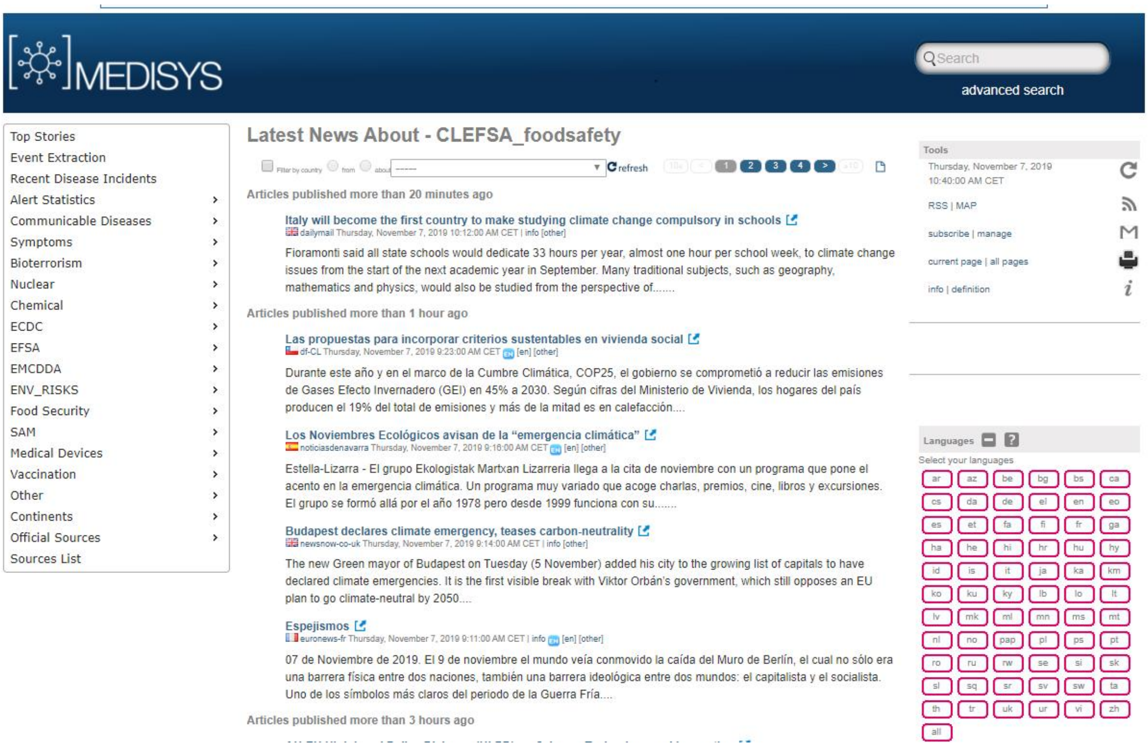
- Uyttendaele and Hofstra, 2015
- Climate Change Library[13].

In most cases, however, the issues used in the following characterisation exercise have been identified in literature linked to the supporting information provided in the survey.

2.3.5. Europe Media Monitor/MediSys and Tools for Innovation Monitoring tools

EFSA has also explored the potential use of the text mining and data collection, analysis and visualisation tools developed by the European Commission's Directorate-General Joint Research Centre (JRC) for the identification of emerging issues[14]. Two relevant data intelligence tools have been developed at the JRC Competence Centre on Text Mining and Analysis (TMA): Europe Media Monitor (EMM)[15] and Tools for Innovation Monitoring (TIM)[16]. EMM was established in 2002 for monitoring open-source news information coming from both traditional and social media (unstructured data). EMM continuously monitors more than 8.000 websites of the world's online media and extracts information in almost 70 different languages. It presents the latest news from those websites and classifies them according to subjects. EMM is updated every 10 minutes, 24 hours per day, 7 days a week. Over the past years, JRC has developed some customised versions of EMM to satisfy specific needs. One of these is the Medical Information System (MediSys) for real-time news analysis targeted on medical and health-related topics. The database of MediSys includes websites focused on public health area, food safety, plant health and environmental, ecological issues.

To retrieve online articles for CLEFSA project, it was requested to JRC to set up extra categories addressing the climate change and food safety issues (Figure 7). The search string used for this purpose is shown in Table 2. The keywords used have also been translated into Greek, Italian and Spanish language. An automatic daily newsletter containing articles extracted by MediSys was set up for the analysis of the published articles.



[13] https://www.mendeley.com/campaign/climate-change
[14] https://ec.europa.eu/knowledge4policy/text-mining_en
[15] http://emm.newsbrief.eu/NewsBrief/clusteredition/en/latest.html
[16] http://www.timanalytics.eu/

Figure 7: CLEFSA on MediSys tool

The TIM Analytics project regroups a collection of tools and services that helps policymakers to extract knowledge from complex and large datasets of semi-structured data (e.g. scientific literature), in various policy fields. One of the tools (TIM Technology) specifically focuses on the monitoring of innovation and technological development: it enables the users to monitor thematic Science and Technology areas and to carry out various analyses. TIM can extract information from more than 60 million documents ranging from 1996 to today. The database contains scientific publications (Elsevier's Scopus), patents (European Patent Office-PATSTAT) and EU-funded projects (CORDIS). Scientific publications include research articles, conference proceedings, reviews and book chapters. All the documents in the database are in English[17].

To address the scope of the CLEFSA project, TIM Technology was used to create specific datasets focused on the concept of climate change as a driver of emerging risks for food and feed safety, plant, animal health and nutritional quality. The search queries, composed by Boolean operators and keywords, were designed according to the scope of the project. TIM Technology can be considered advantageous to use in the event of complex search strings and for the visualisations of the results. TIM Technology[18] was used by JRC to retrieve and select scientific publications to identify emerging issues and contribute to the CLEFSA online survey through the submission of some articles from both scientific literature and online magazines. The sources include scientific publications, patents and EU-funded projects.

TIM Technology allows the users to create several datasets, which are collections of documents that will be analysed and visualised together. The documents are retrieved from the TIM database by using a search string. The design of a search string and the selection of keywords are essentials to retrieve relevant documents. For the scope of the CLEFSA project, the search string was designed to combine two textual concepts: words describing climate change and words describing the major areas of impacts investigated by the project. The query used in this specific case is a combination of concepts related to climate change (e.g. 'heat wave', 'fluctuating temperatures', 'intense storms' , 'droughts', 'fluctuating sea level') together with the keywords of the selected CLEFSA categories (e.g. 'plant health', 'animal health', 'zoonoses'). In addition, a time filter was applied to retrieve only recent publications (Table 2).

TIM Technology also displays the list of documents collected in the dataset which contains some basic information about document such as type (for scientific publications: articles, book chapters, reviews, conference proceedings), year of publication, abstract and a link to the original location (Figure 8). The articles retrieved from the TIM search were selected from the list of documents (Figure 9) and submitted to the CLEFSA survey as emerging issues potentially linked to climate change.

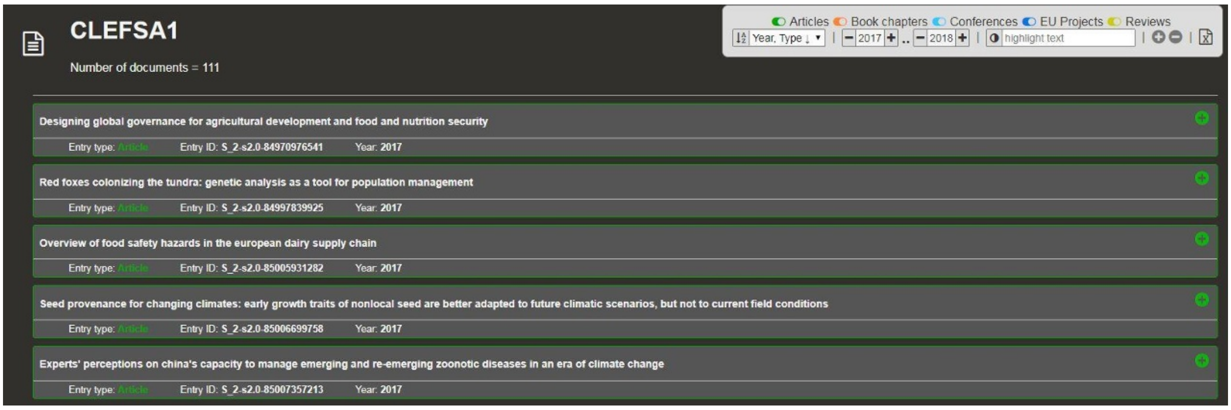


Figure 8: Example of the list of documents retrieved for CLEFSA ('Document list' page)

TIM Technology can then be used to perform several types of analysis on the datasets, including analysing author keywords and keywords computed by a text mining algorithm which calculates the relevance of keywords for the dataset ('Relevant Keywords').

[17] http://tech.timanalytics.eu/html/timData.html
[18] https://www.timanalytics.eu/website/

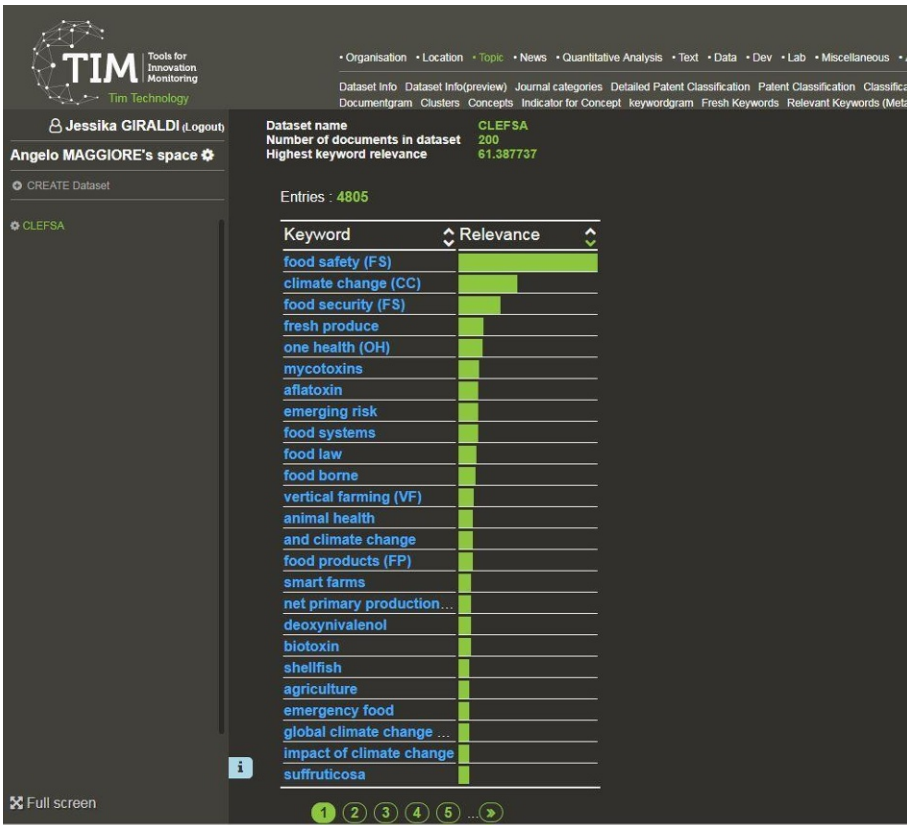


Figure 9: Example of TIM output for CLEFSA project: 'Relevant keywords'

Indicators can be applied to keywords to further the analysis. For example, the indicator 'activeness' can be used to highlight the keywords with high frequency of use over a specific period. In the present case, activeness for the last 3 years was calculated for each keyword, giving some indications on recent trends in the topic being investigated (Figure 10).

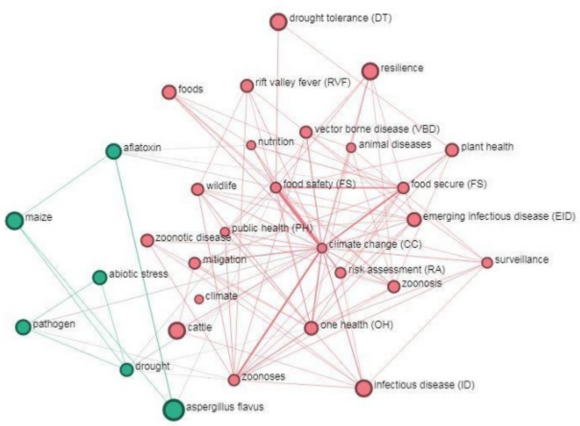


Figure 10: Keywords graph with indicator activeness: the size of a node represents the 'Activeness3' of the keyword (number of documents where the keyword is mentioned over the last 3 years / total number of documents)

Other examples of types of information and visualisations performed by TIM Technology are shown in Figures 11 and 12.

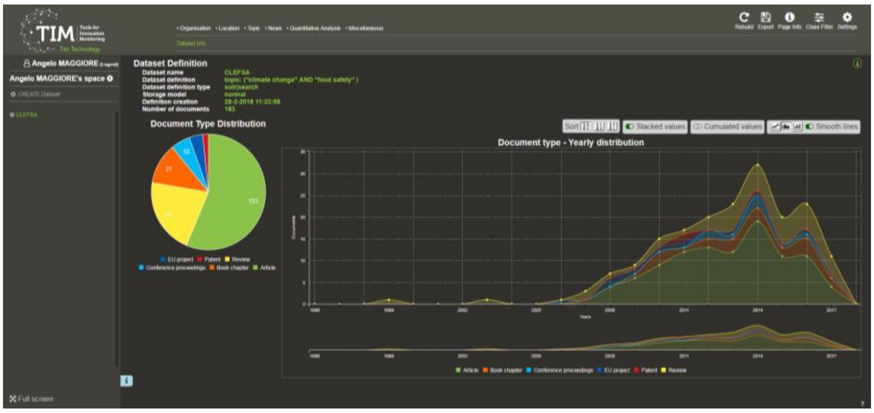
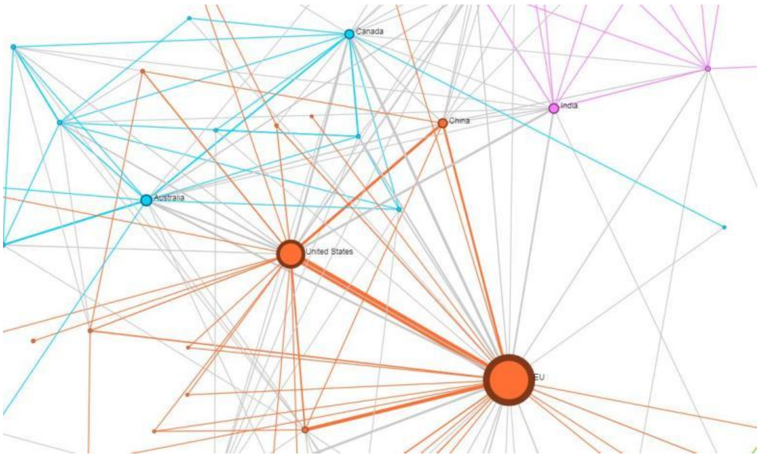


Figure 11: Example of TIM output for the CLEFSA project which displays information about the dataset, the distribution in types of documents and trends in time. The sources in TIM are scientific publications (articles, book chapters, reviews and conference proceedings), patents and EU projects



The size of the nodes represents the number of documents retrieved in the countries where the players are located. The edges (lines between two nodes) show the collaborations between those countries i.e. publications or patents or EU grant where players from these two countries contribute or take part.

Figure 12: Example of TIM output for the CLEFSA project: countrygram

EFSA explored further the opportunities of the TIM tool applying different search strings for each area of interest. In detail, the keywords 'climate change', 'climat*', 'extreme weather' combined with 'animal health', 'welfare', 'plant health', 'food safety', 'feed safety', 'emerging risk', 'nutrition*', 'contamin*' were searched in TIM sources for the time period 2017 to 2019. The search strings used are shown in Table 2. Many of the results received have been also identified in the online survey, such as issues related to mycotoxins, aflatoxins, marine and freshwater biotoxins and vector-borne diseases.

Table 2: Search strings

Editor	Tool	Search string
JRC	MediSys	(climate+change% OR climate OR extreme+weather OR (cambiamento+climático) OR (cambiamenti+climatici) OR (fenómeno+meteorológico+extremo) OR (fenómenos+meteorológicos+extremos) OR (eventi+meteo+estremi) OR (condizioni+meteo+estreme) OR (condizioni+metereologiche+estreme) OR (cambio+climático) OR (Κλιματικ%+αλλαγ%) OR (Αλλαγ%+κλίματ%) OR (Αλλαγ%+τ%+κλίματ%) OR (Μεταβολ%+κλίματ%) OR (ακραίος+καιρός) OR (ακραί%+καιρικ%+φαινόμεν%) OR (ακραί%+καρικ%+συνθήκ%)) AND (welfare OR (seguridad+alimenticia) OR (seguridad+de+alimentación) OR nutrition% OR nutrizione OR (sanidad+vegetal) OR contamin% OR (plant+health) OR (salud+animal) OR (salute+delle+piante) OR (salute+degli+animali) OR (feed+safety) OR (food+safety) OR (animal+health) OR (sicurezza+alimentare) OR ευπορία OR (κοινωνική+πρόνοια) OR ευτυχία OR πλούτος OR τροφή OR θρέψη OR Φυτοϋγειονομικ% OR (Φυτοϋγειονομικ%+προϊό%) OR (υγεία+του+φυτού) OR (υγεία+των+φυτών) OR (ασφάλεια+των+ζωοτροφών) OR (ασφάλεια+τροφίμων) OR (ασφάλεια+των+τροφίμων) OR (υγεία+ζώων) OR (υγεία+των+ζώων))
JRC	TIM	topic: (("climate change" OR "heat wave" OR "fluctuating temperatures" OR "intense storms" OR "droughts" OR "fluctuating sea levels") AND ("animal health" OR "plant health" OR "food safety" OR "zoonoses") AND (emm_year:[2017 TO 2018]))
CLEFSA team	TIM	topic: (("climate change" OR climat* OR "extreme weather") AND ("food safety" OR "emerging risk") AND (emm_year:[2017 TO 2019])) topic: (("climate change" OR climat* OR "extreme weather") AND ("feed safety" OR "emerging risk") AND (emm_year:[2017 TO 2019])) topic: (("climate change" OR climat* OR "extreme weather") AND ("animal health" OR "animal welfare") AND (emm_year:[2017 TO 2019])) topic: (("climate change" OR climat* OR "extreme weather") AND "plant health" AND (emm_year:[2017 TO 2019])) topic: (("climate change" OR climat* OR "extreme weather") AND (contamin* AND "food safety") AND (emm_year:[2017 TO 2019 topic: (("climate change" OR climat* OR "extreme weather") AND ("food safety" AND nutrit*)AND (emm_year:[2017 TO 2019]))

2.3.6. CLEFSA network

The CLEFSA network has assisted in the identification of emerging risks to human, plant and animal health and nutrition potentially associated with climate change.

2.4. Characterisation criteria

The choice of the characterisation methodology and the selected criteria depend on the purpose of the characterisation exercise, which needs to be as clearly formulated as possible. The purpose of characterisation is to support decisions on follow-up actions (like discussion with knowledge networks, promotion of data collection and/or generation, follow-up risk assessments) and relevant players (risk managers, risk assessors, researchers).

A MCDA method was chosen because it provides a systematic way to integrate and compare information from a broad range of signals and a variety of sources, and it offers guidance for the experts involved in the characterisation, for the risk assessors (panel working in related areas, i.e. follow-up risk assessments) and risk managers (ECDC, 2015). MCDA was used to help characterise emerging issues according to multiple aspects in a standardised way such that later the characterised issues can be jointly analysed and compared, rather than creating a ranked list or choosing a single most relevant issue. To our knowledge, this represents a different and novel application of MCDA in a health-related context (Del Rio Vilas et al., 2013).

MCDA requires identifying a set of criteria for characterisation (including a scoring system) and to apply them to each identified issue in a standardised and reproducible manner. The possibility of calculating an overall score in the evaluation of the issues against the criteria was proposed and discussed. However, this would imply an implicit weighing of the criteria for integration, which is considered as not falling within the remit of the assessor (rather of the risk management).

The established criteria support a standardised and comparable characterisation of the emerging issues retrieved in the CLEFSA project. Although characterisation is not providing an overall risk, the resulting list of characterised emerging issues could aid decision makers to make informed decisions and use the correct resources to handle potential emerging risks. Considering the limited evidence available in the area of emerging risk, criteria characterisation implies a weight-of-evidence process based on a subjective judgement. This increases the levels of uncertainty and limits reproducibility. However, CLEFSA proposes strategies to document and visualise uncertainty in an easily communicable way.

The established criteria support the characterisation of the emerging issues retrieved in the CLEFSA project. It is important to note that characterisation is performed within the specific area of interest and has been repeated for each relevant area by different experts having expertise in the specific area. In particular, for zoonotic diseases (e.g. West Nile Fever or anthrax) a separate assessment has been conducted for the animal and human health part. In most cases the risk managers that will need to take a decision would be different for animal, plant and human health, so that they might need an assessment considering risks for their specific sector of interest. In addition, possible interactions among different sector need to be considered. The criteria used to characterise each identified issue are indicated below. They need to be applicable to all issues and independent of each other.

The criteria need to be formulated and described very clearly to reduce, as much as possible, room for interpretation and inter-assessor variations. Clear descriptions on how to interpret the criteria and applying the score have been provided. They are a of from intense discussions with the CLEFSA network.

In order to avoid the potential bias that could emerge if the experts designing the criteria are also involved in the assessment of the issues, EFSA has taken the leading role in the design of the criteria and the scoring system. A discussion with the experts has followed to make sure that criteria and scoring system would be correctly understood. Finally, the characterisation criteria were agreed through a resource-intensive process. Several online and physical meetings were held with the members of the CLEFSA network for that purpose. The criteria were based on those currently used in the EFSA ERI procedure. The characterisation of the identified emerging issues is based on:

- criteria for scoring;
- other qualifying criteria;
- risk management measures.

The characterisation of these criteria is supported by expert assessment in the form of evidence and appropriate justifications. Figure 13 below outlines the process of characterisation that is detailed in this section.

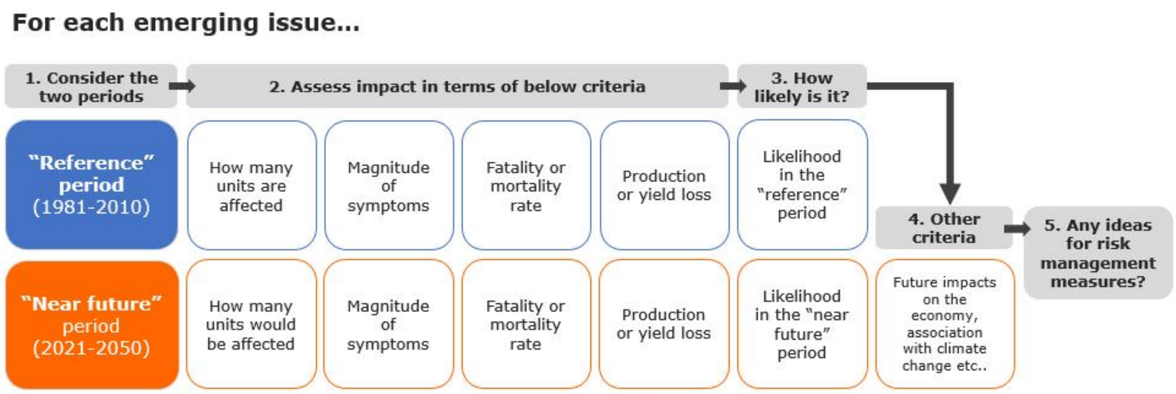


Figure 13: Schematic diagram for the characterisation procedure followed by the experts for the assessment of each identified issue

These criteria have been pre-tested with a group of internal EFSA colleagues. They have been extensively discussed by the CLEFSA network in order to achieve an agreed description, suitable for different areas.

2.4.1. Scoring

The two main criteria used for characterisation are impact and likelihood, representing the two components of risk. These two criteria are linked to a scoring system, which is described in Table 3 below.

Table 3: Criteria for scoring and their description. The description provided in the table helps the user to identify the aspects to be considered during the assessment and scoring of the issue

Criteria	Description
Impact	*Severity, duration and/or frequency* of the potential effects of the hazard considered in the identified issue considering 'reference' and 'near-future' conditions, the latter characterised by the selected climate change scenario. The following aspects should be considered: • number of individuals or units (for plant health) affected in Europe; • magnitude of symptoms/signs, including the duration and frequency of the effects. For vector-borne diseases please consider the most relevant disease the vector may transmit; • case fatality (for human and animal health) or mortality rate (for plant health) • production/yield loss (for animals and plants).
Likelihood	Likelihood of emergence of the risk in Europe in terms of emergence of a new hazard, or increased exposure/susceptibility to a known hazard or variation in micro/macronutrient content in environmental matrices or food items, considering 'reference' and 'near-future' conditions, the latter characterised by the selected climate change scenario. The following aspects should be considered: • potential/probability for introduction/entry of a vector/agent/vehicle/host in the European area (through products/commodities, animals, plants or vectors carrying the agent); • probability of establishment in Europe; • potential extent of transmission/spread; • potential increase of exposure, toxicity, pathogenicity, susceptibility. When assessing these four components of the likelihood, the following aspects should be considered, where relevant: • presence/absence/endemicity of the vector/agent/vehicle/host in Europe (absent, recently applied, widespread). When the vector/agent/vehicle/host is already present in Europe or likely to be introduced, this contributes to a higher likelihood; • the organism is known to be invasive somewhere in the world or known to have established viable (reproducing) populations somewhere outside of its native range. If so, this contributes to a higher likelihood, if the conditions for reproduction are favourable in the place it has entered; • the type of climate and environmental conditions of the regions where the vector/agent/vehicle/host is endemic; • • the specific environmental conditions in the establishment area.

Both criteria are divided into sub-criteria and levels, linked to a scoring system (Tables 4 and 5 below).

Table 4: Criteria, sub-criteria and scores for Impact to human health (including biological hazards to human health, contaminants and nutritional quality), animal health and welfare and plant health

IMPACTS				
	Human health	**Animal health and welfare**	**Plant health**	**Scores**
A. Number of individuals or units affected in Europe	None or few individuals	None or few animals	None or few units	1
	Moderate number of individuals	Moderate number of animals	Moderate number of units	2
	Large number of individuals	Large number of animals	Large number of units	3
	Very large number of individuals	Very large number of animals	Very large number of units	4
B. Magnitude of symptoms/signs	No or mild symptoms/signs. Intervention usually not required. Symptoms transient. Effects not long lasting.	No or mild symptoms/clinical signs. Intervention usually not required. Symptoms transient. Effects not long lasting.	No or little quality loss. Intervention usually not required. Symptoms transient. Effects not long lasting.	1
	Moderate symptoms/signs. Intervention may be required. Persisting effects are rare.	Moderate symptoms/clinical signs. Intervention may be required. Persisting effects are rare.	Moderate quality loss. Intervention may be required. Persisting effects are rare.	2
	Serious symptoms/signs. Intervention usually required. Persisting effects.	Serious symptoms/clinical signs. Intervention usually required. Persisting effects.	Serious quality loss. Intervention usually required. Persisting effects.	3
	Very serious symptoms/signs, life-threatening or disabling	Very serious symptoms/clinical signs, life-threatening or disabling	Very serious quality loss	4
C. Case fatality (human health and animal health) or mortality rate (plant health)	Zero	Not applicable or zero	Not applicable or zero	1
	Low case fatality rate	Low case fatality rate	Low mortality rate	2
	Medium case fatality rate	Medium case fatality rate	Medium mortality rate	3
	High case fatality rate	High case fatality rate	High mortality rate	4
	Very high fatality rate	Very high fatality rate	Very high mortality rate	5
D. Production/ yield loss	Not applicable	Not applicable or none	Not applicable or none	1
		Limited	Limited	2
		Moderate	Moderate	3
		Large	Large	4
		Very large	Very large	5

Please note that for the sub-criterion C: (a) 'case fatality rate' is defined as the proportion of deaths within a designated population of 'cases' over the course of the disease; and (b) 'not applicable' is used when it is irrelevant for a certain disease/issue to talk about case fatality rate. Conversely 'zero' indicates that the disease/issue does not cause mortality.

In relation to the sub-criterion D (production/yield loss), the 'not applicable' option is actually given a specific score (zero) and plays the same role as 'none'. This is relevant for the field of animal and plant health in those cases when a specific animal or plant species does not have a use value, in terms of production or yield, therefore not contributing to the overall effect. For human health (issues falling in the following EFSA's areas: biological hazards to human health, contaminants and nutritional quality), this argument does not apply, and the sub-criterion does not contribute to the overall impact. This translates in no score being attributed to it.

It is also important to note that the sub-criteria are often measured through qualitative descriptors like moderate, large or very large. This was justified because the same absolute number of for example affected individuals can be considered as 'moderate' or 'very large' depending on the area and even on the specific issue (e.g. individual bees or cows or humans; wheat plants or olive trees). Therefore, this descriptor should take the relevant population into consideration. The experts involved in the characterisation are supposed to justify their choices (in the justification boxes, see Section 2.5.3). It is acknowledged that the definition of qualitative attributes for impact (e.g. few, moderate, large, very large) might include risk management considerations or individual value judgement and perceptions. CLEFSA mitigates this through an assessment of the justifications provided by the experts in support of their scores.

In the plant health remit, the expert needs to clearly define the 'unit' used in the assessment. In the plant health guidance for quantitative assessment (EFSA PLH Panel, 2018) a 'pathway unit' is described as 'A unit of material … potentially affected by the pest that can be used to measure … the flux (i.e. change)'. Examples could vary in scale and dimension, for example from an area of crop (ha), to the number of plants, numbers of fruits (for example numbers of individual blueberry fruit), cubic metres of timber or individual packs of strawberry plants for planting.

Table 5: Scores for likelihood of emergence for human health, animal health and welfare and plant health

Likelihood of emergence	Score
Very unlikely: ≤10%	1
Unlikely: ≤ 33%	2
About as likely as not: ≈50%	3
Likely: ≥66%	4
Very likely: ≥90%	5

In general, the understanding of terms like 'likely/unlikely' is highly subjective. However, the attribution of specific % values to them aims to avoid any misunderstanding. This makes the likelihood values standardised and allows a comparison of the likelihood of different issues. The likelihood ranges are not in full agreement with the EFSA guidance on Communication of Uncertainty (EFSA, 2019). Tough and largely overlapping, the ranges in the EFSA guidance have been considered as too detailed for the aim of this work. Given the nature of the emerging issues, it is rare to have enough data to characterise them against defined cut-off ranges. Moreover, the characterisation criteria are designed to be applicable to a wide variety of issues. In contrast, eventual cut-off ranges would be quite context and species dependent. For example, in the animal health remit the same number of affected animals should trigger different scores for the 'impact' criterion depending on the affected species (bees, chicken or cows). The adopted solution is to describe criteria by a set of categories that have qualitative definitions but that also have a definite order on a four or five point-scale (e.g. few, moderate, large or very large number of individuals). Scores are essentially relative in nature, therefore while it is not possible to give it a quantitative interpretation defining cut-off values, they are consistent i.e. two issues having same scoring for a particular criterion should be broadly equivalent.

Experts involved in the scoring are requested to give a quantitative interpretation of score categories and to justify it. Each sub-criterion is scored at 'reference' and 'near-future' conditions. The 'reference condition' refers to the period 1981–2010. The expert is asked to characterise the potential impact or the likelihood of emergence of the risk under the current climatic conditions (more specifically, following climate prediction practices, during the years 1981–2010). The 'near-future' conditions refers to the period 2021–2050 and are characterised by the climate scenario (see Section 2.5), and the evolution of the other relevant drivers in this period. The relative scores of the different sub-criteria of 'impact' are assumed to be additive in nature. The best way to combine the scores of the two criteria (impact and likelihood) has been subject of lengthy discussions. An option could have been to combine them together, applying a weight factor to each criterion. However, the overall score obtained through combining the scores for likelihood and impact should be taken with caution. For emerging issues with particular social or public awareness, even for minor or moderate impacts and low likelihood of emergence, the overall score can be unacceptable for risk managers and still requiring urgent action. Therefore, it was deemed not advisable to combine the two scores into a single score because defining criteria weights would imply judgement which is not in the assessors' remit. Therefore, the resulting scores for the two different criteria (impact and likelihood) are kept separated. The characterisation of each issue is designed in such a way that it can be conducted in one area at a time (e.g. either animal health or human health). The interlinkages with other areas are identified through in the issue description, through the other qualifying criteria and/or handled through separate characterisation exercises.

2.4.2. Other qualifying criteria

In addition to the criteria used for scoring purposes, the following criteria can be addressed should the requested information be readily available. They provide useful information for deciding what kind of follow-up is suitable and by whom (risk assessors, risk managers, researchers, etc.). The criteria are:

- impact on economy, environment, social aspects and food security
- scale
- evidence base
- strength of the association with climate change
- imminence
- parallels and interactions with other emerging issues
- impact on other areas in the remit of EFSA.

The description of the criteria is provided in the Table 6 below.

Table 6: Description of the other qualifying criteria and relevant information for their assessment

Criteria	Description
Impacts on economy, environment, social aspects and food security	Potential effects on: • economy • environment • social aspects • food security. The following aspects should be considered: *economy*: • economic value of the production/yield losses related to primary production (in e.g. agriculture, horticulture, forestry, animal production, aquaculture and fishery); • economic effects for food industry; • cost of inspection, control and eradication programmes; • cost of health care and long-term disability; • effects on trade of commodities; • effects on travel. *environment*: • impact of the preventive, control and/or eradication measures on e.g. soil, air, water, biodiversity, wildlife, protected species, landscape and ecosystem services. *social aspects:* • impact on people's values and risk perception; • changes in human behaviour and habits; • impact on media attention and public concern. *food security*: • impact on availability, access and utilisation of food products.
Scale	Scale of the problem considering the selected climate change scenario and including information on the following factors: • the number or individuals potentially *exposed* to the hazard. This is different from the number of individuals *affected*, which is a measure of the impact. • geographical area potentially exposed to the hazard (local, national, multi-national, number of Member States); • duration and frequency (no repetition, repeated occasionally or recurrent year after year, sporadic or seasonal) at which the hazard is present; • change in geographic distribution.
Evidence base	Amount of and consistency of the data (information) observed/obtained by different persons in different places with different samples and underpinning the proposed issue. 'Evidence' can refer to a single piece of potentially relevant

	information or to multiple pieces (study, expert knowledge, experience, models, single observation).
Strength of the association with climate change	It considers the following aspects: • relevance of the contribution of climate change relative to other potential drivers on the detected change; • relevance of the contribution of climate change to the likelihood that the risk will emerge or increase. For both, a low association does not necessarily mean that there is not a causal effect, though the higher the association, the more likely that climate change be the cause.
Imminence	Estimated timeframe for the issue to be detectable. It characterises the shape of the trend of response of the emerging issue to the changing climate. Possible ranges are: • within 5 years • within 15 years • in more than 15 years.
Parallels and interactions with other emerging issues	This section includes: • interactions among different emerging issues with possibilities of synergisms or antagonisms; • proposals for other issues belonging to the same category but raising more concern or more strictly linked with climate change. The scoring expert can propose to score the alternative issues instead of the one originally proposed.
Impact on other areas in the remit of EFSA	This criterion expresses whether the issue is relevant in different areas within the remit of EFSA (e.g. animal health and human health).

The opportunity of including an assessment of the relevance and reliability of the information source was discussed. However, it was considered as not appropriate to disqualify an issue based on the relevance of its source (e.g. a magazine or newspaper) for this specific scientific context because of the foresight and horizon scanning nature of the exercise. Therefore, the assessor was requested to score independently of the relevance and reliability of the source. The criteria 'Strength of the association with climate change' has been used for monitoring emerging infectious disease risk due to climate change (Lindgren et al., 2012). It needs to be stressed that in many instances the globalisation of trade plays a role in the emergence of emerging issues and that it is difficult to distinguish the relative contribution of climate change. The IPCC has defined a guidance on detection and attribution of observed impacts of climate change in its IPCC AR5 WG2[19,20]. This has supported the experts in assessing the issue against this criterion.

It is important to acknowledge that the different issues may interact with each other and that these interactions themselves may be affected by climactic factors. The criterion 'parallels and interactions with other emerging issues' attempts to grasp these important aspects.

2.4.3. Risk management measures

The following aspects of current risk management measures and/or controls and their application in the given climate change scenario should be considered for the characterisation of the issue:

- availability of control tools;
- efficacy of control tools in reducing disease spread (e.g. vaccines);
- efficacy of control tools in mitigating impact (e.g. treatment).

2.5. Methods and tools for characterisation

The process of characterisation of emerging issues consists in a streamlined and systematic assessment of emerging issues through qualitative evaluation (i.e. a structured expert evaluation based on the agreed evaluation criteria).

[19] http://sedac.ipcc-data.org/ddc/observed_ar5/Guidance/Ch18_Guidance_on_definitions_postLAM3.pdf
[20] https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-Chap18_FINAL.pdf

The aim of the characterisation process is to provide a rationale for focusing on those issues presenting an emerging food and feed safety risk and protocols for communicating the risk to EFSA's wider audience and the public. Characterisation helps to frame issues in such a way that the data source of the potential threat can be more objectively examined and selected. It facilitates the identification of emerging issues relevant to the priorities and policies of EFSA's audience and the definition of recommendations for follow-up actions. The characterisation of issues should emerge from discussions around: (i) potential impacts and likelihood of emergence of the risks; (ii) the timeline of emergence of the risk; i.e. from now to the identified time horizon; (iii) uncertainty and evidence gap(s) to be considered; and (iv) who the issue most concerns, who and how should take it forward.

Characterisation requires collaboration with a wider audience than the EFSA Emerging Risks Networks (e.g. whole staff, panels, scientific committees, CLEFSA network) to validate the output.

2.5.1. Scenarios of climate change in Europe

Experts were requested to characterise each issue in two different climate scenarios, reference and near future. Geographically explicit information (maps) of the relevant climate variables were provided to the experts during the characterisation phase.

Essential climate variables, defined as physical, chemical or biological variables or groups of linked variables that critically contributes to the characterisation of Earth's climate, particularly relevant for the emergence of diseases may be identified consulting the WMO[21] and in European Space Agency (ESA)[22] websites. The climate variables, relevant for Europe and selected for the CLEFSA project, are listed in Table 7.

Table 7: Climate variables and maps*

Climate variable	Maps
Annual temperature	2-metre air temperature (average, 17th, 83rd)
Seasonal temperature	Winter 2-metre air temperature (average, 17th, 83rd)
	Spring 2-metre air temperature (average, 17th, 83rd)
	Summer 2-metre air temperature (average, 17th, 83rd)
	Autumn 2-metre air temperature (average, 17th, 83rd)
Seasonal precipitation	Annual precipitation (average, 17th, 83rd)
	Winter precipitation (average, 17th, 83rd)
	Spring precipitation (average, 17th, 83rd)
	Summer precipitation (average, 17th, 83rd)
	Autumn precipitation (average, 17th, 83rd)
Extreme events	Cold temperature spells
	Warm temperature spells
	Heavy rainfalls events
	Drought

The climate maps were drawn up by the JRC in cooperation with the European Environment Agency, from the climate data store provided by the Copernicus C3S platform[23] implemented by the European Centre for Medium-Range Weather Forecasts (ECMWF) on behalf of the European Commission. The maps illustrate the change in climate between 'reference' and 'near-future' periods, so defined:

- 'reference period': 1981–2010
- 'near-future period': 2021–2050.

The 'reference' condition is equivalent to the most updated 30-year period (from 1981 to 2010) used to approximate the current climate, while the 'near-future' condition is equivalent to the 30-year period from 2021 to 2050 projected by different climate models.

For the projected climate changes, mid-century (2021–2050) has been selected as period to be analysed with respect to the reference. This choice is motivated by the key interest in the 'near-future'

[21] https://public.wmo.int/en/programmes/global-climate-observing-system/essential-climate-variables
[22] http://cci.esa.int/content/what-ecv
[23] https://climate.copernicus.eu/

changes for this kind of impact studies and to simplify the study. Indeed, as the emission scenarios (as defined by the Representative Concentration Pathways-RCPs) start diverging significantly around 2045 (see Figure 14), by focusing on the 'near future' only one of them can be selected and analysed, without adding supplementary uncertainties (e.g. the mid-range mitigation RCP4.5). Based on climate evidence the scenarios start diverging significantly only after mid-century also in terms of surface parameters. In principle, some variables as precipitation might be more uncertain. However, the uncertainty is linked more to the different climate models used (11 different models considered in this work) rather than the RCPs, at least considering only the near-future period.

In addition, a far future period (e.g. end of the century) may be well beyond the lifetime of the current risk mitigation measures.

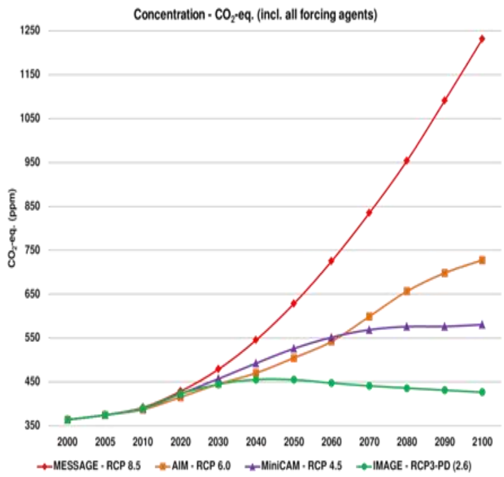


Figure 14: CO_2 concentration under different RCPs (IPCC AR5 Representative Concentration Pathways)

Note that other studies using different time horizons could come to somehow different estimates of the impacts of climate change on the areas in the EFSA's remit. However, all of them agree on the importance of adaptation at the farm level and beyond[24].

The possibility to replace the temporal dimension with the global warming (e.g. 1.5°C) has been discussed as well. To simplify the study, considering the limited amount of time available and the clear time horizon for the climate projections, it has been decided to work by selecting a fixed time period common to all model simulations.

In addition to the climate variables indicated in Table 7, CO_2 concentration may play an important role as well. Its predicted values do not differ much in the different RCPs considered. In the year 2035 the CO_2 concentration is projected to be around 450/500 ppm (Figure 14). The measured CO_2 concentration considered for the reference period was about 360 ppm (Figure 15).

[24] https://experience.arcgis.com/experience/5f6596de6c4445a58aec956532b9813d

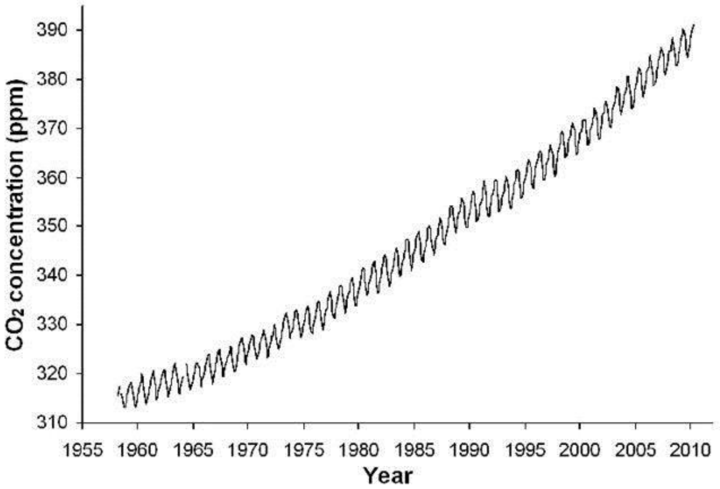


Figure 15: Monthly average CO_2 concentration (ppm) through time at Mauna Loa Observatory, Hawaii (data from https://scrippsco2.ucsd.edu/)

For each climate variable, three maps are provided to indicate the spread among the 11 climate models considered:

- a map displaying the ensemble median of the 11 climate models (unweighted average change);
- a map displaying the 17th percentile of 11 climate models considered;
- a map displaying the 83rd percentile of 11 climate models considered.

The percentile maps are quantifying the spread among the 11 climate models considered. The higher the divergence between the two percentiles maps the higher the variability across the different climate models. The maps produced by the JRC in cooperation with the European Environment Agency, in the context of the CLEFSA project, are reported in Appendix F. The European Environment Agency has provided a textual description of projected changes of key climate variables and access to some of the data, in particular if they are covered in existing indicators[25]. The information available from the European Environment Agency is comprehensively described in (EEA, 2017). A few indicators have been updated in the meantime, but no completely new information has become available. For further information, the following data sources can be used:

- IMPACT2C web-atlas: https://www.atlas.impact2c.eu/en/
- CLIPC Climate information portal: http://dev.clipc.eu/indicator_toolkit/indicator_toolkit.php?theme=1
- Climate Data Store of the Copernicus Climate Change Service: https://cds.climate.copernicus.eu/#!/home

Two possible methods for considering scenarios of climate change were proposed (see Table 8).

[25] https://discomap.eea.europa.eu/climate

Table 8: Methods for considering scenarios of climate change

Method	Description	Advantages	Disadvantages
Based on the combination of different climate variables	The assessor attributes a score to each combination issue/criterion which implicitly takes into consideration the entire climate change scenario without disentangling the effects of the single variables/phenomena (for example the score for the criterion 'severity' may depend on the magnitude of the increase of temperature).	The score considers the interactions between the multiple climate variables specific for each issue (e.g. increase of summer temperatures and decrease of summer precipitations). Results (final scores) are comprehensive and easy to interpret by the risk managers.	This method implies an effort from the expert to analyse the interactions between the different climate variables (multiplication and compensation effects) and requires description notes to detail the different type of emergences.
Based on single climate variables	Includes the assessment of the impact of chosen changing climatic parameters (e.g. temperature and precipitation) on the emergence of a certain issue (inhibition or promotion). This aspect would contribute to the criterion 'likelihood of emergence'. In addition, the possibility of assessing the impact of alternative opposite scenarios was discussed (e.g. the impact of an increase in winter temperature and a decrease in winter temperature), against an assessment based on a single scenario.	The scoring system is detailed and explicit for each singular climate variable/issue.	This method is not considering the combination effects between different climate variables. If we try to add it, it might become extremely complicated because of the multiple interactions between the different climate variables (not only temperatures and precipitations) Results (final scores) are not so easy to interpret by the risk managers, as you might obtain contrasting results for different combinations of singular climate variable/issue.

Considering the advantages and disadvantages of the two different methods and the limited time and resources available, the method based on the combination of different climate variables was preferred for this study.

2.5.2. Shiny tool

An R-Shiny app has been developed to support experts in characterising issues and to analyse and visualise results. Shiny is a package from RStudio that allows to build interactive web applications with R. The app has two main components: a user interface and a server function. The user interface (ui) object controls the layout and appearance of the app. The server function contains the instructions needed to build the app. The app uses as input external files with the following information:

- a file listing invited experts (id, name, email, institution)
- a file listing emerging issue (name, description, links to additional resources, type)
- a file describing which expert is assessing which issue.
- interface for characterisation.

Experts needed to register on the server hosting the app and subsequently log into it and access the app. The app has a multi-page user interface (Figure 16) that includes the following sections:

- background information on the project
- project description
- workflow of the tasks to be completed by the expert
- climate scenarios

- expert assessment.

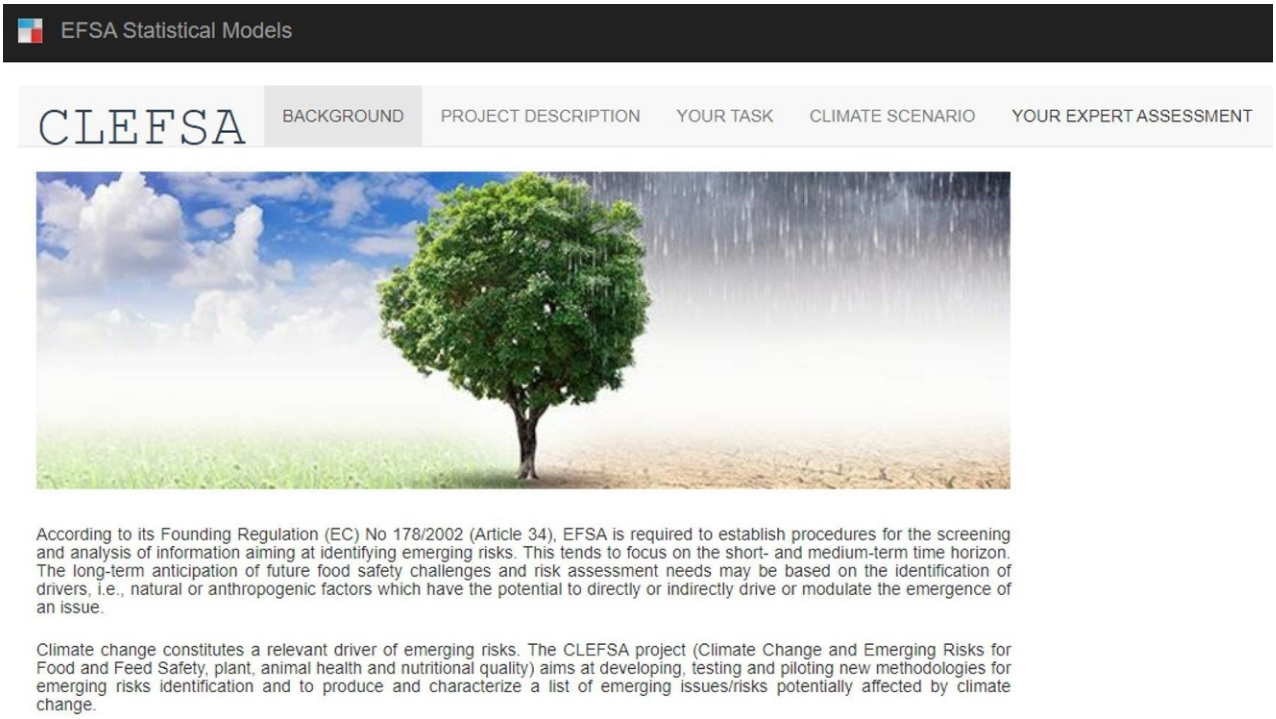


Figure 16: Multi-page user interface for R-Shiny App

Selecting the item 'Your expert assessment', takes the expert into the characterisation section (Figure 20) with different subsections:

- Home, where all the issues that are to be assessed by the expert are listed
- Emerging issue, where information about the issue is displayed
- Impact
- Likelihood
- Other qualifying criteria
- Risk management measure.

For the impact and likelihood criteria, the expert was requested to provide evidence and reasoning driving the assessment, to select lower and upper limit of the credibility range and assess the most probable value for each criteria and sub-criteria, in the reference condition and in the near-future condition (Figure 17).

All the assessments performed by experts were stored in an external file.

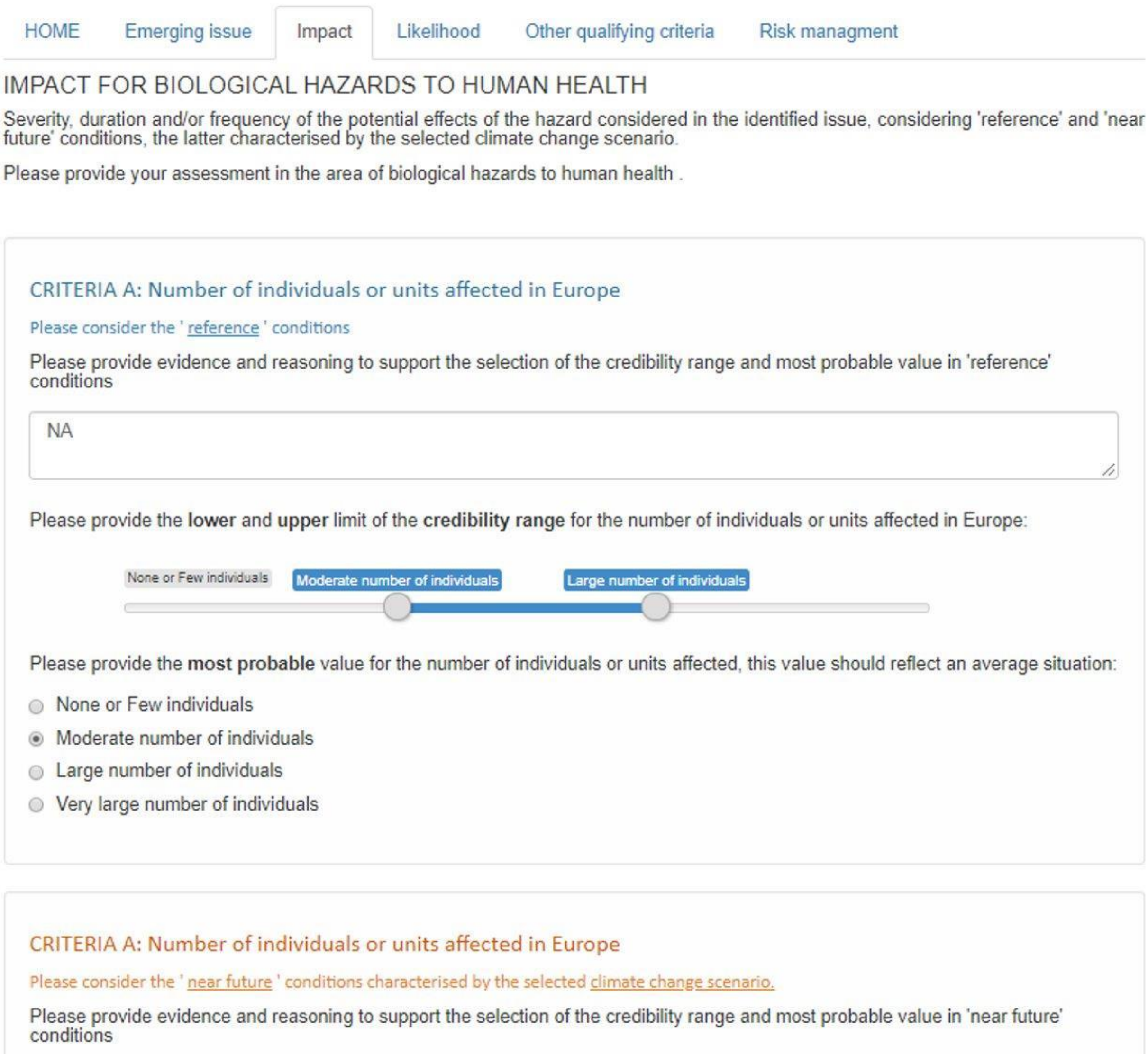


Figure 17: Shiny App interface for characterisation of impact criteria

For the other qualifying criteria and risk management measures, the experts were required to insert text addressing each of them, should the requested information be readily available.

2.5.2.1. Interface for analysis and visualisation

The R-Shiny app also provides an interface for the analysis and visualisation of the information and scores provided by the experts. This interface is available only to the project manager and not to the single individual expert accessing the tool.

It makes it possible to visualise:

- individual uncertainty distribution for the 'impact' sub-criteria and 'likelihood' criteria, for each expert contributing to that judgement, for both reference and near-future conditions;
- aggregated uncertainty distribution for the 'impact' sub-criteria and 'likelihood' criteria, averaged over all the experts contributing to that judgement, for both reference and near-future conditions;
- uncertainty distribution averaged over all 'impact' sub-criteria;
- delta values (see Section 2.7.2) for impact and likelihood;

- variance of the probability distribution for criteria or sub-criteria;
- contour plot for bivariate distribution for impact and likelihood.

All these features were illustrated in the issue scoresheets described in Section 3.3.4 and are presented in the Appendix B. This interface will be made publicly available as a repository of all information submitted by the experts (scores, justification and information on the other qualifying criteria, when available) and analysis related to the identified issues (anonymising the names of the experts) at this link: https://shiny-efsa.openanalytics.eu/app/scoring

2.6. Characterisation of the identified emerging issues

The emerging issues collected through the methodology described in Section 2.3 have been characterised by a group of experts (characterisation group) using the Shiny tool (Section 2.5.2). Only the issues containing a specific agent have been characterised. Generic issues related to drivers (e.g. change of pesticides or veterinary drugs use) or wide categories of agents (e.g. unspecified insects or pests) cannot be characterised using the MCDA system described in Section 2.4. The CLEFSA project used expert opinion to characterise the identified issues. The following channels were followed to call experts for the characterisation exercise:

- CLEFSA network and related circles
- EFSA's Scientific Cooperation newsletter #13 (28/3/19)
- EFSA's Advisory Forum and Focal Point
- EREN and StaDG-ER meetings
- EFSA Scientific Committee
- CONTAM, BIOHAZ, AHAW, PLH and NDA Panels
- scientific conferences

A briefing note, explaining the purpose of the project and including the list of identified issues, and the informative note published on the EFSA website[26], was sent. The interested experts were given the opportunity of selecting the preferred issues either through the briefing note or through an ad hoc EU survey[27]. Experts have been encouraged to try and assess as many issues as possible, within their past or present field of work, but also issues that they do not feel they have a very high level of expertise. In total, 92 experts expressed their interest to participate. Sixty out of these 92 experts have finalised the assessment (Appendix A). The R-Shiny tool (Section 2.5.2) and related instructions for the characterisation has been distributed to the experts (Appendix A) on 4 November 2019 and the characterisation exercise has lasted until the 24 January 2020. The experts were asked to provide their assessment by scoring and additionally to characterise the criteria. The characterisation exercise lasted two months (November–December 2019). In that period, brief teleconferences or physical meetings (e.g. in the breaks of panel plenaries) have been organised to discuss the difficulties faced by experts during their assessments.

2.7. Analysis and visualisation

2.7.1. Experts' submissions check

The post-characterisation phase is the critical appraisal of the whole characterisation exercise and the final use of the results. All experts' submissions have been checked in order to amend potential cases of mis-scoring due to negligence, misunderstanding of the issues or the criteria. The submissions were screened for:

- most probable value out of the credibility range (13 issues);
- inconsistency between score and corresponding justification provided (19 issues);
- unfinished assessments (15 issues);

[26] https://www.efsa.europa.eu/en/topics/topic/climate-change-and-food-safety
[27] available online here: https://ec.europa.eu/eusurvey/runner/CLEFSA_AvailabilitySurvey2019

- missing justifications (12 issues in which only one expert performed the assessment; a score without justification is difficult to compare to other experts' scores);
- justifications that suggest misunderstanding of the criterion (4 issues);
- bimodal probability distributions of assessments combined over the different experts (35 issues, 73 bimodal distributions).

In 19 cases (over 13 issues) the experts have chosen a most probable value that is outside of the credibility range. It was therefore necessary to get back to the expert and ask clarification and resubmission of the issue. In some cases, a single assessment has been submitted reflecting the position of several contributing experts. When calculating the probability distribution averaged across the different experts, this contribution was considered as a single assessment. In the event of the bimodal distributions, experts were asked to participate in discussions (by email or telemeetings) about the assigned scores, in order to understand the reasons for such differences. They were invited to add or expand their justifications (in the CLEFSA Shiny tool) so that other experts could better understand the reasoning behind the assigned score. The following questions were asked in order to facilitate the discussion:

1) Was the issue and the criterion clearly defined? Did the experts have any difficulty understanding what exactly they were asked to assess?
2) While assigning the scores, did they all take the same approach, i.e. did they all consider the same scenario (average scenario, worst case or most conservative)? For instance, whenever the assessment is focused on a certain family or genus (e.g. *Brucella*) of organisms did they all consider the same species or affected animals (sheep, goats, wild boar, pigs)?
3) Did any of the experts miss a piece of evidence that others mentioned in their justifications?

The aim of the discussions was not only to understand the reasons behind diverging scores, but also to allow the experts to reconsider their scores in light of more evidence or arguments. If after the discussions the bimodal distributions were not eliminated (no scoring convergence), the experts were not pushed to agree. 'Agree to disagree' is also a valuable output as long as some explanation was provided. The disagreement was recorded and considered as contributing to the variability associated with the issue. The experts were given one week to amend their individual scores. Before starting any discussions, all experts were asked for permission to de-anonymise their scoring and justifications. After all experts agreed, the discussion stage lasted for two weeks, unless experts asked for an extension.

2.7.2. Characterising uncertainty and probability distributions

Uncertainty is defined as referring to all types of limitations in the knowledge available to expert at the time a characterisation is conducted and within the time and resources available for the characterisation. Uncertainty is subjective, since different people have different knowledge and experience and therefore different uncertainty.

EFSA uncertainty guidance provides a flexible framework within which different methods may be selected, according to time and resources available for scientific assessments. The application of the EFSA uncertainty guidance requires the implementation of the following steps of the uncertainty analysis: identifying and describing uncertainties, assessing individual sources of uncertainty, assessing the overall impact of all identified uncertainties and their relative contribution and reporting. The final output of uncertainty analysis is the overall characterisation of uncertainty that takes all the identified uncertainties into account.

CLEFSA has attempted to address the issue of characterising uncertainty in a data-poor environment. Within the characterisation step, the main source of uncertainty is the limitation of knowledge available for answering to the four criteria question.

The possibility to prepare a question covering overall uncertainty was considered. Overall uncertainty assessment implies judging several components of uncertainty, associated to each criterion and combining multiple uncertainties. It may therefore be more reliable to divide the uncertainty analysis into parts and quantify uncertainty separately for each single criterion.

There are several methods for analysing uncertainty. Qualitative methods characterise uncertainty using descriptive expression or ordinal scales, without quantitative definitions. It has been proved that qualitative expressions are ambiguous since the same word or phrase can mean different things to different people. At the opposite, a complete quantitative expression of uncertainty would specify all the answers or values that are considered possible and probabilities for them all. The CLEFSA project explores the possibility of expressing the uncertainty in a quantitative form. Therefore, when assessing the issue against a criterion the following question needs to be answered: what is the range of possible answers, and how probable are they? Replying to these questions means characterising uncertainty for each criterion. In principle a formal or informal Expert Knowledge Elicitation (EKE) could be used to judge on the uncertainty distribution of the parameter of interest (for example number of individual affected) in a fully quantitative way using the quartile method. However, this is not considered effective since most of the issues are characterised by lack of evidence and for that reason an ordinal scale was considered more appropriate. Therefore, each criterion is an ordinal variable taking a limited number of ordered scores and rather than using a single score to characterise a criterion, experts are requested to provide a range of the score (specifying both a lower and upper limit of the credibility range) and the most probable value in the ordered scale. Credibility range is assumed to cover all possible values.

In order to convert range and most probable value into probabilities values, each point on the ordinal scale is mapped to a suitable numerical scale, under the assumption that the distance between categories is constant. For instance, for criterion likelihood, the following mapping applies:

- 'Very unlikely' is mapped to 1
- 'Unlikely' is mapped to 2
- 'About as likely as not' is mapped to 3
- 'Likely' is mapped to 4
- 'Very likely' is mapped to 5.

Therefore, a range on the ordinal scale from 'Very unlikely' to 'Very likely' is translated directly into a 1 to 5 range on the numerical scale, while for example 'Unlikely' as most probable value on the ordinal scale translates directly into a most probable value of 2 on the numerical scale.

Expert judgement about uncertainty on the numerical scale is then converted in probabilities fitting a Pert distribution (a continuous probability distributions defined by the minimum, most likely and maximum values that a variable can take) to the numerical range and most probable value. Finally, to each score of the ordinal scales a probability is attributed calculated as:

$$\int_{i-0.5}^{i+0.5} F(t)dt$$

where F is the cumulative distribution of the estimated Pert distribution and *i* is the score for which the probability is calculated.

Therefore, for each expert the discrete probability distribution of uncertainty will be calculated for each judged sub-criteria or criteria. Judgements of several experts can be aggregated according to different methods:

- Behavioural aggregation: Individual judgements are aggregated by group interaction of the experts, e.g. using the Sheffield method.
- Mathematical aggregation: Individual judgements are aggregated by a weighted average using e.g. the Cooke method.
- Mixed methods: Individual judgements are aggregated by moderated feedback loops avoiding direct interactions in the group, e.g. the Delphi protocol.

Individual uncertainty distributions are mathematically combined to derive an average uncertainty distribution over all experts, where the probability of each score is equal to the average of individual probabilities for that score:

$$p_i^E = \frac{\sum_{e \in E} p_{i,e}}{|E|}$$

where $p_{i,e}$ is the individual uncertainty probability for score *i* for expert *e*, |E| is the cardinality of the set E containing all the experts involved in the judgement for that criteria.

Under the assumption of independence and additivity of sub-criteria for impact, uncertainty distribution can be combined over sub-criteria to derive an average uncertainty distribution for impact, where the probability of each score is equal to the average of sub-criteria probabilities for that score:

$$p_i^{Impact} = (p_i^{Impact_A} + p_i^{Impact_B} + p_i^{Impact_C} + p_i^{Impact_D})/4$$

where $p_i^{Impact_A}$ is the uncertainty probability for score *i* for sub-criteria A, , $p_i^{Impact_B}$ is the uncertainty probability for score *i* for sub-criteria B, $p_i^{Impact_C}$ is the uncertainty probability for score *i* for sub-criteria C and $p_i^{Impact_D}$ is the uncertainty probability for score *i* for sub-criteria D.

As sub-criteria A and B of 'impact' have 4 categories while criteria C and D have 5 categories and considering that the 'no individuals affected' or 'no symptoms' options can be reasonably excluded (it would not constitute an emerging issue), for practical reasons when calculating the average the probability associated with the first score level is set by definition equal to zero:

$$p_{i=1}^{Impact_A} \equiv 0;\ p_{i=1}^{Impact_B} \equiv 0$$

In case of biological hazards to human health, contaminants and nutritional quality, as justified in Section 2.4, sub-criterion D (production/yield loss) is not applicable and no score is attributed to it. This criterion does not contribute to the average. The average over all criteria is therefore calculated as:

$$p_i^{Impact} = (p_i^{Impact_A} + p_i^{Impact_B} + p_i^{Impact_C})/3$$

Being the criteria mapped to an ordinal variable, we can apply two summary statistics:

- central tendency, defined as probability weighted average and calculated as:

$$\bar{x} = \sum_{i \in I} i \cdot p_i$$

- sample variance and calculated as:

$$s = \sum_{i \in I} (i - \bar{x})^2 p_i$$

Probability weighted average can be used to summarise in one value the individual uncertainty distribution or the aggregated (over all contributing experts) uncertainty distribution for a sub-criteria or criteria. Variance can be used to measure how spread is the individual uncertainty distribution or the aggregated (over all contributing experts) uncertainty distribution for each sub-criteria or criteria.

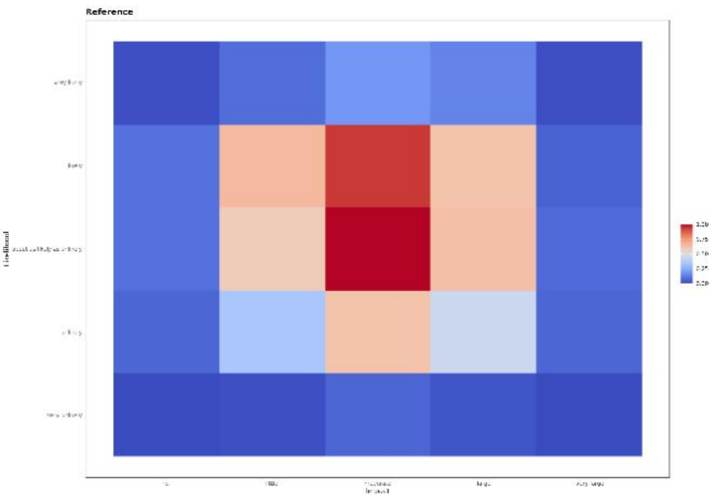
Both probability weighted average and variance are summary statistics used to summarise the full uncertainty distribution and therefore provide only a partial description of it: asymmetry of the distribution and thickness of the tails are indeed ignored.

Finally, in order to quantify the effect on a specific issue of the selected climate change scenarios relative to the reference condition, an indicator named 'Delta' has been proposed as the difference between probability weighted average judged for future and probability weighted average judged for reference scenario. Delta is calculated for probability distribution aggregated over all experts contributing to the assessment of that specific issue and aggregated over all sub-criteria. Delta can be used to summarise in one value the change due to climate change effect in the central tendency value for each criteria and sub-criteria, for individual expert or aggregated.

For each expert, uncertainty distributions are calculated for each sub-criterion or criterion. The assessments of the experts are mathematically combined into an aggregate uncertainty distribution. For 'impact' criteria, uncertainty distribution for sub-criteria are assumed independent and additive in nature. Therefore, uncertainty distribution for sub-criteria can be averaged over sub-criteria providing an overall uncertain distribution for 'impact'.

Combining uncertainty distributions for impact and likelihood would require assumption on dependence structure of the two variables, assumption on additivity and on the weight to apply. The definition of weights is debatable and more pertinent to risk managers than to risk assessor. Therefore, it was deemed preferable to avoid combining impact and likelihood. Instead, probability distribution of all components of characterisation are displayed separately.

The probability distribution for each sub-criteria and criteria is presented as a bar plot (see Appendix B), where the bar measures the aggregated (over all contributing experts) probability p_i^E associated with that score level *i*. Under the assumption of independence among likelihood and impact, it is possible to calculate the joint uncertainty distribution for impact and likelihood and to display the probability density contour plot for the bivariate distribution. Contour plots make it possible to represent a three-dimensional surface on a two-dimensional plane (see example in Figure 18). This type of graph is widely used in cartography, where contour lines on a topological map indicate elevations that are the same. Being the variables discrete, contour is similar to a heatmap were cells colour indicate the value of the joint probability and cells having same colour have same joint probability. This graphical representation will make it possible to display simultaneously probability distributions for impact and likelihood and to compare different Future and Reference conditions. It also makes it possible to easily detect bimodal curves.



The x-axis represents five impact levels (no, little, moderate, large, very large) and y-axis shows five likelihood levels (very unlikely, unlikely, about as likely as unlikely, likely, very likely). The colour grading represents probability distribution, from blue to red (high).

Figure 18: Probability density contour plot for the bivariate distribution of impact and likelihood

3. Results

3.1. Emerging issues identification

As described in Section 2.3, several sources have been used for identifying emerging issues affected by climate change. The number of issues for each source is shown in Table 9.

Table 9: Sources of the CLEFSA emerging issues

Source	Number of issues
Survey	99
EFSA's past work related to Climate Change	15
EREN	15
StaDG-ER	2
Literature	9
TIM tool	4
MediSys tool	5
CLEFSA network	9
TOTAL	157

Some issues have been identified through different sources, as illustrated in the diagram below (Figure 19).

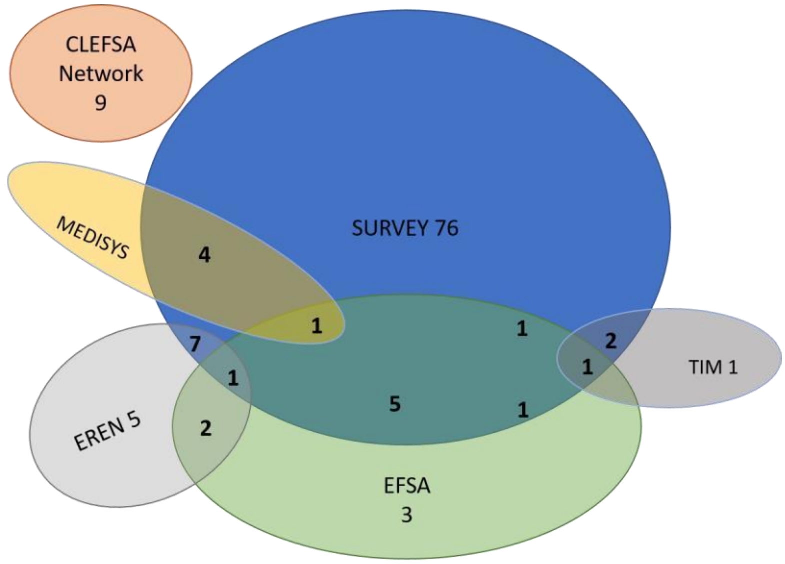


Figure 19: Sources and links of the CLEFSA emerging issues

Considering the issues provided by different sources, the total number of identified issues is 129. This number includes issues that are characterised under two different areas (i.e. for both human and animal health).

3.1.1. CLEFSA survey statistics

Most of the issues have been retrieved through the CLEFSA survey. The number of respondents was 606. The countries of the respondents and their country are illustrated in the Figure 20:

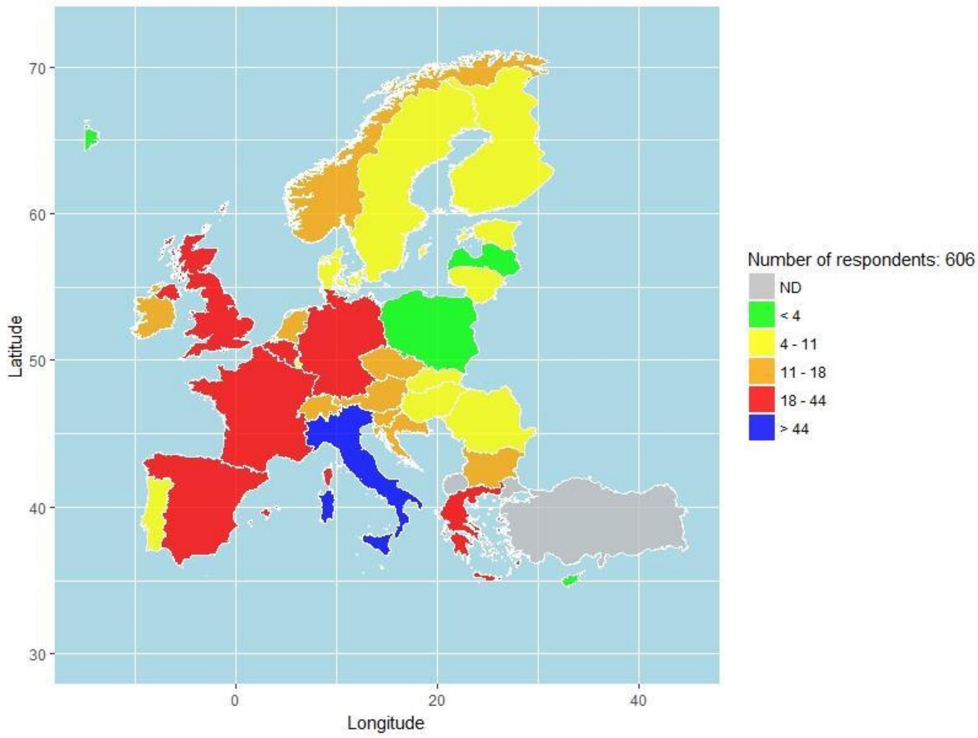


Figure 20: Country of the responders

Of these, 66 respondents did not declare the country and 72 declared non-EU countries. Additional information about the survey is provided in Table 10:

Table 10: Information about the responders

Survey response	Number
Number of respondents	606
Number of contributing persons	173
Number of issues	241
Number of persons contributing with more than one issue	38
Max. number of issues contributed by one person	9

Most of the respondents did not propose additional issues with respect to those which have already been considered by EFSA and listed in Section 2.3. Only 173 submitted new ones. These 173 contributing persons are distributed according to the following diagram:

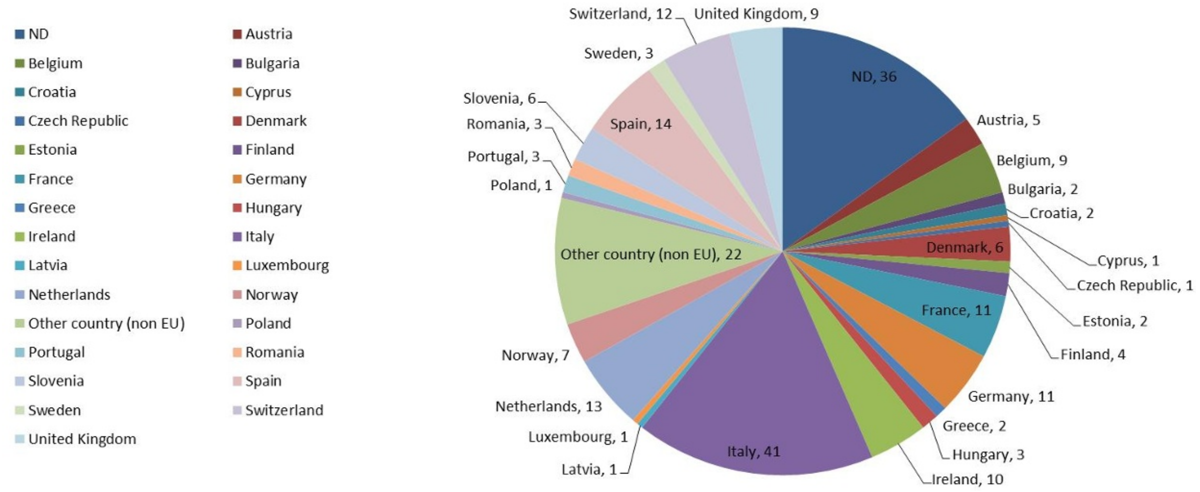


Figure 21: Number of contributors and country

The sources of information described by the respondents are reported in the following diagram (Figure 22).

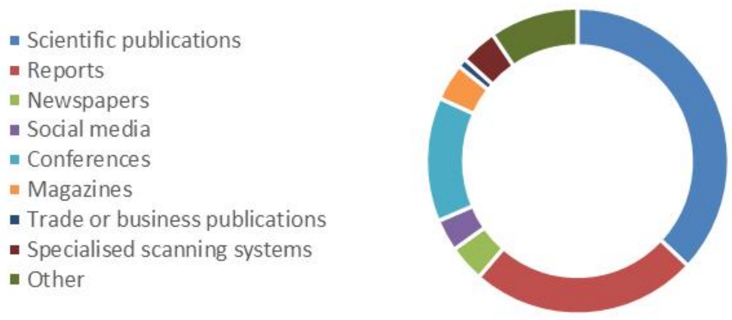


Figure 22: Sources of information used by the submitters

The type of sources per issue and area on EFSA's remit are presented in Table 11.

Table 11: Type of source of the submitted issues per area

Type of source	Number of issues	Biological hazards to human health	Contaminants	Animal health	Plant health	Nutrition	GMO
Scientific publications	152	36	30	26	25	9	3
Reports	100	28	21	21	16	3	1
Newspapers	16	10	2	1	1	0	0
Social media	14	4	3	4	2	1	0
Conferences	54	11	10	12	9	1	0
Magazines	16	6	2	1	4	0	0
Trade or business publications	4	1	0	0	0	0	0
Specialised scanning systems	16	2	1	6	4	0	0
Other	39	7	3	10	10	0	0

The different issues have covered all EFSA's areas according to the following Figure 23.

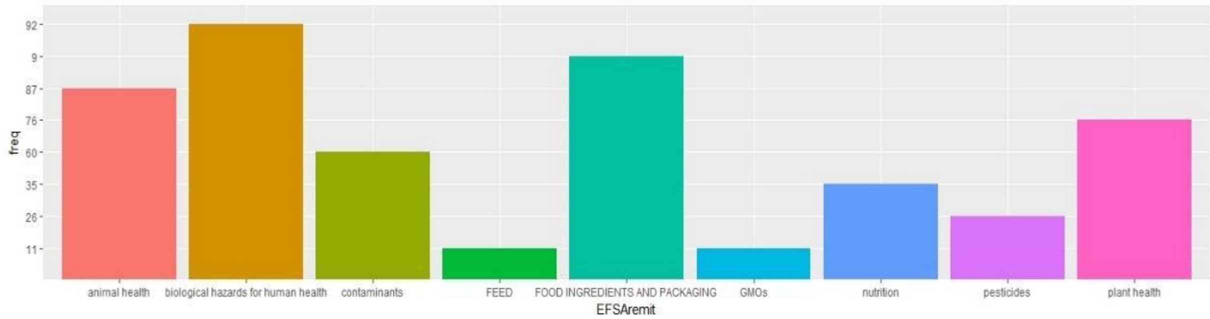


Figure 23: Distribution of submitted issues per area of EFSA (as represented on the x-axis)

The full set of issues retrieved in the CLEFSA survey has been downsized to 107 issues. The issues received in the survey were screened by the EFSA secretariat supported by the CLEFSA network, through the steps described in Section 2.3.

Table 12: Results from the screening of CLEFSA survey

Action	Number of issues
Eliminate	23
Ask submitter	2
Split	24
Cluster	126
Keep as it is	119
Archive	78

3.2. Emerging issues characterisation

Each issue has been scored and characterised by five experts on average, while each expert has assessed seven issues on average. Out of a total of 693 planned assessments (combinations of experts and 129 issues), 284 (41%) were performed and 409 were not performed. The 284 performed assessments correspond to 101 issues (14 of which assessed for both human and animal health) and have involved 60 experts. Of the 129 identified issues, therefore, 101 were characterised by at least one expert. The remaining 28 issues have not been characterised for any criterion and are listed in

Appendix C. Table 13 summarises the number of characterised and uncharacterised issues for each area.

Table 13: Characterised and not characterised issues for each area

EFSA's area	# characterised	# uncharacterised	TOTAL
Animal health	34	-	34
Biological hazards to human health	25	5	30
Plant health	17	19	36
Contaminants	19	4	23
Nutrition	6	-	6
TOT	101	28	129

Some of the 60 experts involved have contributed to more than one area. The distribution of the experts for each area is shown in Figure 24.

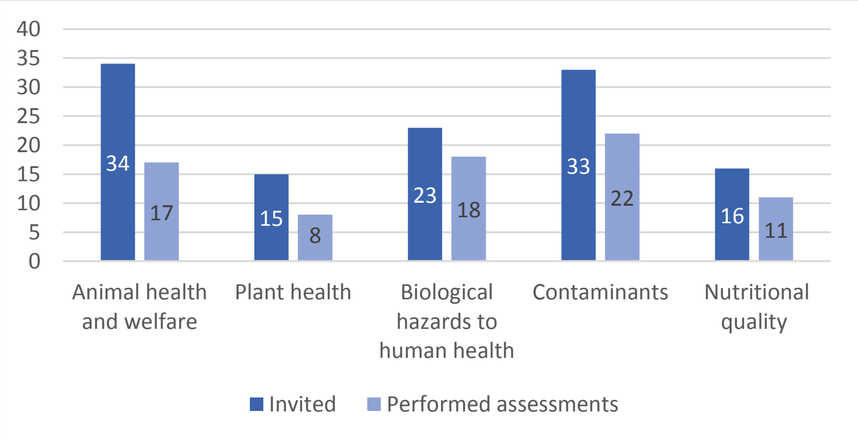


Figure 24: Number of experts invited to assess issues from each area and number of experts who completed the assessments

As shown on Figure 25, plant health issues have the lowest average/median number of experts per issue. Moreover, in the plant health area, over half of the issues have not been characterised because of insufficient number of scoring experts. Conversely, contaminants show the highest average number of experts per issue.

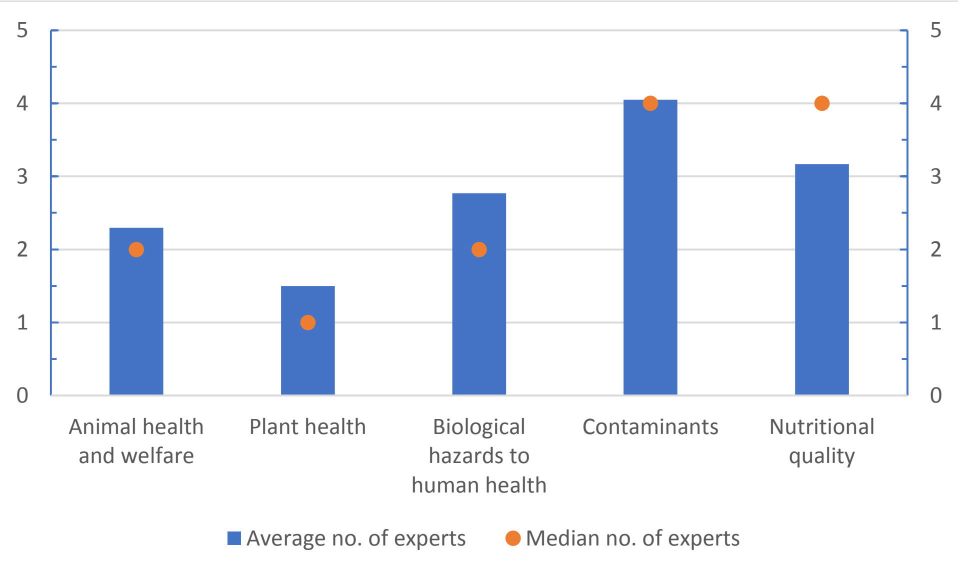


Figure 25: Average and median number of experts per issue performing assessment of issues belonging to each category

Several issues may be relevant in more than one area. There is a clear connection between issues belonging to categories 'animal health and welfare' and 'biological hazards to human health'. Moreover, several issues belonging to the 'contaminants' area may affect animal, plant and human health. Some of these issues have been fully characterised in two areas. They are all biological hazards to both human and animal health: *Bacillus anthracis, Brucella, Campylobacter, Clostridium botulinum, Echinococcus spp*., flukes, hepatitis E virus, norovirus, Rift Valley Fever virus, roundworms, *Salmonella, Toxoplasma gondii, Trichinella parasites,* and *Yersinia*.

During the characterisation exercise the experts have also proposed risk management measures that would apply to several issues belonging to the same category. These are described in Appendix E.

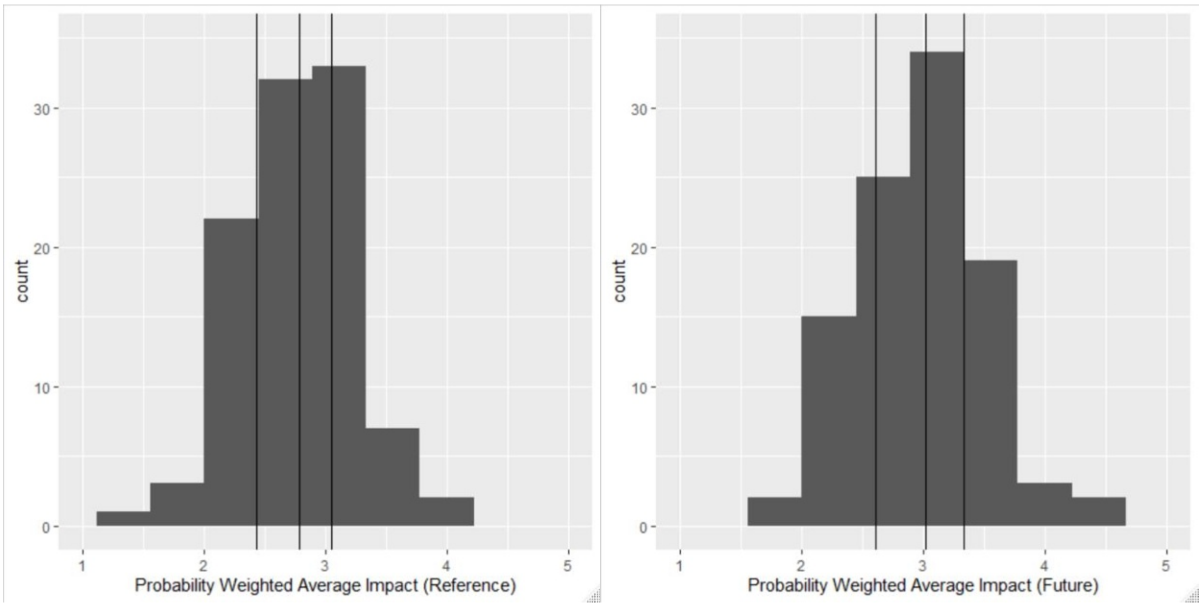
3.3. Analysis of the characterisation results

A list of emerging issues/risks potentially affected by climate change has been produced for each area within EFSA remit: (1) Public health impact – biological hazards; (2) Public health impact – chemical contaminants; (3) Animal health impact; (4) Plant health impact; and (5) impact on nutritional quality.

The characterised issues are described separately for each area (Sections 3.3.5–3.3.9). As specific risk management measures (RMMs) were identified for each area (see Appendix E), this division might facilitate identifying the most relevant issues and corresponding RMMs. For each area the issues are presented in a bi-dimensional Impact/likelihood diagram. The axes of this bi-dimensional diagram represent the probability weighted average score (averaged over all criteria in case of impacts) in the near-future scenario. Each square represents a certain combination of scores for impact and likelihood and gathers the issues characterised by this combination. Each issue is further characterised by the indicators of impact of climate change (delta – expression faces) and assessment uncertainty (variance).

3.3.1. Distribution of probability weighted average values

The histograms of probability weighted average values of impact, for both reference and future scenario, are shown on Figure 26.



Black vertical lines represent the 1st, 2nd (median) and 3rd quantiles.

Figure 26: Distribution of probability weighted average values for impact, in the reference conditions (left) and for future scenario (right)

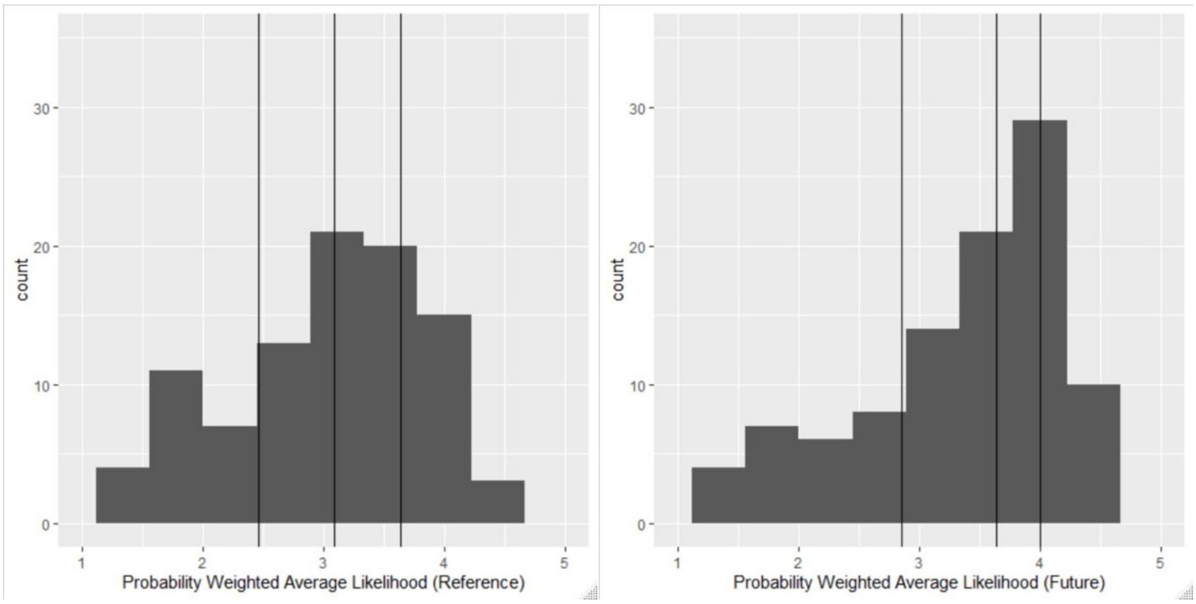
The relevant quantiles characterising the probability weighted average values distributions are shown in the Table 14 below:

Table 14: Quantitative description of probability weighted average values distribution for impact

	Reference	Future
Minimum	1.544	1.632
1st quantile	2.432	2.605
Median	2.786	3.019
Mean	2.752	2.964
3rd quantile	3.048	3.331
Maximum	4.038	4.417

When moving from reference to future, a slight shift towards a more serious impact can be observed, as expressed by the higher statistical values.

The histograms of probability weighted average values of likelihood, for both reference and future scenario, are shown on Figure 27.



Black vertical lines represent the 1st, 2nd (median) and 3rd quantiles.

Figure 27: Distribution of weighted average values for likelihood, in the reference conditions (left) and for future scenario (right)

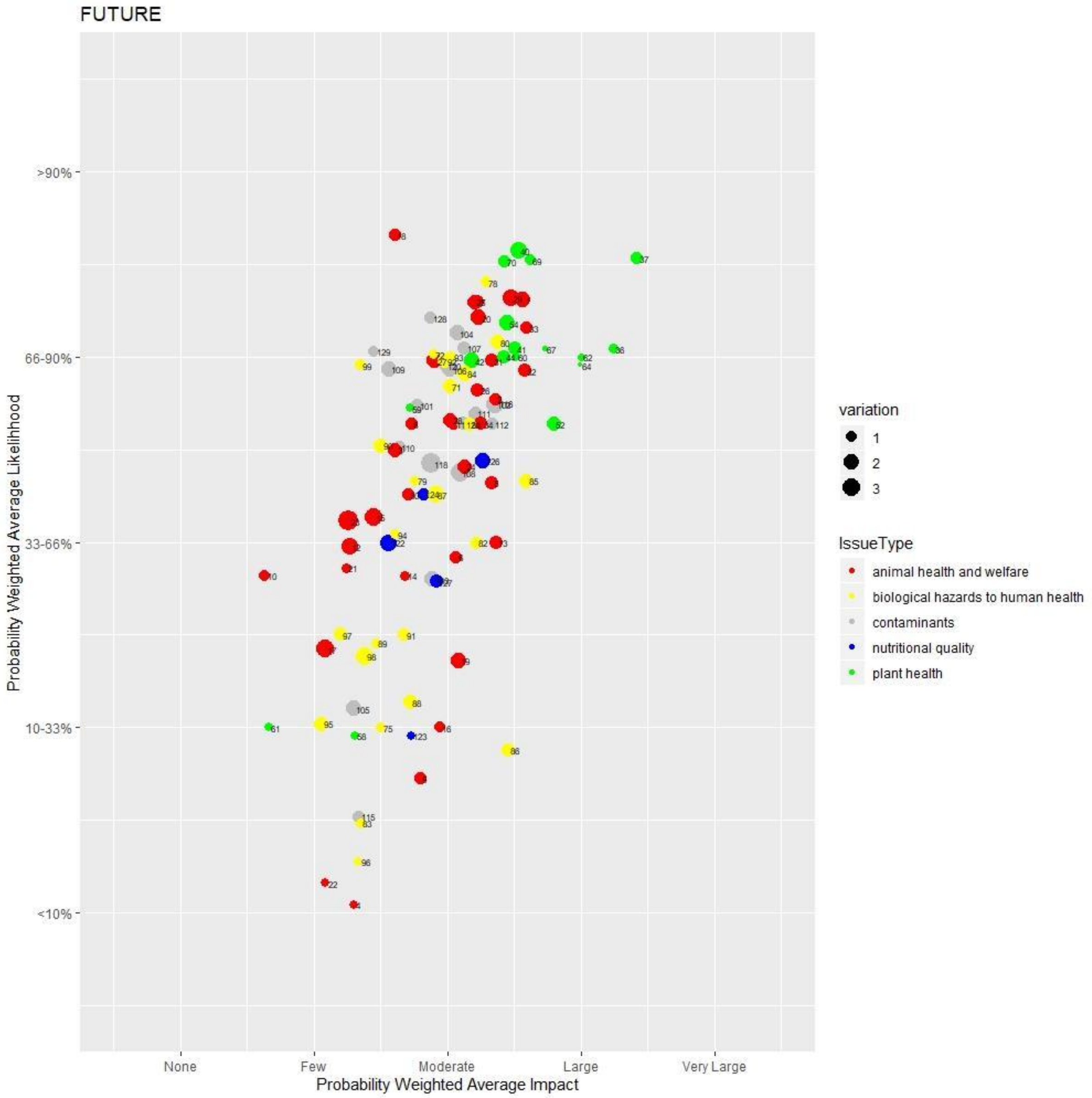
The relevant quantiles characterising the weighted average values distributions are shown in the Table 15:

Table 15: Quantitative description of weighted average values distribution for likelihood

	Reference	Future
Minimum	1.029	1.044
1st quantile	2.454	2.851
Median	3.083	3.640
Mean	3.041	3.354
3rd quantile	3.640	4.000
Maximum	4.956	4.659

The two distributions, for impact and likelihood, are quite different: likelihood distribution is more concentrated on high values; indeed the 3rd quantile for likelihood is quite high, especially in the future (the score 4 corresponds to a likelihood of 66–90%). Compared with impact, the likelihood of emergence shows a more prominent shift towards higher values in the future scenario.

Figure 28 shows all characterised issues, visualised as circles in a two-dimensional impact–likelihood matrix. The sizes of these circles were generated using variance values summed over impact and likelihood and the colours correspond to the five areas. Most of the issues related to plant health are clustered together, having high impact and likelihood of emergence, especially compared to issues from other categories. However, as described in previous sections, these issues were also scored by the lowest average number of experts.

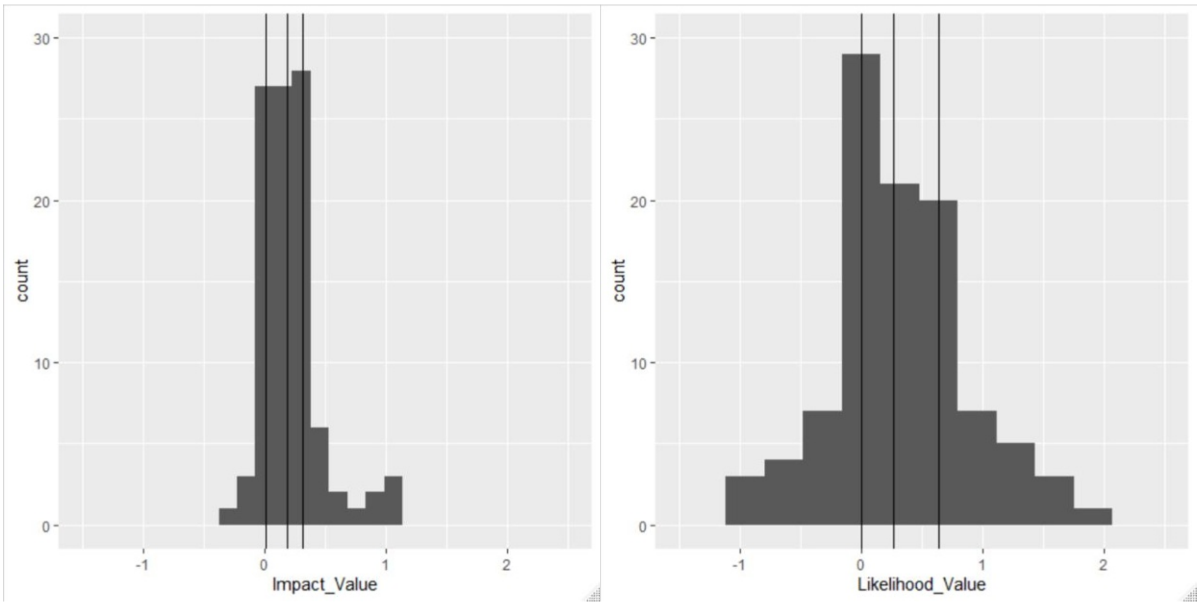


Probability weighted average values for impact are plotted on the x-axis, and those for likelihood – on the y-axis. Sizes of the circles correspond to variance values (sum of variance-impact and variance-likelihood) and their colours to the different EFSA's areas.

Figure 28: Graphical comparison of all characterised issues

3.3.2. Distribution of delta values

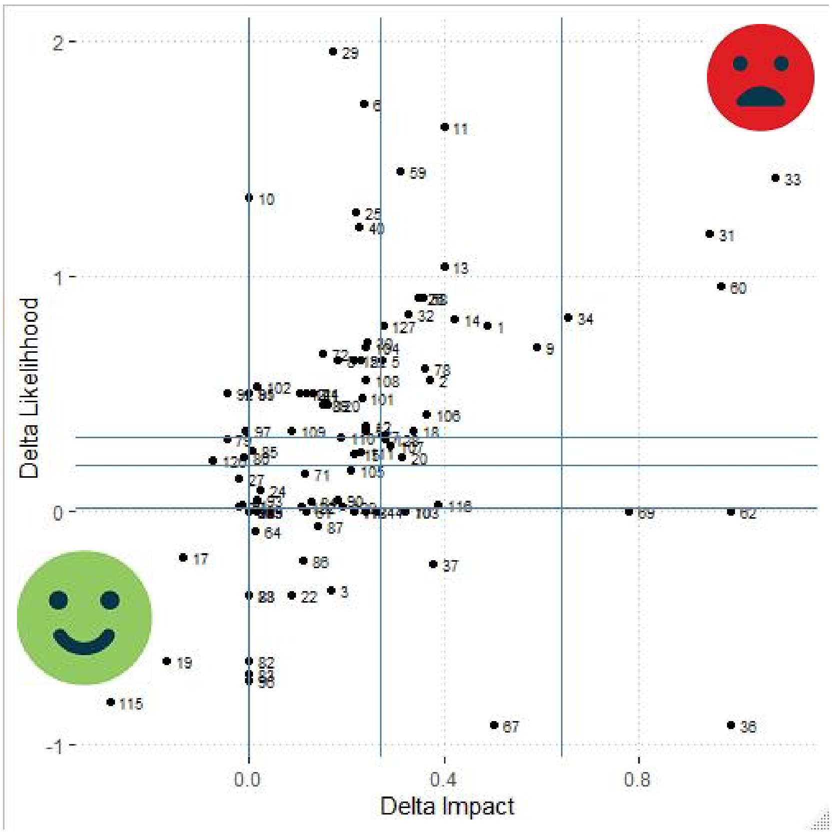
Figure 29 shows the distribution of the delta values for each issue, for both impact and likelihood. The delta values for likelihood show wider spread and a higher average value, confirming that climate change is expected to affect likelihood more than impact.



Vertical lines represent the 1st, 2nd (median) and 3rd quantiles.

Figure 29: Distribution of delta values for impact (left) and likelihood (right)

These distributions are combined to create a 2-dimensional plot, presented on Figure 30. Symbols used in the issue scoresheets (see Section 3.3.4) are shown to give an idea of how these ranges correspond to symbols.



Each point represents an issue, blue lines represent the 1st, 2nd (median) and 3rd quantile.

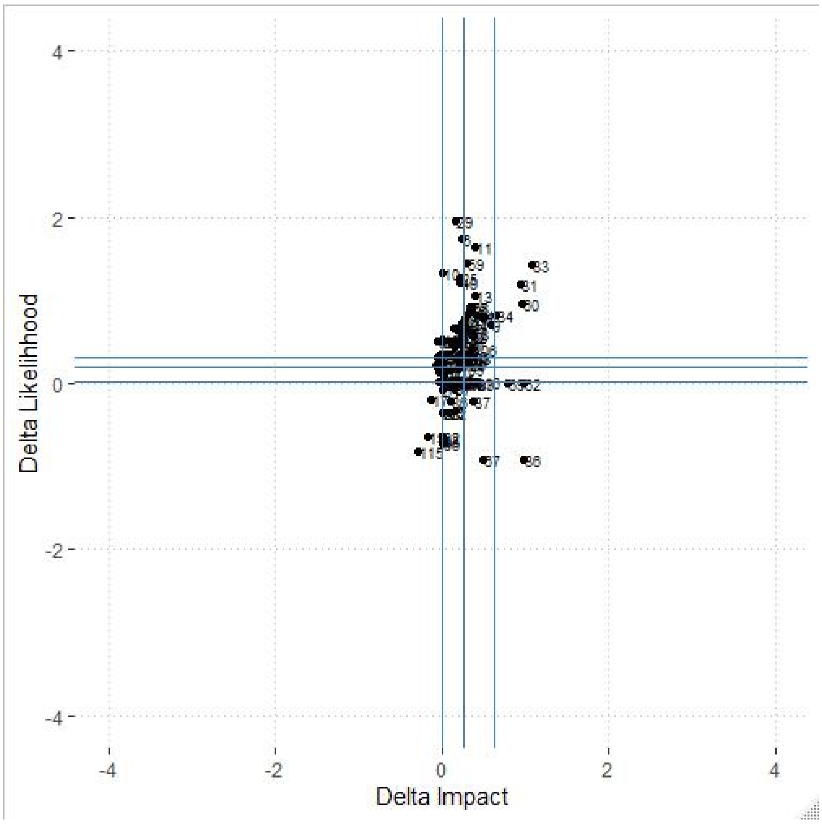
Figure 30: Two-dimensional representation of delta values distribution, where delta for impact is plotted on the x-axis vs delta for likelihood on the y-axis

The relevant quantiles characterising these distributions are shown in the Table 16.

Table 16: Quantitative description of delta values distribution

	Impact	Likelihood
Minimum	−0.2870	−0.9120
1st quantile	0.0095	0.0000
Median	0.1895	0.2680
Mean	0.2122	0.3134
3rd quantile	0.3090	0.6400
Maximum	1.0790	1.9590

Figure 31 shows that when compared to the theoretical range of delta values (−4; +4), the obtained delta distribution is narrow and focused on the central values, especially for impact. This might be caused by the fact that experts were usually conservative in their assessments and focused on the average, rather than worst-case scenarios. Generally speaking, experts were reluctant to give very high or very low scores for impact (see weighted average values distributions), which also affects the obtained delta values.



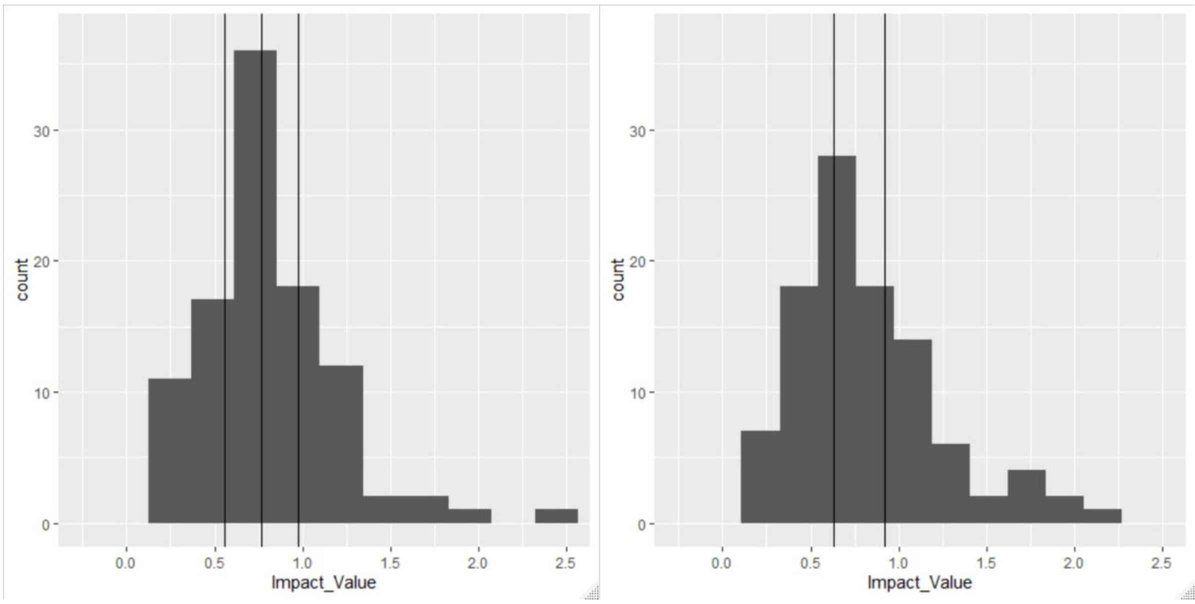
Each point represents an issue, blue lines represent the 1st, 2nd (median) and 3rd quantile.

Figure 31: Two-dimensional representation of delta values distribution in comparison to the theoretical range, where delta for impact is plotted on the x-axis vs delta for likelihood on the y-axis

3.3.3. Distribution of variance values

3.3.3.1. Impact

Figure 32 shows the distribution of variance values for each issue, for impact in the reference period and future scenario. The same is shown for variance values for likelihood in Figure 33. The relevant quantiles characterising these distributions are shown in Tables 17 and 18. Similarly to probability weighted average values, a slight shift towards higher values can be observed when moving from reference to future. This was expected, since future scenario was predicted to be characterised by higher uncertainty.



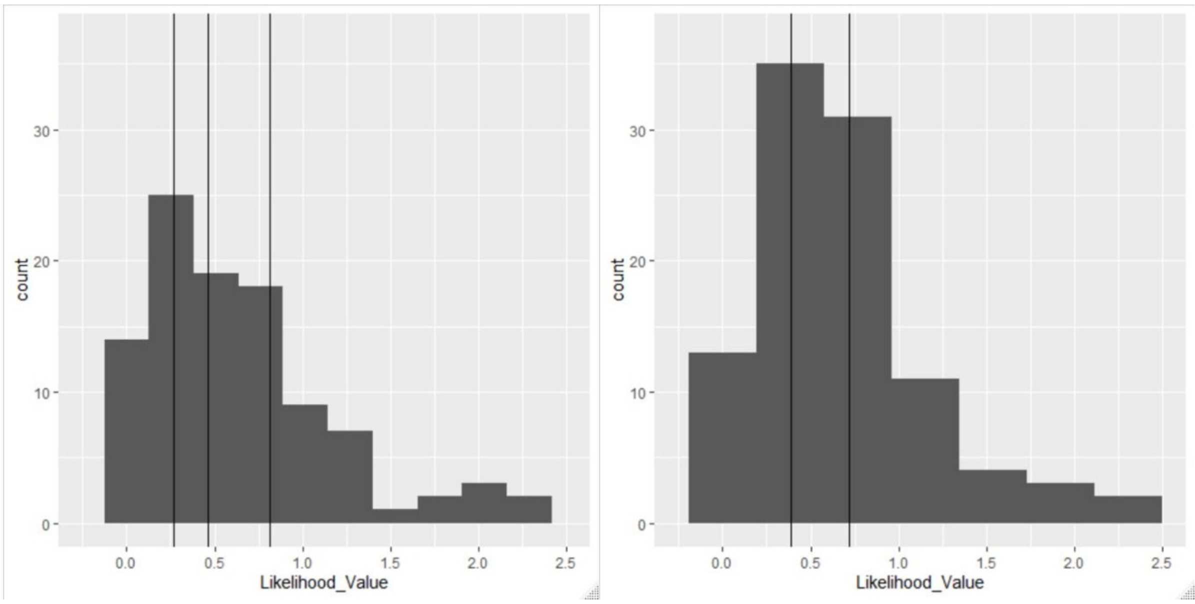
Vertical lines represent the 1st, 2nd and 3rd quantile (left) and 33% and 66% (right).

Figure 32: Distribution of variance values for impact, for the reference period (left) and future scenario (right)

Table 17: Quantitative description of variance values distribution for impact

	Reference	**Future**
Minimum	0.1360	0.1820
1st quantile	0.5570	0.5435
Median	0.7665	0.7385
Mean	0.8047	0.8233
3rd quantile	0.9745	1.0513
Maximum	2.3370	2.1300
33%		0.63
66%		0.92

3.3.3.2. Likelihood



Vertical lines represent the 1st, 2nd and 3rd quantile (left) and 33% and 66% (right).

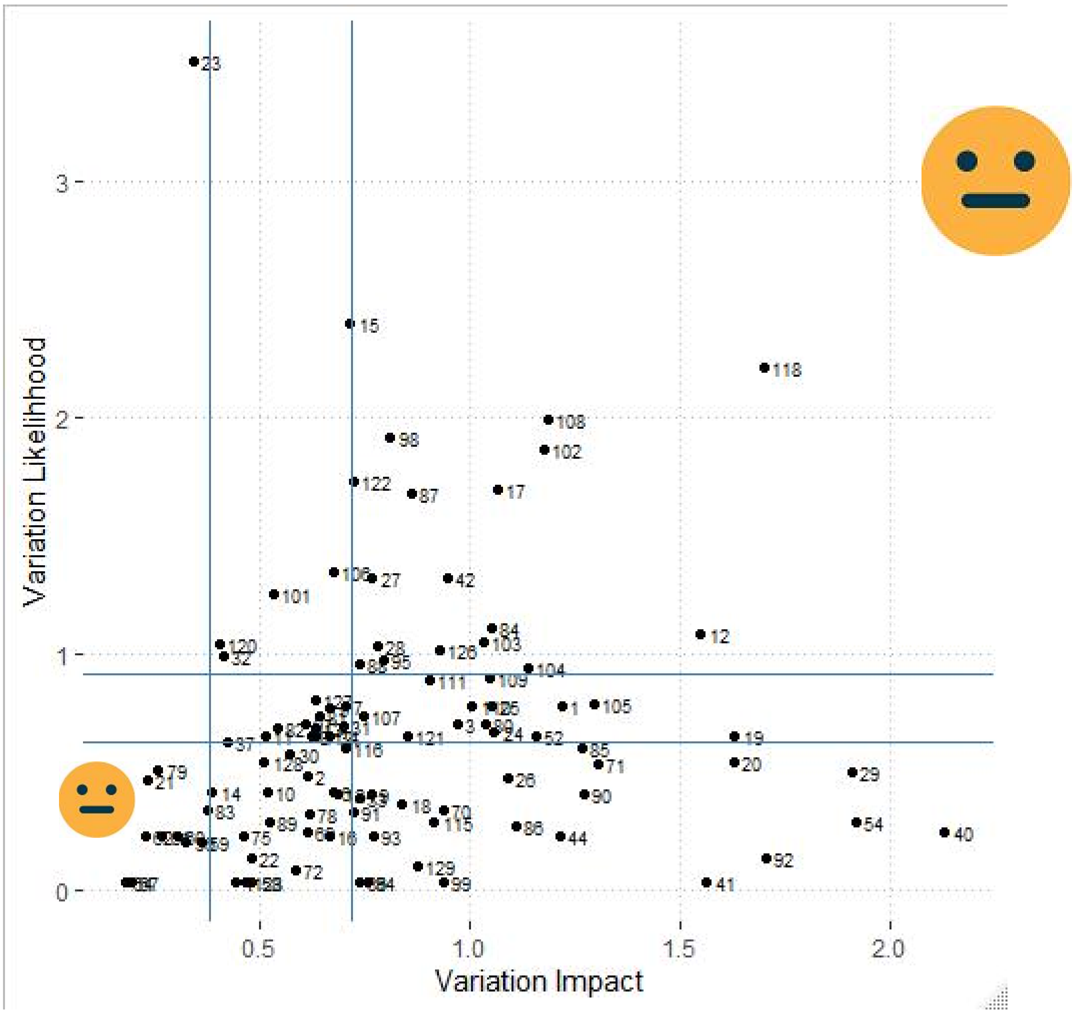
Figure 33: Distribution of variance values for likelihood, for the reference period (left) and future scenario (right)

Table 18: Quantitative description of variance values distribution for likelihood

	Reference	Future
Minimum	0.0290	0.0420
1st quantile	0.2657	0.2888
Median	0.4610	0.6045
Mean	0.6237	0.6833
3rd quantile	0.8105	0.8327
Maximum	2.3200	3.5080
33%		0.39
66%		0.72

A comparison of the variance quantiles in the future scenario for impact and likelihood indicates a lower variance for the latter. As discussed later in the report (Section 4.2.2), this might be a result of less ambiguity in the definition of likelihood ranges, compared to impact.

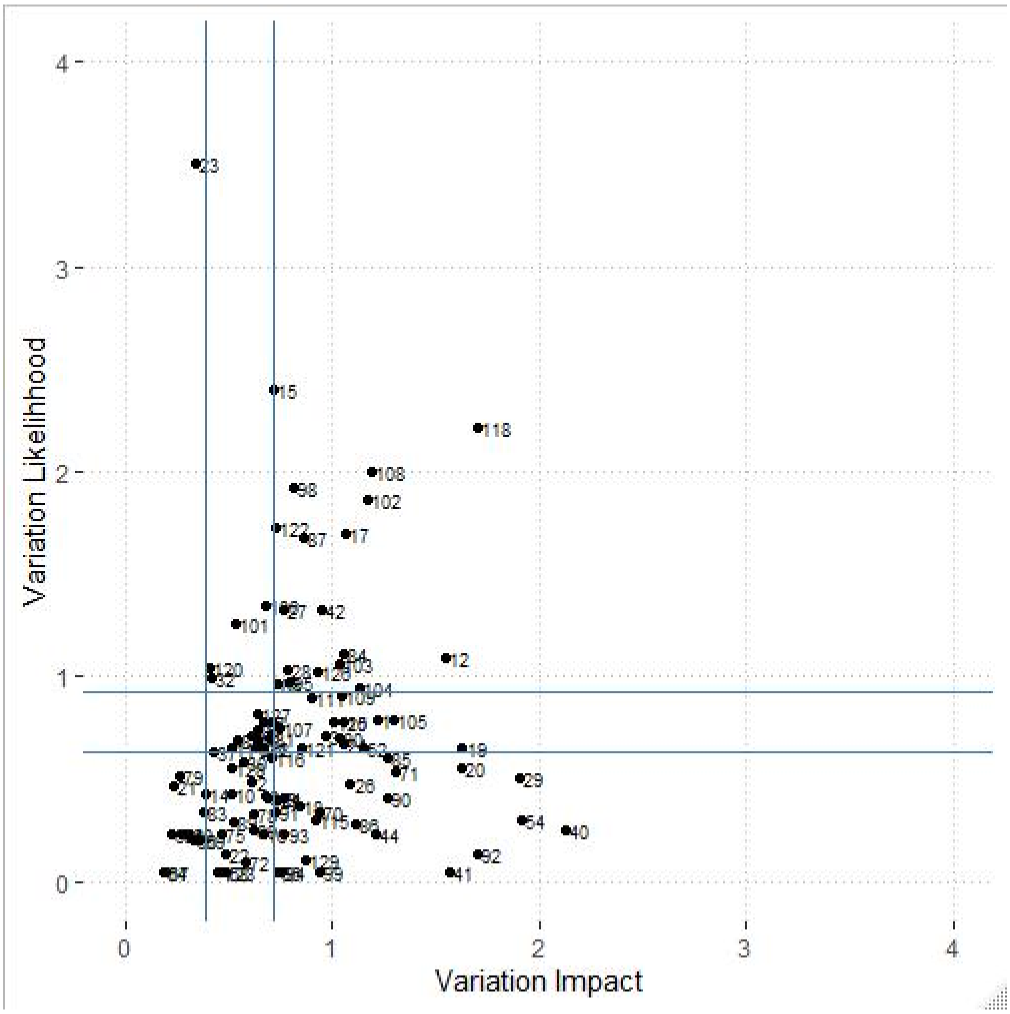
These distributions for the future scenario are combined to create a two-dimensional plot, presented on Figure 34. Symbols used in issue scoresheets are shown to give an idea how these ranges correspond to symbols.



Each point represents one issue, fine lines represent the 33% and 66% of cases.

Figure 34: Two-dimensional representation of variance values distribution in the future scenario, where variance for impact is plotted on the x-axis vs variance for likelihood on the y-axis

As shown on Figure 35, the variance distribution is only a fraction of the theoretical range (0; 4), but compared to delta values (Figure 31), the distribution is not as narrow.



Each point represents an issue, lines represent the 1st, 2nd and 3rd quantile.

Figure 35: Two-dimensional representation of variance values distribution in comparison to the theoretical range, where variance for impact is plotted on the x-axis vs variance for likelihood on the y-axis

3.3.4. Issue scoresheets

A template has been developed with the aim of integrating the information retrieved for each issue undergoing characterisation, the experts' assessment and the successive analyses. An attempt has been made to achieve a balance between information needs and communication efficacy. The template includes the following information:

EFSA's scientific area: the area of the issues that have been characterised (biological hazards to human health, contaminants, animal health, plant health and nutritional quality).

Source of the issue: indicates the sources used for identifying the emerging issue potentially affected by climate change (see Section 2.3).

Description of the issue: when the source of the issue is flagged as SURVEY, the text provided is taken from the original information as submitted in the online crowdsourcing survey. When available, information related to the same issue has been combined. EFSA has not performed a systematic review of the issues submitted through the survey. The scoresheets describe the issue as received in the crowdsourcing and as provided to the experts.

Supporting information: web links to publications, magazines, newspapers etc., provided by the sources of the issues.

Impact on other areas: this field indicates if the issue has been assessed also in other areas in the EFSA's remit.

Expertise range: Expresses a self-judgement of the expertise on the considered issue. It is not used for weighing purposes. Possible levels: very high, high, medium, low.

Scoring results: this section contains the uncertainty distribution averaged over all experts, for each impact sub-criterion and for likelihood criteria. This probability distribution curve is represented for both reference climatic condition and for the future scenario of climate change. In addition, a contour plot is provided describing the joint probability distribution of uncertainty for impact and likelihood, under the assumption of independence.

Contour plot of impact vs likelihood for the reference period and future scenario: two-dimensional impact–likelihood diagrams showing the probability distribution aggregated across the different experts and sub-criteria (for impact). It makes it possible to easily identify bimodal curves requiring expert discussions, with the aim of eliminating divergences.

Indicator of the effects of climate change: it represents the effects of the selected climate change scenarios on likelihood and impact of the identified issues, relative to the reference condition. The effect is characterised through a bi-dimensional plot where the x-axis represents impact and the y-axis represents likelihood. In the plot two points are depicted, representing the probability weighted average score for the future climate scenario and that for the reference condition. For communication purposes, probability weighted averages are arranged into four classes, defined on the basis of quartiles of delta value distribution for all the issues (Table 16). Emojis are used to illustrate the different classes.

Indicator of confidence level of the assessment: it represents the variance of the probability distribution for each score for the future scenario, i.e. how accurately the experts were able to assess the impact and likelihood of the issue in the future (see Section 2.5.2). For communication purposes, variance is classified into three classes, defined on the basis of the 1st tertile (33%), the 2nd tertile (66%) (Table 17 for impact and Table 18 for likelihood). Three sizes of emoji are used to illustrate the classes.

Outcome: it summarises the outcome of the aggregated analysis of the experts scores and uncertainties associated with impact and likelihood and the effects of climate change.

The emojis used to represent the ranges of the indicators described above are presented in Tables 19 and 20.

Table 19: Symbols corresponding to four ranges of indicator of the effects of climate change

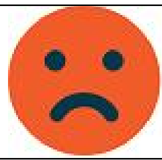
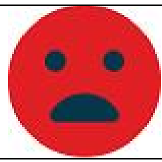
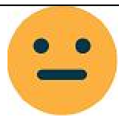
Climate change indicator				
Impact/description with respect to the reference condition	Climate change may have a positive or no effect on the impact of the considered hazard	Climate change may mildly aggravate the impact of the considered hazard	Climate change may moderately aggravate the impact of the considered hazard	Climate change may seriously aggravate the impact of the considered hazard
Impact/range	[−0.29; 0.01]	(0.01; 0.19]	(0.19; 0.31]	(0.31; 1.08]
Likelihood/description with respect to the reference condition	Climate change may have a positive or no effect on the likelihood of emergence	Climate change may mildly increase the likelihood of emergence of the issue	Climate change may moderately increase the likelihood of emergence of the issue	Climate change may seriously increase the likelihood of emergence of the issue
Likelihood/range	[-0.91; 0]	(0; 0.27]	(0.27; 0.64]	(0.64; 1.96]

Table 20: Symbol sizes corresponding to three ranges of indicator of confidence level of the assessment

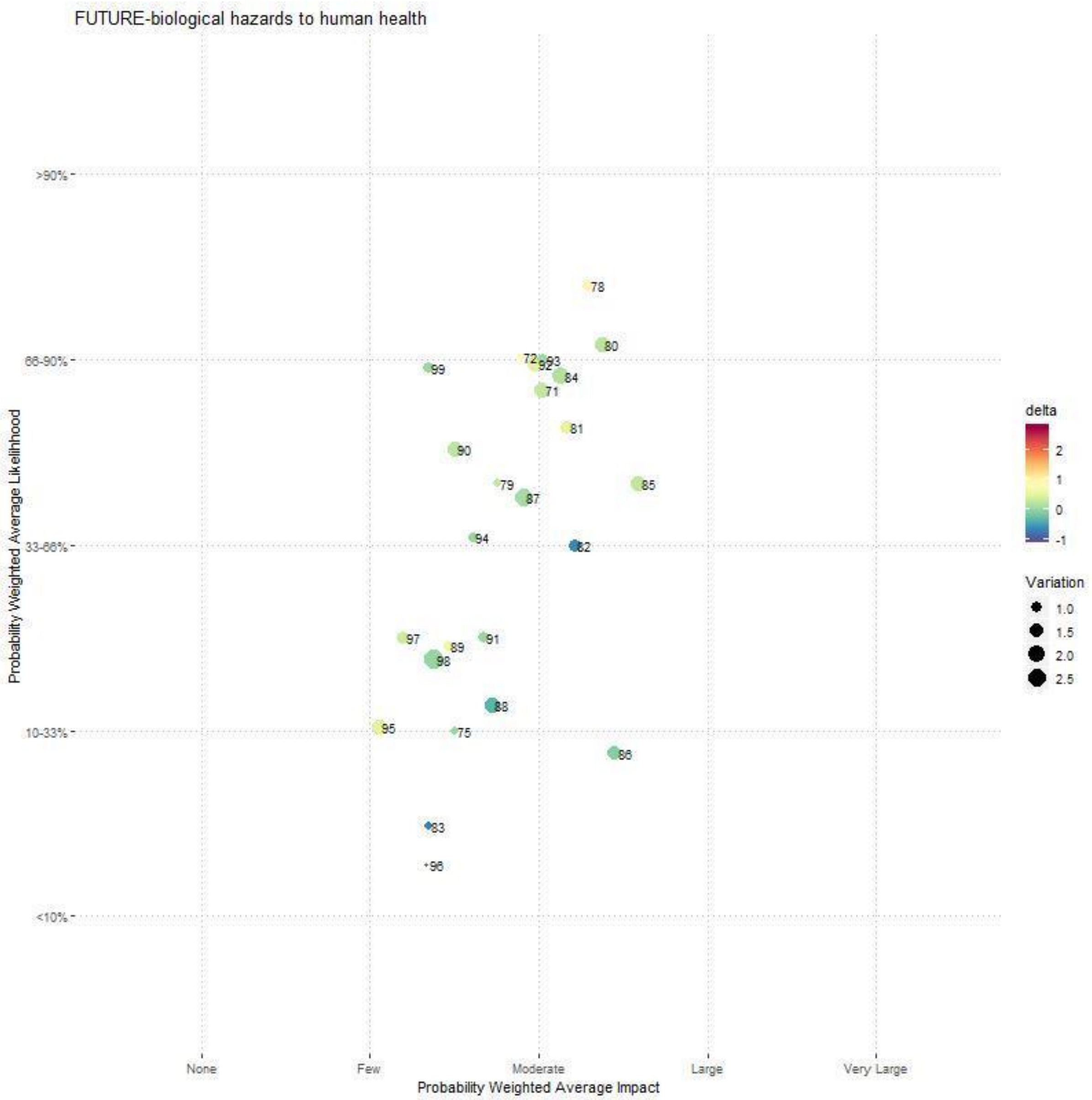
Confidence level indicator			
Impact/description	High confidence	Medium confidence	Low confidence
Impact/range	[0; 0.63]	(0.63; 0.92]	(0.92; 2.13]
Likelihood/description	High confidence	Medium confidence	Low confidence
Likelihood/range	[0; 0.39]	(0.39; 0.72]	(0.72; 3.51]

A list of 27 scoresheets is given in Appendix B. These are related to the issues with the highest number of experts for each area:

- plant health: 3 experts
- nutritional quality: 4 experts
- contaminants: 5 to 8 experts
- biological hazards to human health: 6 or 7 experts
- animal health: 4 or 5 experts.

3.3.5. Biological hazards to human health

Figure 36 shows all the issues related to biological hazards to human health, visualised as circles in a two-dimensional impact–likelihood matrix. Impact and likelihood are visualised under the near-future climate scenario. The sizes and colours of these circles were generated using delta and variance values summed over impact and likelihood.



Weighted average values for impact are plotted on the x-axis and those for likelihood on the y-axis. Colours of the circles correspond to delta values and their sizes to variance values.

Figure 36: Graphical comparison of all issues belonging to 'biological hazards to human health' category

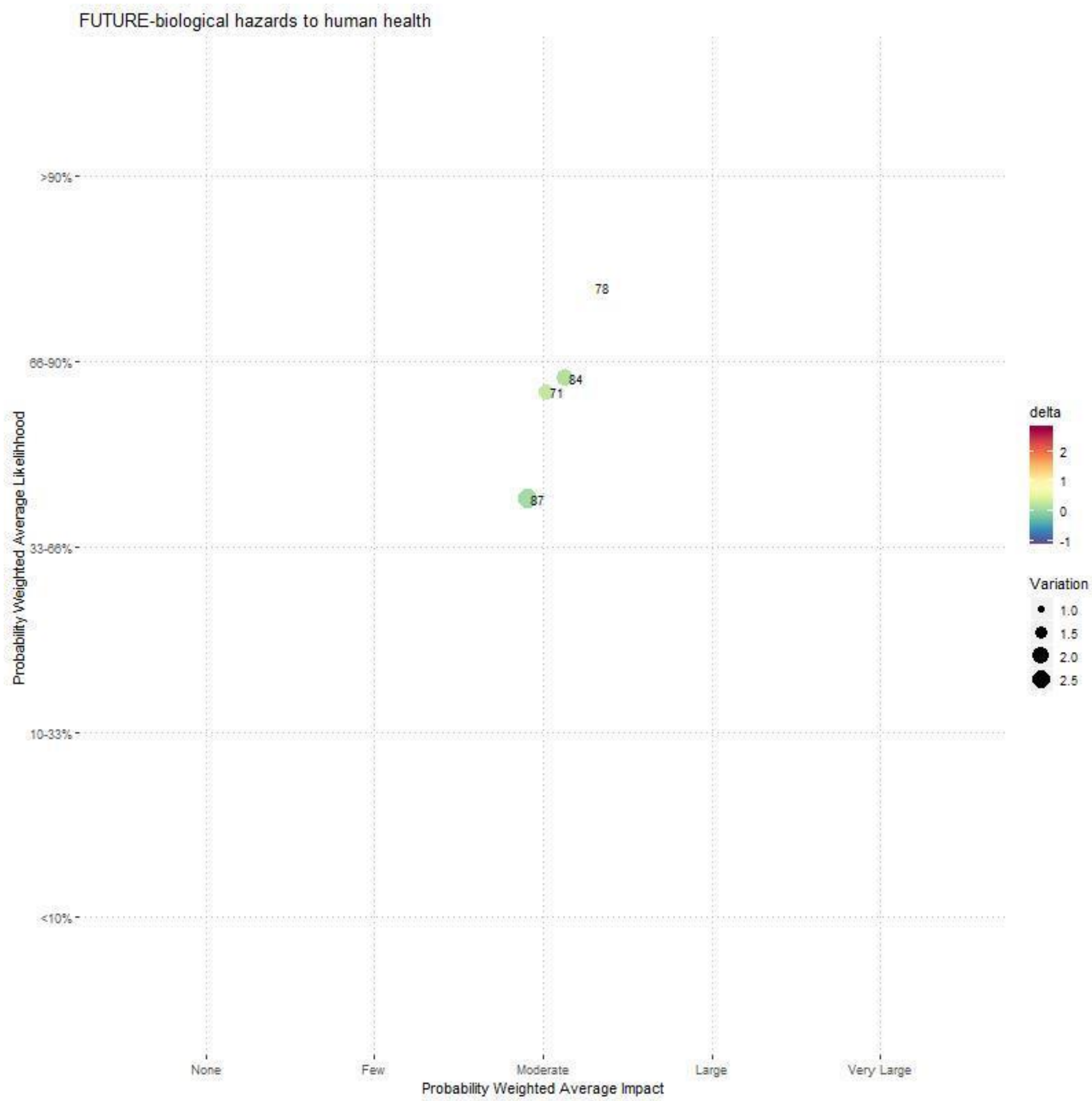
The issues and corresponding numbers used in these graphs are listed in Table 21.

Table 21: List of characterised issues belonging to the 'biological hazards to human health' area. Issues in bold were scored by the highest number of experts (6 or 7) and described in scoresheets (Appendix B)

Issue ID	Issue name
71	**Norovirus**
72	Hepatitis E virus
75	Rift valley Fever
78	***Vibrio* spp., especially *V. parahaemolyticus* and *V. vulnificus***
79	*Escherichia coli*
80	*Listeria*
81	*Salmonella*
82	*Yersinia*
83	*Brucella*
84	***Campylobacter* spp.**
85	*Clostridium botulinum*
86	*Bacillus anthracis*
87	***Cryptosporidium* spp.**
88	*Trichinella* spp.
89	*Fasciolidae* family
90	*Cyclospora cayetanensis*
91	*Toxoplasma gondii*
92	*Giardia*
93	*Angiostrongylus cantoniensis*
94	*Ascaris*
95	*Toxocara*
96	*Echinococcus* spp.
97	Roundworms
98	Flukes
99	*Anisakis*
	Total: 25 issues

As shown on Figure 36, no issues with extremely low or high impact were identified in this area under the near-future climate scenario. The likelihood of the issues in the future ranges from very high (issue 78, *Vibrio* spp.) to very low (issue 96, *Echinococcus* spp.).

Figure 37 shows the issues related to human health scored by the highest number of experts, i.e. 6 or 7. They are clustered together and are likely to emerge, with moderate impacts. The pathogens described by these issues are also known to affect animal health, demonstrating interactions across areas. Scoresheets have been produced for these issues.

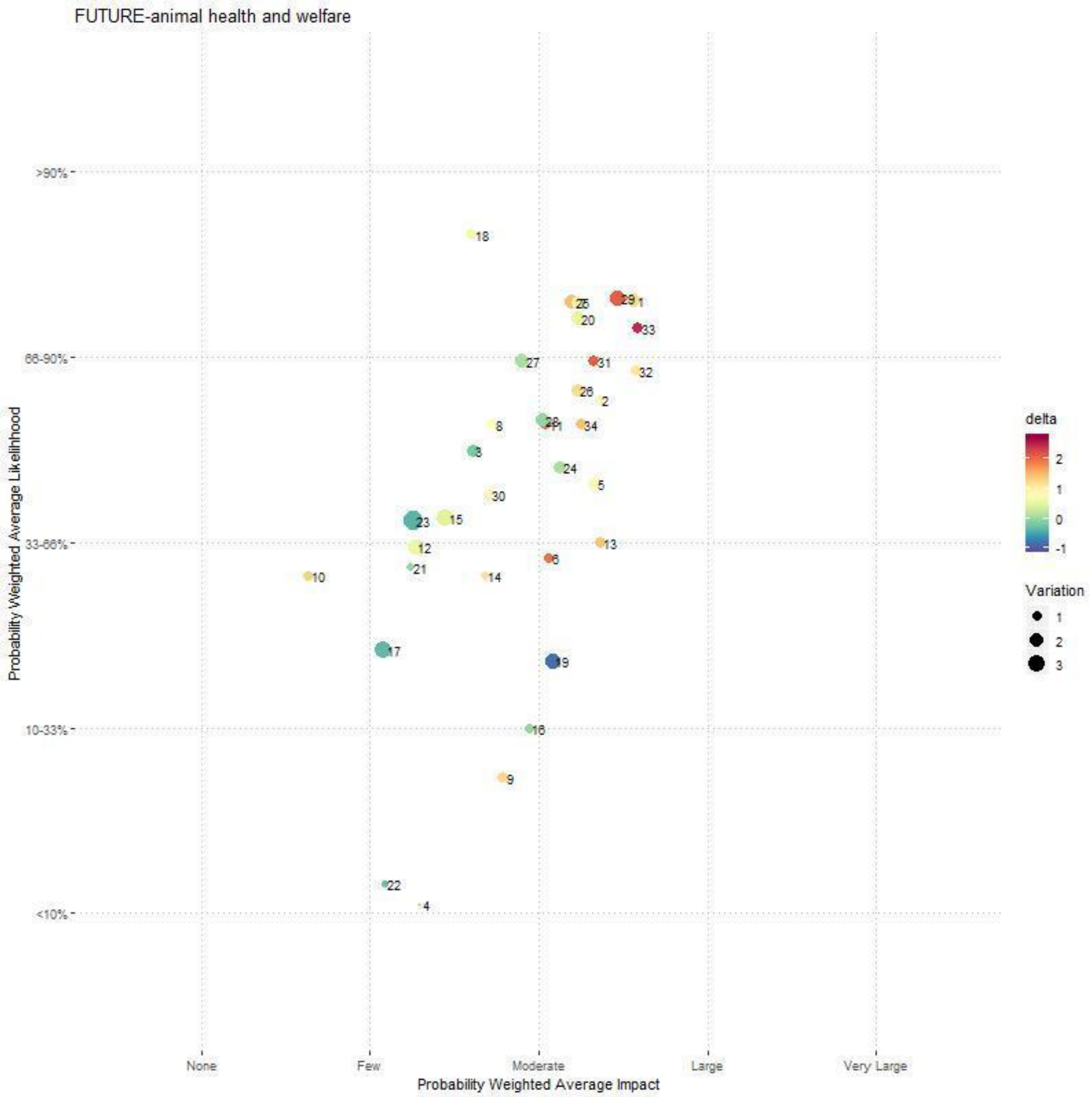


Probability weighted average values for impact are plotted on the x-axis and those for likelihood on the y-axis. Colours of the correspond to delta values and their sizes to variance values, calculated for the sum of impact and likelihood. Numbers refer to issue IDs listed in Table 21.

Figure 37: Graphical comparison of all issues belonging to 'biological hazards to human health' category and scored by at least six experts, under the near-future climate scenario

3.3.6. Animal health and welfare

Figure 38 shows all the issues related to animal health and welfare, visualised as circles in a 2-dimensional impact–likelihood matrix. Impact and likelihood are visualised under the near-future climate scenario. The sizes and colours of these circles were generated using delta and variance values summed over impact and likelihood.



Probability weighted average values for impact are plotted on the x-axis, and those for likelihood on the y-axis. Colours of the circles correspond to delta values and their sizes to variance values, calculated for the sum of impact and likelihood. Number refer to issue IDs listed in Table 22.

Figure 38: Graphical comparison of all issues belonging to 'animal health and welfare' category under the near-future climate scenario

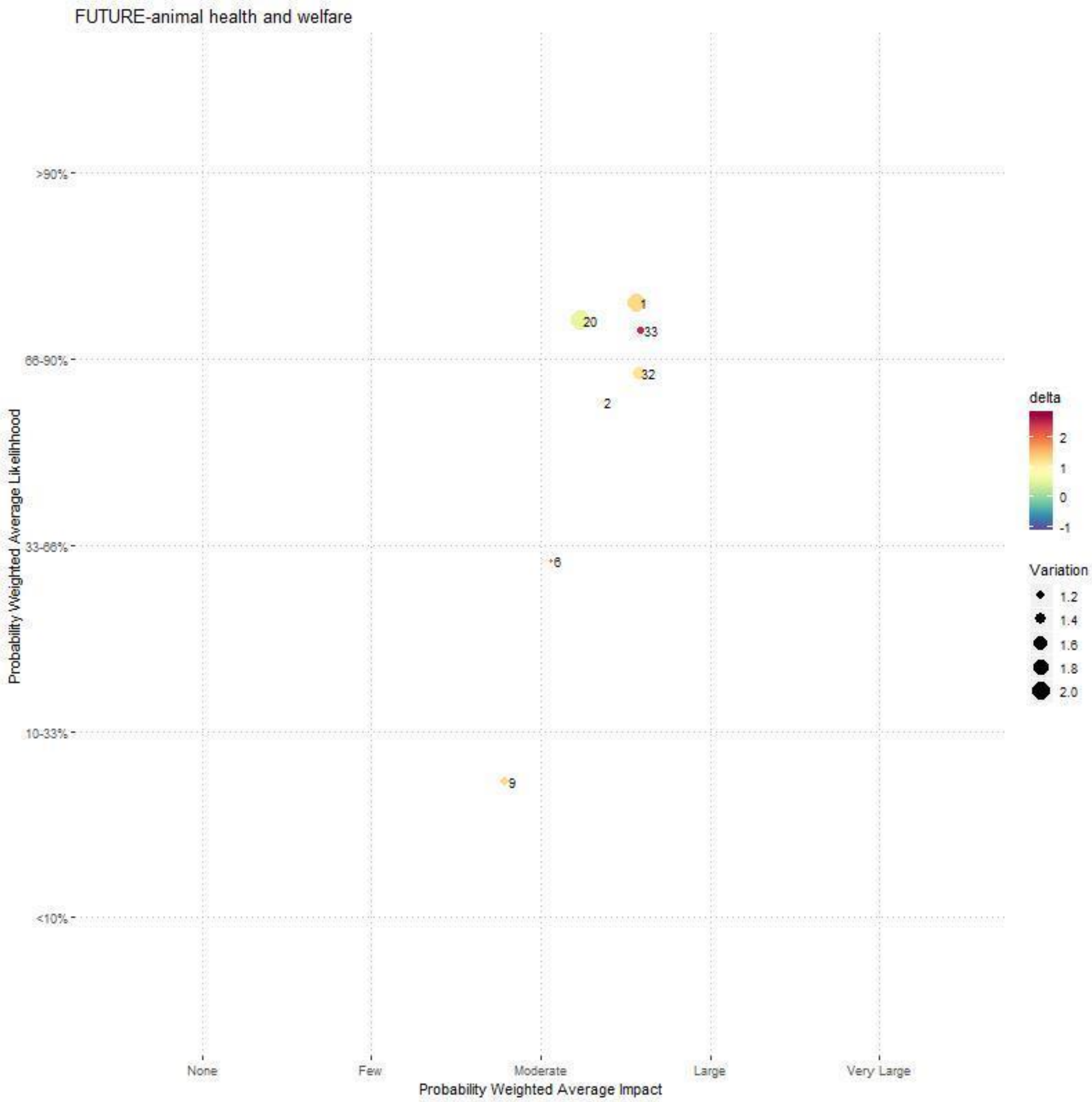
The issues and corresponding numbers used in these graphs are listed in Table 22.

Table 22: List of characterised issues belonging to 'animal health and welfare' category. Issues in bold were scored by the highest number of experts (4 or 5) and described in scoresheets (Appendix B)

Issue ID	Issue name
1	***Aedes albopictus, Culicoides imicola***
2	***Culex pipiens, C. obsoletus***
3	*Hyalomma marginatum* (vector of Crimean–Congo haemorrhagic fever-CCHF)
4	Nipah virus
5	Influenza A viruses
6	**Rift Valley Fever virus**
7	Bluetongue virus-BTV
8	Lumpy skin disease virus (LSDV)
9	**Peste des Petits Ruminants (PPR) virus**
10	Norovirus
11	Emergence of piscine reovirus (PRV) in France
12	Hepatitis E virus
13	*Clostridium botulinum*
14	*Ehrlichia chaffeensis*, *E. ewingii* or *E. muris*
15	*Salmonella*
16	*Yersinia*
17	*Brucella*
18	*Campylobacter*
19	*Bacillus anthracis*
20	***Leishmania* parasites**
21	*Toxoplasma gondii*
22	*Trichinella* parasites
23	*Echinococcus* spp.
24	Roundworms
25	*Dirofilaria* spp.
26	Heartworms and lungworms
27	Flukes
28	*Fasciola hepatica*
29	Chronic wasting disease (CWD) prion
30	*Vespa velutina*
31	Impact on wildlife distribution
32	**Development of the proliferative kidney disease in Swiss trout**
33	**Heat stress in Swiss dairy cows**
34	Climate change as a possible stressor for bee decline
	Total: 34 issues

As shown on the figures above, no issues with extremely low or high impact were identified in this area under the near-future climate scenario. The scores were clustered, with some notable exceptions like issue 10 (*Norovirus*), 18 (*Campylobacter*) and 22 (*Trichinella* parasites). However, there is no clear tendency in delta and variance values.

Figure 39 shows the issues related to animal health scored by the highest number of experts, i.e. 4 or 5. A majority of them is clustered together and are likely to emerge, with moderate to large impacts. These issues, except for heat stress in Swiss dairy cows, are all related to vector-borne diseases that have been shown to have strong relationships with climate change. Similar infectious diseases were identified by ECDC as threats to human health (Lindgren et al., 2012), demonstrating interactions across areas. Scoresheets have been produced for these issues.

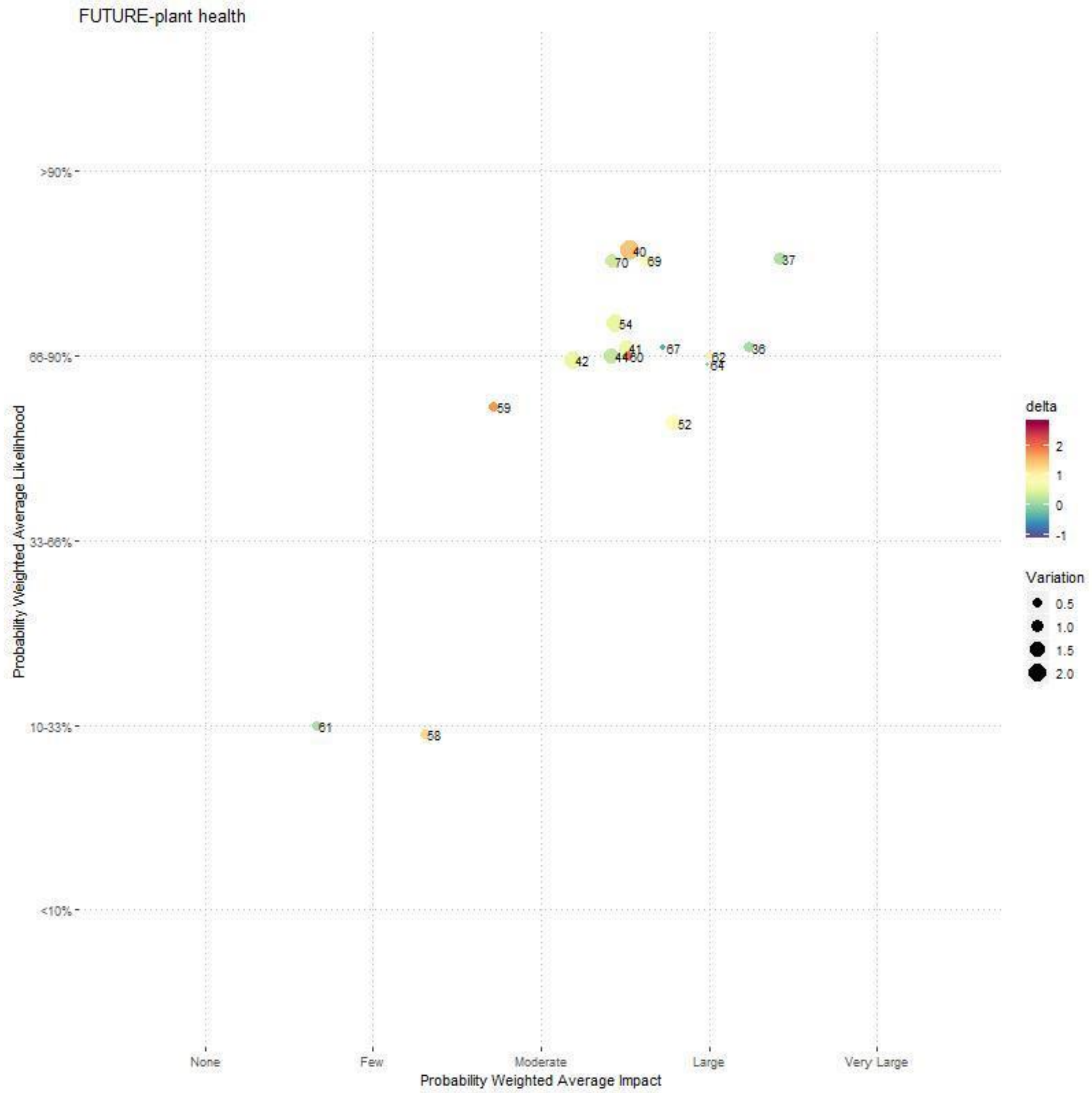


Probability weighted average values for impact are plotted on the x-axis, and those for likelihood on the y-axis. Colours of the circles correspond to delta values and their sizes to variance values, calculated for the sum of impact and likelihood. Numbers refer to issue IDs listed in Table 22.

Figure 39: Graphical comparison of all issues belonging to 'animal health and welfare' category and scored by 4 or 5 experts, under the near-future climate scenario

3.3.7. Plant health

Figure 40 shows all the issues related to plant health, visualised as circles in a two-dimensional impact–likelihood matrix. The sizes and colours of these circles were generated using delta and variance values summed over impact and likelihood.



Probability weighted average values for impact are plotted on the x-axis, and those for likelihood on the y-axis. Colours of the circles correspond to delta values and their sizes to variance values, calculated for the sum of impact and likelihood. Numbers refer to issue IDs listed in Table 23.

Figure 40: Graphical comparison of all issues belonging to 'plant health' category under the near-future climate scenario

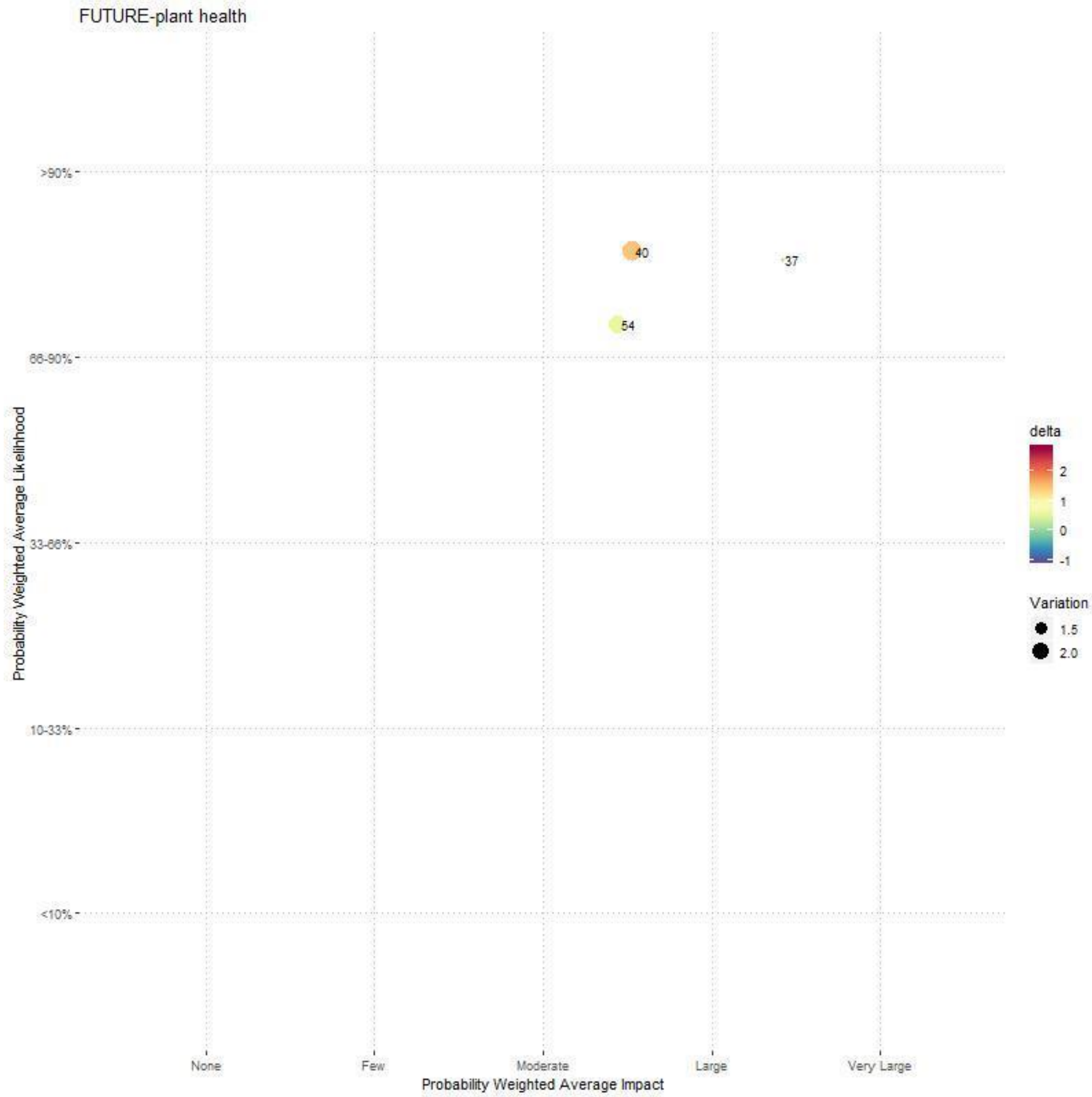
The issues and corresponding numbers used in these graphs are listed in Table 23. They include regulated and non-regulated pests, with a much broader scope than the pests covered by (EUR-Lex 2016).

Table 23: List of characterised issues belonging to 'plant health' category. Issues in bold were scored by three experts and described in the scoresheets (Appendix B)

Issue ID	Issue name
36	Potential establishment of the apple snail in the EU
37	**Increased area of potential establishment and spread of *Xylella fastidiosa* and its insect vectors**
40	**Fruit flies, like Mediterranean fruit fly (*Ceratitis capitate*)**
41	Spread of Tomato leaf miner, *Tuta absoluta* in tomato
42	Pine processionary moth and its expansion north and to higher latitudes due to climate change
44	Codling moth *Cydia pomonella*
52	Brown marmorated stink bug damaging vegetable production in South Europe
54	**Olive fruit fly (*Bactrocera oleae*)**
58	*Spodoptera frugiperda*
59	Potential distribution of huanglongbing (HLB) caused by *Candidatus* Liberibacter asiaticus (CLas)
60	Wheat stem rust and yellow rust
61	Wheat blast (*Magnaporthe oryzae* Triticum pathotype)
62	Wheat Fusarium head blight
64	Citrus tristeza virus
67	*Ralstonia solanacearum*
69	Heat and drought stress
70	Heavy rainfall and floods
	Total: 17 issues

Strikingly, all issues except for 58 (*Spodoptera frugiperda*) and 61 (Wheat blast) are clustered together and are expected to likely emerge in the future and have large impact. However, there is no clear tendency as far as delta and variance values are concerned.

Figure 41 shows three issues (*Xylella fastidiosa*, *Ceratitis capitate* and *Bactrocera oleae*) related to plant health scored by the highest number of experts, i.e. 3. They are clustered together and are likely to emerge, with moderate to very large impacts. Each of them is related to biological threats – pests or parasites, that will either emerge or increase their range in Europe in consequence of climate change. Scoresheets have been produced for these issues.



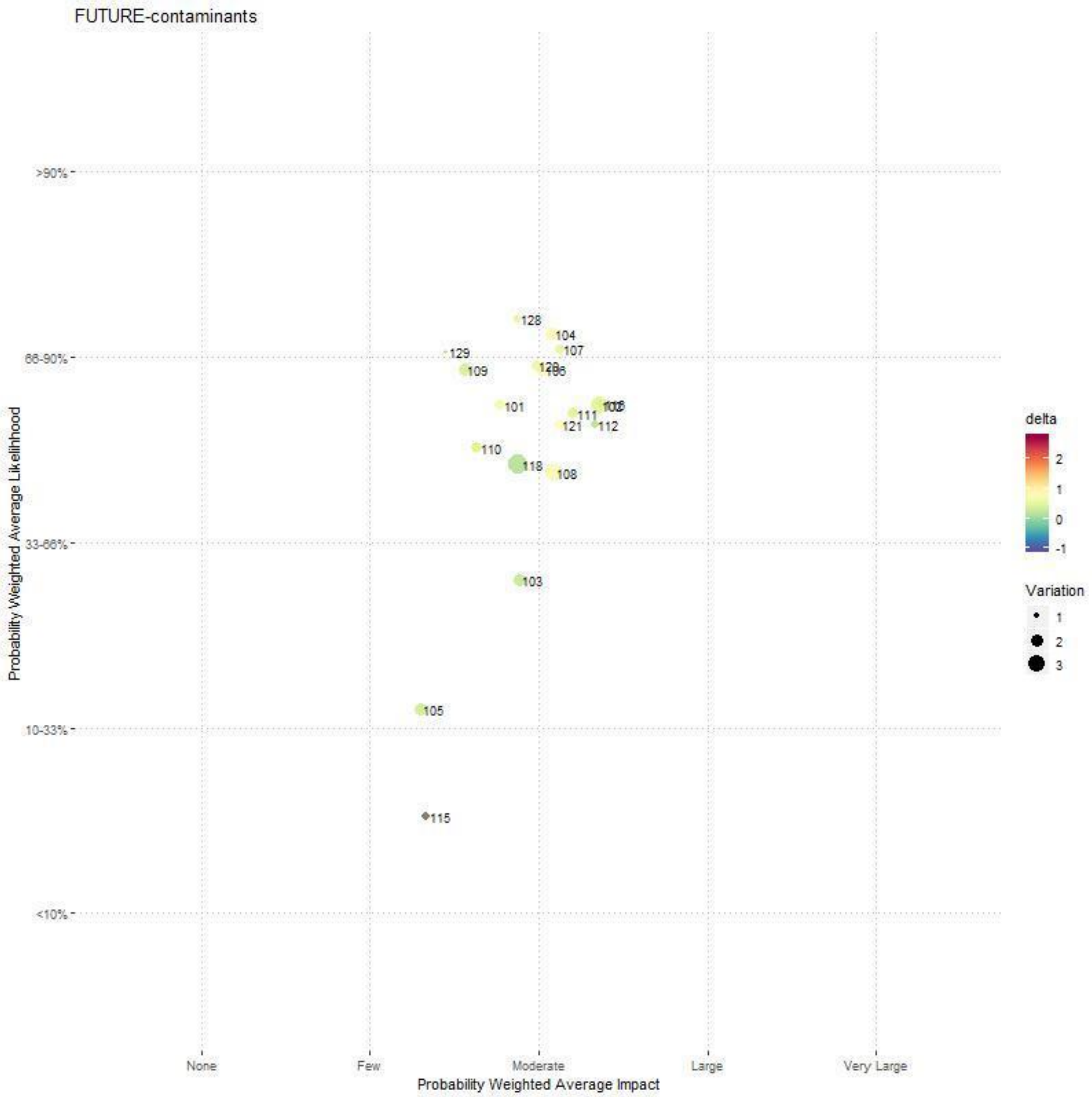
Probability weighted average values for impact are plotted on the x-axis, and those for likelihood on the y-axis. Colours of the circles correspond to delta values and their sizes to variance values, calculated for the sum of impact and likelihood. Numbers refer to issue IDs listed in Table 23.

Figure 41: Graphical comparison of all issues belonging to 'plant health' category and scored by the maximum number of experts (i.e. three), under the near-future climate scenario

3.3.8. Contaminants

As explained in Section 2.4, the characterisation of each issue is designed to be conducted in one area at a time. In order to ensure consistency with this design, issues in the area of contaminants have been analysed only in relation to their impacts on human health. The scores provided for criterion D (production/yield loss), which is applicable to animals and plants only, have therefore been disregarded. However, the interlinkages with plant and animal health are recognised for many issues and expressed in the issue description or through the other qualifying criterion 'Impact on other areas in the remit of EFSA'.

Figure 42 shows all the issues related to contaminants, visualised as circles in a two-dimensional impact–likelihood matrix. The sizes and colours of these circles were generated using delta and variance values summed over impact and likelihood.



Probability weighted average values for impact are plotted on the x-axis, and those for likelihood on the y-axis. Colours of the circles correspond to delta values and their sizes to variance values.

Figure 42: Graphical comparison of all issues belonging to 'contaminants' category under the near-future climate scenario

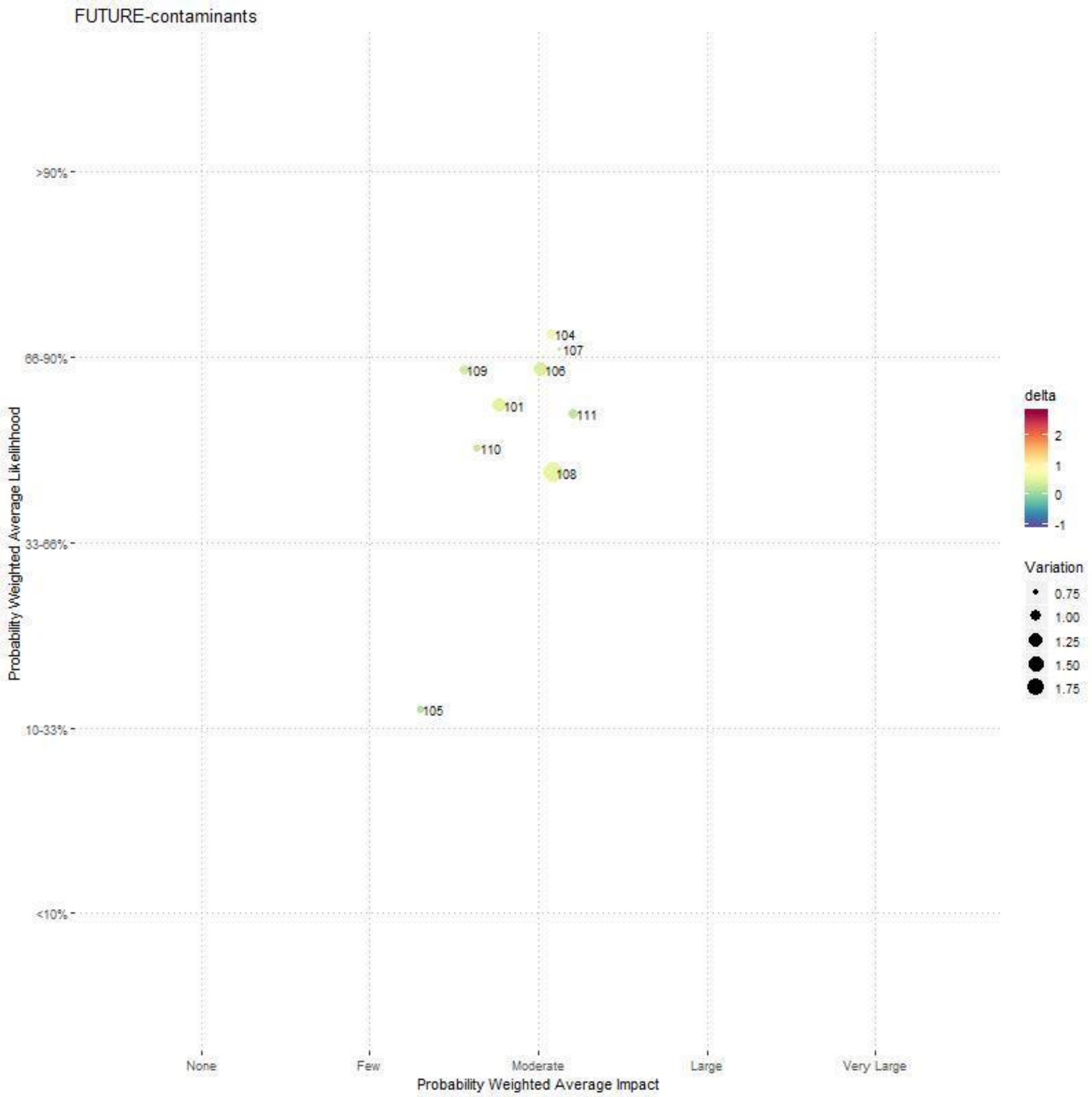
The issues and corresponding numbers used in these graphs are listed in Table 24.

Table 24: List of characterised issues belonging to 'contaminants' category. Issues in bold were scored by 5 to 8 experts and described in scoresheets (Appendix B)

Issue ID	Issue name
101	**Deoxynivalenol (DON) and zearalenone (ZON)**
102	Aflatoxins
103	Ochratoxin A
104	**Ciguatoxins**
105	**β-Methylamino-L-alanine (BMAA)**
106	**Cyanotoxins**
107	**Domoic acid**
108	**Palytoxin**
109	**Okadaic acid**
110	**Pinnatoxins**
111	**Tetrodotoxin (TTX) and TTX analogues**
112	Hormones
115	Pyrrolizidine alkaloids
116	Mercury
118	Plastic debris
120	Heavy metals as As, Pb, Cd
121	Polycyclic aromatic hydrocarbon
128	Saxitoxin
129	Azaspiracid
	Total: 19 issues

As shown on the figures above, no issues with extremely low or high impact were identified in this area under the near-future climate scenario. The scores were clustered, with some notable exceptions like issue 105 [β-methylamino-L-alanine (BMAA)] and 115 (pyrrolizidine alkaloids), characterised by markedly lower likelihood of emergence.

Figure 43 shows nine issues related to contaminants scored by the highest number of experts, i.e. 5 to 8. They are clustered together and are likely to emerge, with moderate impacts. They are all related to toxins produced by organisms (bacteria, fungi, algae) whose growth is strongly affected by climate change, like extensively described harmful algal blooms. For these issues, scoresheets have been produced.

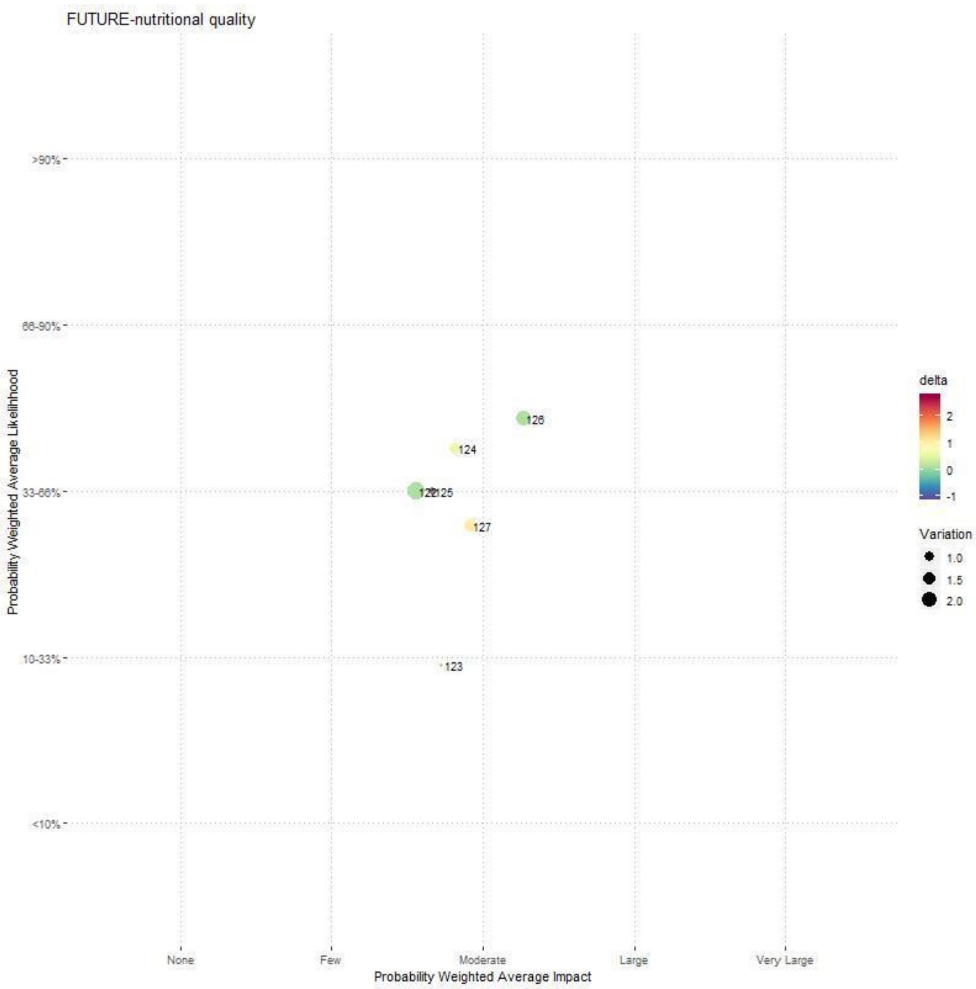


Probability weighted average values for impact are plotted on the x-axis, and those for likelihood on the y-axis. Colours of the circles correspond to delta values and their sizes to variance values.

Figure 43: Graphical comparison of all issues belonging to 'contaminants' category and scored by at least five experts, under the near-future climate scenario

3.3.9. Nutritional quality

Figure 44 shows all the issues related to nutritional quality, visualised as circles in a two-dimensional impact–likelihood matrix. The sizes and colours of these circles were generated using delta and variance values summed over impact and likelihood.



Probability weighted average values for impact are plotted on the x-axis, and those for likelihood on the y-axis. Colours of the circles correspond to delta values and their sizes to variance values.

Figure 44: Graphical comparison of all issues belonging to 'nutritional quality' category under the near-future climate scenario

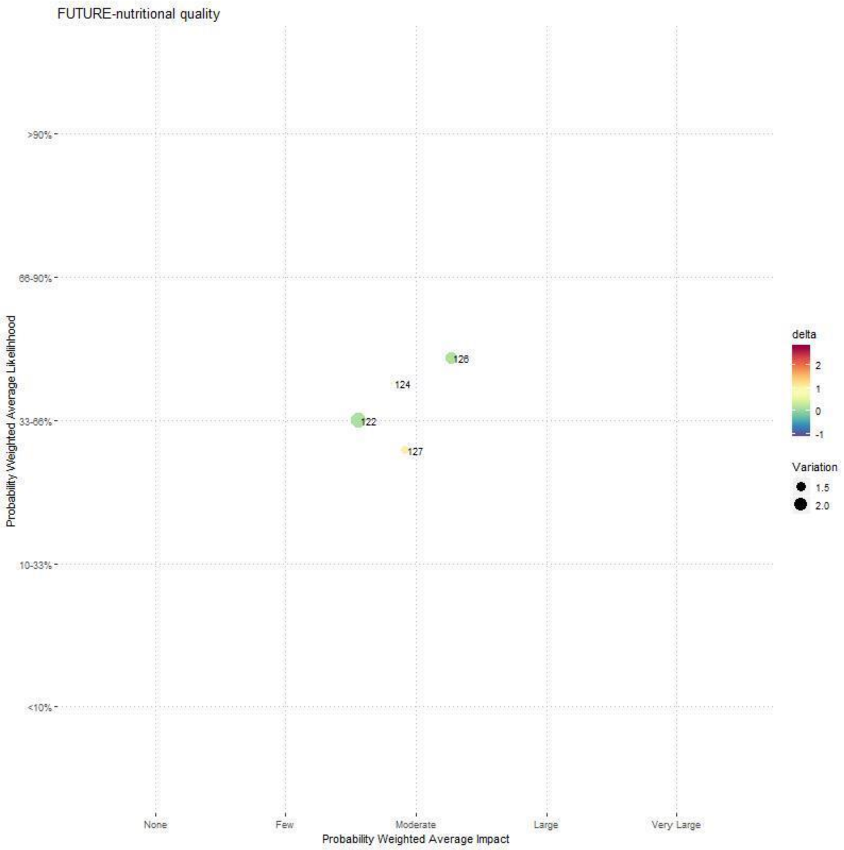
The issues and corresponding numbers used in these graphs are listed in Table 25.

Table 25: List of characterised issues belonging to 'nutritional quality' category. Issues in bold were scored by four experts and described in scoresheets (Appendix B)

Issue ID	Issue name
122	**Selenium content**
123	Gluten content
124	**Manganese content**
125	Protein content
126	**Zinc content**
127	**Iron content**
	Total: 6 issues

As shown on the figures above, no issues with extremely low or high impact were identified in this area under the near-future climate scenario. The scores were clustered, and exception of issue 123 (gluten content) which was scored as less likely to emerge than other issues from this area.

Figure 45 shows four issues related to plant health scored by the highest number of experts, i.e. 4. They are clustered together and are as likely as not to emerge, with moderate impacts. They are all related to micronutrient deficiency, in agreement with lower micronutrient contents observed in plants, as a result of increased atmospheric CO_2 concentrations (Myers et al., 2014). Scoresheets have been produced for these issues.



Probability weighted average values for impact are plotted on the x-axis, and those for likelihood on the y-axis. Colours of the circles correspond to delta values and their sizes to variance values.

Figure 45: Graphical comparison of all issues belonging to 'nutritional quality' category and scored by at least four experts, under the near-future climate scenario

4. Discussion

4.1. Evaluation of the CLEFSA approach: weaknesses and opportunities

The CLEFSA project has explored a variety of methods to identify, characterise and analyse emerging issues in the areas within EFSA's remit and has brought them together. As normal in exploratory innovations, some aspects have shown strengths, while other have shown weaknesses that need to be addressed in future developments. An analysis of the weaknesses of the CLEFSA approach and of the opportunities to improve it has been carried out for each of the three phases (identification, characterisation and analysis). The analysis considers the feedback received by the experts of the CLEFSA network, those involved in the issue characterisation and the EFSA Uncertainty Working Group. The challenges faced during the implementation and management phase of the different methodological steps are also described.

4.1.1. Identification

4.1.1.1. Weaknesses

Broad description of some issues. Experts pointed out that some issues (*Vibrio* spp., heavy metals) were defined too broadly and contained several aspects of very different effects. Therefore, splitting these issues would be recommended. Overall, definitions of issues must be improved so that it is clear what aspect should be assessed. Some experts did not know which species, pathogenic variant or type of contaminant they should have considered in the assessment (e.g. *V. parahaemolyticus* or *V. vulnificus;* heavy metals) and whether they should average the impact (e.g. mortality rates (Kim et al., 2011; Newton et al., 2012)) or consider just the most hazardous one. It was not clear to the experts that it was their role to make the issue more concrete by focusing on the most serious hazard when the issue was related to a broad family. The experts were supposed to add a justification clarifying which region/species they considered and add references. For issues related to a specific hazard or host (e.g. *Salmonella* in wild boars) for which the expert thought another hazard or host belonging to the same family or category might have been more relevant (e.g. *Salmonella* in pigs), the expert was supposed to score the issue as received and to indicate the other more relevant hazard under the qualifying criteria 'Parallels and interactions with other emerging issues'.

4.1.1.2. Opportunities

Driver analysis. Driver analysis is proposed as a useful tool supporting preparedness for future challenges in the EFSA areas. It allows for long-term anticipation or even risk prevention. The following steps could frame the process of driver analysis: (1) Driver(s) identification; (2) Scenario development; (3) identification of appropriate indicators and trend tracking; and (4) Detection of signals of change.

Continuous updates of the list of identified issues. The search strings for TIM and Medisys should be refined and the searches through these platforms, together with the crowdsourcing exercise, could be repeated periodically to detect any new issues. Scientific surveillance tools and monitoring relevant reports (e.g. IPCC reports) will also be helpful in extending the list. Strengthening the collaboration with relevant directorates-general within the EC (JRC, DG-ENV, DG-AGRI) is also recommended. Other sources (INFOSAN, RASFF network etc.) can also contribute to the identification of emerging issues/risks potentially associated with climate change. Knowledge and Innovation Communities on Climate Smart Agriculture like the EIT Climate KIC, and the Global Alliance for Climate Smart Agriculture (GASCA) could further improve horizon scanning capacities. These additional sources have not been used for CLEFSA because of the high number of issues already collected through the sources listed in Section 2.3. Other possibilities can be explored in the future. JRC text mining tools could be used for updating the list of issues. They can process text in large volumes and at high speed, automatically scan selected websites (EMM/MediSys), scan world news in potentially 70 languages (EMM/MediSys), search and analyse literature (TIM Technology) and identify emerging patterns in targeted scientific research (TIM Technology). However, expert evaluation is necessary, and they are not always enough specific or sensitive (i.e. more effective when hazard-driven). Finally, feedback to this report might bring to the attention new issues or literature sources that might be useful for any future iterations of this exercise.

Citizen engagement. It is necessary to design a roadmap that outlines how citizen science can be integrated into the formal emerging issues reporting mechanisms. Efforts could be made to make the input easier and possibly more entertaining (e.g. through gamification) but as in every crowdsourcing exercise, additional steps will be required to ensure the accuracy, precision and completeness of the information. Text mining and machine learning could be employed to analyse a large amount of data in text format.

Systematic literature review. Another tool deserving further assessment is the systematic literature review. In general, it can hardly be implemented to identify emerging risks as it is not possible to prepare an appropriate specific question. Indeed, not all the relevant key aspects for framing a question (for example PICO or PECO (EFSA, 2010)) can be specified a priori. In this case the question would be:

> 'Which are the emerging risks driven by climate changes?'

where 'emerging' could be rephrased as new (and therefore unknown) or associated with an unexpected new or increased significant exposure or associated with new or increased susceptibility or changes in composition or intakes. This question is an open-framed one and may not readily translate into closed-framed questions and therefore it would not be suitable for systematic literature review.

Creation of a library. A library could be created, published and continuously updated with data and relevant papers for the identified issues or for new ones.

4.1.2. Characterisation

4.1.2.1. Weaknesses

Not implementing 'One Health' approach. The characterisation is designed to be conducted in one area at a time (either animal, human or plant health). Several issues (see Section 3.2) affect both human and animal health and as such could be merged into one single issue, with separate criteria for animals and humans. This would be in line with the concept of One Health and could be handled jointly with ECDC. The interconnectedness among human, animal and plant health, given their shared environment, emphasises the need to design a characterisation system encompassing impacts on all areas.

Uncertainty about assessment strategy for issues describing animal diseases. It was unclear for the experts whether they should focus on the disease itself or its vectors, and which species (pathogen, vector and/or host) they should consider. This often led to different interpretations and required follow-up discussions. In some cases, experts limited their assessment to scoring the impact of climate change on the distribution of vectors or wildlife (and the pathogens they transmit). This was not the aim of the exercise, as CLEFSA sought to determine the effect of such geographical changes on the disease itself.

Difficulties in characterising the issues on nutritional quality. In such cases, considerations related to soil science, agronomy and human nutrition/epidemiology need to be combined. Predictions must be made on: 1) future nutrient content in soil or other environmental matrices due to climate change, 2) the uptake, assimilation and accumulation of nutrients by plants, 3) the changes in intake by humans. Since in all these areas further research is needed, assessments made based on this incomplete information need to be interpreted with caution.

Some criteria perceived as not easily applicable to issues from 'contaminants' category. Experts assessing these issues also remarked that the category is very heterogeneous, and it was difficult to choose a strategy for scoring that would be applicable to all of them. The criteria were perceived as not easily applicable because according to the experts, these issues often have less apparent, indirect consequences that are difficult to describe.

Difficulties in scoring heat/drought stress, as well as other issues directly affected by them. If heat and drought stress are considered when scoring other issues, we are effectively scoring these stresses multiple times.

Ambiguity on the scale of the assessment (Europe, regions, EU, world, etc.) It was unclear for the experts whether they should focus on specific region in Europe or in specific season. Experts were supposed to add a justification so that is clear which region/species they considered and add references. In order to reduce ambiguity a clear reference to geographic area and time of the year should be included in the criteria question.

Disentangling variability and uncertainty. In order to assess only uncertainty and disentangle uncertainty and variability, the expert was asked to elicit a specific parameter of the variability, the average. Variability arises when the issue consists of a group of heterogeneous aspects (like vectors, having different ability to fly, or to infect target species), in various regions and different seasons (variability in space and time). In this case, the judgement for a particular criterion may consider an 'average vector', an 'average region' and 'average season'. An alternative strategy to help experts focusing on uncertainty and avoiding mixing uncertainty with variability is to make a clear reference to a specific vector, a specific region and a specific season. In the Shiny tool a clear definition of average situation was not provided; experts could have misinterpreted it, and variability could therefore have been applied to the elicitation process.

Ambiguity in the definition of descriptors like low, medium, high or moderate, large and very large. Defining the exact meaning of these terms for each issue specifically was in the experts' remit and their interpretation was supposed to be recorded in the justifications to the scores. In order to reduce ambiguity in the interpretation of descriptors, the possibility of adopting a quantitative range to define the score should be further explored.

Difficulty in understanding the terms 'reference period' and 'future scenario'. The reference period is not meant to refer to the occurrence of a specific hazard in the past but to the emergence of the issue under present climatic conditions.

Several impact criteria perceived as independent of climate change conditions. In some experts' view, magnitude of symptoms, mortality rate and yield loss are specific to a certain disease and are therefore mostly independent of climatic condition and geographic area where they occur. For instance, in the assessment of Rift Valley fever and bluetongue, while the climate change scenario could indeed have an impact on the distribution of the diseases, it is not expected to affect the clinical signs and case/fatality rate in animals that are infected (e.g. an higher number of animals might get infected, but the entity of clinical signs in infected ones, as the % fatality will be the same). However, this reasoning is not applicable to all issues. In many cases, not only the number of units affected, but also other criteria are sensitive to climate change.

The impact of risk management measures on assessments. Any assessment of impact is inevitably biased by assumptions about the RMMs that would be applied. Although it was expected not to consider available RMMs when assessing the issues, some experts still took them into account. Risk management measures were intended to be described in 'other qualifying criteria' instead.

Perceived insufficient expertise for scoring. Despite the invitation to characterise also those issues where they did not have high expertise, some experts did not finish these assessments. In case of perceived insufficient expertise for scoring, experts were expected to self-assess their expertise as low and indicate their reservations in their justifications.

Short time to finish assessments. Several experts remarked on time constraints as the reason why they were either not able to finish their tasks or gave little supporting information.

Because of these weaknesses, experts might have understood the issues in different ways. In some cases, they provided enough justifications to understand their scores (e.g. they clearly stated which species/geographical regions they considered in their assessments), in others they did not. Where there was very little explanation, a request for more information was sent but not all experts provided it. The problem of divergent scores was further mitigated through expert discussions (web conferences or email exchange), but only a handful of problems have been resolved this way. For the others, the scarcity of explanation provided made it impossible to understand how experts interpreted the issues.

4.1.2.2. Opportunities

Providing more background information for the assessment. Experts expressed interest in obtaining preliminary information before the assessment, such as population/species maps and statistical data (e.g. from Eurostat), key references etc. This would ensure that they start from the same understanding of geographical distribution of the problem and what low/medium/high occurrence means for a specific case. Since providing this background information is time-intensive, the CLEFSA exercise relied on the experts to look for this information themselves. However, a possible future follow-up on the issues identified as the most likely/severe could include providing more details to the experts. More detailed scoresheets could be produced, where this additional information would be shown.

Codification of the 'other qualifying issues' (described in Section 4.1.2). Replacing descriptive free-text criteria (called 'other qualifying criteria' in the tool) by drop-down lists, multi-choice questions etc. could increase the amount of collected information and make it available for analysis.

Increasing the pool of experts. A larger number of experts could compensate for different levels of expertise. Moreover, it should focus of more equal representation of different disciplines, which was not achieved in this exercise (Figure 24). Efforts must also be made to elicit a higher number of completed assessments from the experts that expressed their interest in participating in the exercise. Only 41% of assessments were completed.

Introducing a short preliminary discussion between experts assessing the same issue(s). The expert discussions are a useful tool to achieve a common understanding of the criteria, issues and tasks across the different experts and help prevent any misconceptions at an early stage.

Adding additional climate parameters and repeating the exercise for single parameters. Experts have expressed the need to add the following: humidity, sea surface temperature, salinity and seawater pH. It was also recommended to separately assess the impact of each parameter on the impact and likelihood of emergence of an issue.

Repeating the scoring exercise for specific regions. Since some issues might be endemic and only occur for specific regions e.g. the Mediterranean basin, a separate exercise could be launched and focus on one region of interest. In this regard it is however important to consider that experts were encouraged to focus on the factors/regions where they foresaw the biggest impact or likelihood of emergence.

A manual or tutorial about the CLEFSA tool could support the experts involved in the characterisation exercise to harmonise the assessment, highlight the parameters that they need to make more concrete, and encourage them to focus on the most relevant hazard and region, at the appropriate granularity level.

Designing a tool for characterising generic issues. Several generic issues have been identified and discussed in Section 4.3. It is recommended to design a methodology to characterise these issues in a quantitative way. This could be supplemented with a visualisation tool optimising communication power and informative needs. The methodology used in the World Economic Forum (WEF) report[28] or the JRC 2019 technical report on 'Weak signals in Science and Technologies' (Eulaerts et al., 2019) could support this development.

Sensitivity analysis on the criteria definition. The criteria could be described in a different way, with the aim of determining the impact of a different understanding of the criteria on the outcome of the exercise.

Sensitivity analysis over the expert group composition. This analysis could assess the impact of adding/replacing/eliminating experts involved in the characterisation on the outcome of the exercise.

More detailed description of the criteria. Criteria should be described in a more detailed and precise way. This would counteract several weaknesses extensively described for the characterisation phase.

Quantitative description of the criteria for impact. The qualitative nature of the ordered scales used for impact is prone to ambiguity and misinterpretation, bringing additional uncertainty in the resulting assessment has discussed in Section 4.2. Unified numeric definitions of these scales would harmonise the characterisations and allow comparison between issues not only in the characterisation of impact but also for that of likelihood. However, given the limited amount of information underpinning emerging issues, it is not easy to use a common quantifiable matrix for impacts (e.g. disability-adjusted life years (DALY)[29], or economic values or costs) across the different areas and it would bring additional uncertainties. Another, possibly easier, option is to provide concrete examples for each area as a benchmark for characterisation.

Exploring the possibility of using continuous scales. In contrast to the qualitative definition of impact, likelihood is expressed as numeric ranges. As described in Section 2.7.2, these ranges are converted into scores, under the assumption that the distance between categories is constant. This assumption could be relieved by making direct use of ranges in the calculation.

Explicit specification of risk management measures. Any assessment of impact is inevitably conditional on what assumptions are made about the RMMs that would apply. This is still true if the intention is to assume continuation of current measures without change, or to assume complete absence of measures. Therefore, in future studies, the definition of the scenario should include explicit specification of what is to be assumed about RMMs. The experts should not only describe what RMMs exist, but also assess how they would change impact/likelihood.

[28] http://www3.weforum.org/docs/WEF_Global_Risk_Report_2020.pdf
[29] https://www.who.int/healthinfo/global_burden_disease/metrics_daly/en/

Reducing anchoring and adjustment bias. The fact that the question on range for the impact and likelihood is shown in the credibility bar above the question on the 'most probable' value reduces anchoring and adjustment bias. However, it would be preferable that experts were not shown the question on 'most probable' value until they have provided the range. This should be performed in any future study.

Addressing variability. In any future study, variability should be well defined (describing which are the element of variability such as time, region, population, etc.) and uncertainty assessment in the characterisation should be focused or on specific parameter of variability (such as mean, percentile) or on specific context (specific region, specific season, etc.).

Definition of specific food items affected by the identified issues. It would be advisable to define specific food or feed items affected by the issue. This is particularly needed in the area of nutritional quality and contaminants.

4.1.3. Analysis

4.1.3.1. Weaknesses

Uneven number of experts assessing certain issues. More experts were found to assess certain issues (contaminants) than e.g. Plant health (see Figure 24). Comparing the indicators obtained from one expert assessment only to the ones that are averaged over 8 expert assessments might not be very informative and reflect the true difference between the imminence of these issues.

Expert discussions are not sufficient to solve all differences between expert scores. In several cases experts felt strongly about their assessments and sometimes had incompatible views. For divergent scores, the bimodality of probability distributions cannot be removed, and the calculated delta values are difficult to interpret. Ideally, these difficulties and disagreements should be reflected in the scoresheets.

Difficulties with the analysis of expert input for 'other qualifying criteria'. These criteria were formulated as open-ended questions and some suggestions for answers were given. Nevertheless, a lot of experts provided no information at all and among those who did, there was a high variability of the level of detail provided. The replies ranged from one-word to multi-paragraph, complete with references. It is difficult to use this input for any kind of systematic analysis such as text mining, topic modelling, looking for keywords etc. The number of replies might have been higher if the questions were codified, e.g. experts could choose the most appropriate option from a drop-down list or answer multi-choice questions (e.g. 'choose all sentences that apply to the issue X'). Examples of criteria that could have been codified are:

- scale: geographical area could be indicated on an interactive map where affected countries could be chosen (see: https://mapchart.net/europe.html)
- evidence base: picking all that apply from the list (study, expert knowledge, single observation etc.)
- imminence: drop-down list with time intervals
- interactions with other emerging issues: pick all that apply from the list
- impact on other areas in the remit of EFSA: drop-down list
- strength of the association with climate change.

Logical inconsistencies in criteria definition for 'known hazards'. If likelihood is the probability of increase in the exposure, it would be more logical for the impact scale for the known hazards to refer to the magnitude of increase rather than absolute magnitude. It is however acknowledged that this internal inconsistency stems from practical reasons, in particular the lack of suitable data for conducting a meaningful assessment of emerging issues.

4.1.3.2. Opportunities

The collected data offers many more analysis opportunities than these presented in the report. Here several steps are presented that could lead to a better understanding of the information collected through the characterisation exercise.

Detailed assessment for expertise level. Seed questions could have been used for assessing the expertise, but such questions are difficult to design in particular because they should be defined for each issue. Alternatively, expertise levels could be scored according to specific experiences or activities, such as research on the issue, publishing academic papers, field work etc.

Using expertise levels and expert numbers as a weighing factor for expert scores. Expertise levels defined as described above could be more reliably used as weighing factors, compared to self-assessed levels. However, the confidence of the expert in their judgement is already embedded in the interval used to express their uncertainty.

Expert knowledge elicitation (EKE) to quantify overall uncertainty for each area. The EFSA (2019) Guidance on Communication of Uncertainty explains that, when some uncertainties have already been quantified earlier in the analysis, the assessment of overall uncertainty combines the result of that with judgements about the additional uncertainties to arrive at quantitative expressions of overall uncertainty. As described in Section 4.2, several uncertainties accompany the analysis of the expert characterisation data. Only some of them have been quantified. An EKE exercise could be useful to assess and quantify the overall impact of all identified uncertainties on the assessment output. This EKE exercise should consider the justifications provided by the scoring experts in order to understand how criteria are applied and how the impact ranges are defined. Most uncertainty sources are common to all areas, but some are area or issue specific. The analysis of the justifications, when available, should help identifying these.

Introducing indicators more precisely describing sources of uncertainty. Once the impact of different uncertainty sources is quantified during EKE, new uncertainty indicators can be implemented for each issue. They would be especially important for the issues that have been characterised by very few or a relatively large number of experts. These new indicators could facilitate the understanding what proportion of the variation in scores between experts for impact is due to diverging interpretation of the qualitative categories used for scoring. Moreover, numerical indicators could be applied to characterise the probability distribution (e.g. shape and thickness of the tail). While this information can be retrieved from the graphs of probability distribution, the variance value cannot be easily interpreted by itself.

Sensitivity analysis over the assessment criteria. The aim would be to verify the initial assumption that all impact and likelihood criteria are independent of each other. A concern was raised that in the definition of 'magnitude of symptoms', duration and frequency of the event are included, and this might have induced the assessor to assume the existence of correlation between impact and likelihood. Sensitivity analysis could reveal how removing each criterion will affect the results and reveal any relationships between criteria. However, it is important to highlight that in the definition of magnitude of symptoms, duration and frequency are relative to the symptoms or signs and not to the likelihood of emergence of the risk so suggesting any relationship between these two was not intended.

Ranking the identified issues. The aim of this work is not to propose a hierarchy of issues, as various stakeholders might have different priorities and consider different aspects important. However, several criteria could be used to rank the issue, such as:

- delta for impact
- delta for likelihood
- combination of delta for impact and likelihood
- combination of delta and variance
- future impact
- future likelihood
- future impact and likelihood combined.

Studying the interactions and links between the identified issues. Similar to the Sustainable Development goals that have been organised into tiers[30] or pyramids[31], the identified issues are also interconnected. For instance, wild boars have been identified as carriers of many animal parasites, abiotic factors such as drought increase the probability of spread of specific diseases etc. All these relationships could be visualised, e.g. in a manner similar to how relationships between different genes or proteins are represented in interactomics[32].

Making the collected data freely accessible. Should the readers want to assess the raw data and draw their own conclusions, all anonymised assessments could be made available and downloadable in tabular format.

Distinguishing between new and known hazards. The criterion 'likelihood' refers to 'emergence' within the specified time period for 'new' hazards and to 'increased exposure/susceptibility' for 'known' hazards. Comparisons should be made only between likelihoods for hazards of the same type (new, known). They should be distinguished in the likelihood/impact graphs, e.g. by plotting with different symbols, or plotted in separate graphs.

Combining criteria. Equal weight and additivity of sub-criteria for impact is assumed. Weight definition and possible combinations using more interpretable conceptual models could be explored, e.g. number of units and fatality rates or magnitude of symptoms could be combined similarly to the concept for DALYs.

4.2. Sources of uncertainty

4.2.1. Addressed sources of uncertainty

Individual uncertainty distribution was used to quantify expert uncertainty. Whenever an issue was characterised by more than one expert, individual uncertainty distribution was mathematically aggregated over experts, to quantitatively express their uncertainty. Other methodological features used to manage and characterise uncertainty are:

Expressing the expertise level (very high, high, medium, low). This level expresses a self-judgement of the expertise on the considered issue. It is used as an additional qualifier for the individual uncertainty of experts.

Characterising the evidence base, through the ad hoc qualitative criterion. The criterion 'evidence base' is described in Section 2.4.

4.2.2. Sources that have not been addressed

Additional sources of uncertainty were identified in performing characterisation and in analysing characterisation results. These additional sources of uncertainty have not been addressed but need to be analysed and ideally quantified during uncertainty analysis to assess the potential impact. The CLEFSA network members and the experts involved in the characterisation exercise were asked to provide their judgement on potential impact of each identified source of uncertainty on the assessment outputs.

4.2.2.1. Sources of uncertainty in the characterisation

Ambiguity

Ambiguity (possible different understanding and interpretation of both criteria questions and criteria scores) was considered the most relevant uncertainty source and it can affect individual probability distributions, shifting distributions towards higher or smaller scores but also modifying the shape of distributions. This confers large uncertainty to the bi-dimensional impact–likelihood diagrams used to visualise the issues. Sources of ambiguity are:

[30] http://www.teebweb.org/sdgs/
[31] https://www.sdgpyramid.org/
[32] https://www.sciencedirect.com/topics/biochemistry-genetics-and-molecular-biology/interactome

- Ambiguity in the interpretation of the criteria question. Experts may have different understanding of what is the specific hazard they are requested to assess, which specific context (such as region, season, population, etc.) they must take into consideration.
- Qualitative definition of impact attributes (e.g. few, moderate, large and very large). Experts may have a different understanding of these attributes, driven by different knowledge level, values and perceptions. This problem should be mitigated by the justifications provided by the experts, which are however not always present. Furthermore, it is likely that there are systematic differences of interpretation between the different areas (plant, animal and human health). Therefore, it is difficult to interpret the characterisation results across different categories in a consistent manner and the results for the different areas are unlikely to be comparable. An example of this could be the higher impacts experts reported (Section 3.3.9) for plant health. In contrast, likelihood is expressed in terms of precise numeric ranges, which makes this criterion less prone to subjective interpretation. Consequently, the comparative potential of likelihood is higher than for impact and conclusions are therefore based on likelihood.
- Different amount and quality of the evidence base underpinning the issue description and of the information provided by the experts in the characterisation.
- Different practices, values and 'cultures' in the different areas.
- Different interpretation of the time 'reference' and 'near-future' periods. Some experts have interpreted the reference period as requiring assessment of hazards in the past, which has affected their assessment. For example, hazards either occurred or did not in the past, so likelihood and uncertainty of impact for those reflect only limitations in the experts' knowledge, whereas future likelihoods and uncertainty are influenced also by the stochasticity of future events. This may affect the conclusions to be drawn, both overall and for individual hazards.
- The impact scales are a form of Likert scale. Experts may interpret the bottom and top categories as referring to the extreme physical limits of impact, and thus tend to concentrate their responses in the middle three categories when experts are uncertain or have no strong view.

Equal distance between categories

For the impact and likelihood criteria, the categories were assumed to be equally spaced when translated into quantitative scores. For likelihood, this assumption conflicts with its percentage ranges (<10, 10–33, 33–66, 66–90, >90%). For impact, it is unknown what quantitative spacing would be appropriate.

4.2.2.2. Sources of uncertainty in the analysis

For the analysis of the characterisation results, two main sources of uncertainty are:

- The selection of probability distribution to estimate expert probabilities associated to each score and how close the chosen form of distribution (Pert) represents the expert judgement. The impact of changing probability distribution could be assessed via sensitivity analysis, which make it possible to assess the sensitivity of outputs to the distribution choice.
- The assumption of independence between the two criteria, impact and likelihood and among sub-criteria under impact. Sensitivity analysis could be used to explore the sensitivity of outputs to the assumption of independency between criteria and sub-criteria.

4.3. Generic emerging issues driven by climate change in the EFSA's areas

Some of the issues retrieved through the sources listed in Section 2.3 do not identify a specific agent or hazard. They have not been used for the characterisation exercise, i.e. they have not been assessed against the criteria and scored. However, they still provide useful information. Therefore, an attempt has been made to combine these generic issues together with the results of the broader literature study and report them in the following sections. The complete list of the generic issues retrieved in the CLEFSA survey is in Appendix D, together with the supporting information. A deeper analysis for these issues may be recommended (see Section 6.2.2).

4.3.1. Biological hazards to human health

4.3.1.1. Impact of increased temperatures and extreme events on pathogen survival and multiplication

Several naturally occurring pathogenic bacteria living in the marine environment and those involved in faecal contamination of waters show an increasing growth rate at higher water temperatures (Barange et al., 2018). For example, the European Environment Agency reports that the number of *Vibrio* cases per year has increased in the past decades in the Baltic Sea region and the projected risk of vibriosis infections will increase in the northernmost areas. This increase has been linked to increases in sea surface temperature (Vezzulli et al., 2016). Climate change projections indicate that the temperature-related cases of salmonellosis in Europe may increase by almost 20,000 by the 2020s. The larger pool of microorganisms stimulated by higher temperature could facilitate mutations and gene transfer, thus triggering the emergence of new pathogens (Barange et al., 2018). Moreover, warmer climate might displace pathogens into cooler regions where they were not previously found.

Extremes of heat and cold, precipitation, storms, wind and surges, and drought have increased in number and intensity in recent decades (IPCC, 2014; Kron et al., 2019). They could:

- create better conditions for pathogen survival and multiplication (e.g. by disrupting water treatment and sanitation systems (Lake, 2017; Semenza et al., 2012; Tran et al., 2017; WHO, 2018a) MediSys[33]), speeding up pathogen proliferation along the food chain;
- result in increased susceptibility of animals to several diseases and subsequent faecal shedding of food-borne pathogens;
- cause changes in temporal disease pattern;
- alter the risk of pathogen infections and diseases in animals due to the emergence of more resistant bacteria, as some bacteria have evolved stress tolerant mechanisms when exposed to difficult environmental conditions (e.g. extreme heat);
- increase the use of veterinary medicines and the prevalence of antibiotic-resistant pathogens;
- favour the entrance of new vectors that may carry food-borne pathogens to new ecological zones;
- cause an increase in transport of pathogens onto agricultural land as a result of flooding;
- favour the movement of infectious agents over a long distance by wind.

Pathogens that are likely to be of most concern are those which may enhance their competitiveness under extreme climate conditions. In particular, those are characterised by:

- low infective doses (e.g. enteric viruses, *Campylobacter* spp., Shiga toxin-producing *Escherichia coli* (STEC) strains and parasitic protozoa);
- significant persistence in the environment (e.g. *Mycobacterium avium* and tuberculosis complexes, enteric viruses and parasitic protozoa);
- well documented stress tolerance responses to temperature and pH (e.g. *E. coli* STEC and *Salmonella*);
- long-distance transport by wind (e.g. *Coxiella*).

For a more comprehensive description of the implications of climate change for selected food-borne pathogens and parasites and antimicrobial resistance, please refer to FAO (2020).

[33]https://www.cbc.ca/news/canada/nova-scotia/climate-change-food-borne-illnesses-food-safety-1.5342809?cmp=rss; https://www.nature.com/articles/d41586-020-00627-y?utm_source=Nature+Briefing&utm_campaign=e44050dc5e-briefing-dy-20200305&utm_medium=email&utm_term=0_c9dfd39373-e44050dc5e-44963329

4.3.1.2. Impact of snow freeze–melt process on bacterial populations

There are reports of interactions among bacteria, metals, and nanoparticles during freezing/melting processes in the artic snow (Mortazavi et al., 2019). Several metal-interacting bacteria are present in all types of snow and frost flower, many of which are known or associated with ice nucleating properties, namely *Pseudomonas* genus.Emerging food pathogens in fishery and aquaculture products

With higher water temperatures, it can be expected that the concentration of several naturally occurring bacteria, including pathogenic ones, living in the marine environment and those involved in faecal contamination of waters may increase (Barange et al., 2018). In addition, these conditions may generate a larger pool of microorganisms, facilitating mutations and gene transfer. As a result, new pathogens may emerge.

4.3.1.3. Emerging food-borne parasitic infections

Some flukes like *Schistosoma* and *O. felineus* seem to be emerging in Europe, likely due to travel of infected humans to areas where suitable snail hosts occur (*Schistosoma* in Corsica) and the spreading habit of consuming raw or undercooked fish (*O. felineus* in Italy) (Pozio et al., 2013; Wunderink et al., 2014; Boissier et al., 2015, 2016; Caccio et al., 2018; Noel et al., 2018). Climate change may potentially contribute to this emergence, by shortening the lifecycle of snails, triggering higher parasite concentrations due to lower water levels and more numerous water plants.

4.3.1.4. Spread of antibiotic-resistant bacteria operated by bees

If antibiotics were also registered for the beekeeping sector, antibiotics or even worse the antimicrobial-resistant bacteria could be transported by the bees on each flower within a radius of about 3 km from each hive. Considering that in every beehive there are at least 30,000 bees touching thousands of flowers a day and multiplying this number by the number of hives present in Europe, one would create a huge network of contaminations. The bees could therefore turn out to be the amplifying vector of the phenomenon of the antimicrobial resistance.

4.3.1.5. Climate change could drive a third of parasites to extinction by 2070

As many as one in three parasites could become extinct as a result of climate change by 2070, new research suggests (Carlson et al., 2017)[34]. This may sound like good news, but the loss of parasites could destabilise many of the world's ecosystems. Parasites play a critical role in maintaining food webs and, in their absence, a diverse range of animals could be threatened with extinction.

4.3.1.6. Challenges to the integrity of the refrigeration chain

The safety of food chains, in particular in global supply chains (storage, transport and distribution), relies heavily on maintaining the integrity of the cold chain in order to ensure that the product is safe for consumption when it reaches the end consumer. Increasing complexity puts a burden on safeguarding the necessary integrity of the refrigeration chain. Climate change puts further stress on the system and the danger increases that the cold chain becomes compromised with considerable potential impact on the processor and the consumer sphere.

4.3.1.7. Risk of exposure to zombie pathogens (viruses) in the thawing permafrost

Higher temperatures have been found to disproportionately affect northern land areas, particularly the Arctic, which has already experienced fallout from climate change. In the past few years, there has been growing fear about a possible consequence of climate change: zombie pathogens, i.e. bacteria and viruses — preserved for centuries in frozen ground — coming back to life as the Arctic permafrost starts to thaw.

[34] https://www.carbonbrief.org/climate-change-drive-third-parasites-extinction-2070

4.3.2. Animal health

Climate change has a potential impact on the occurrence, dominance and persistence of various parasites, fungi, viruses, vectors and invasive species, harmful to animal health.

4.3.2.1. Impacts on livestock production

Climate change is expected to directly affect livestock production through changes in feed quality and spread of pests and diseases. Extreme warming is expected to cause changes in physiological processes (i.e. thermal distress and methane production) and impair feeding, growth, reproduction and milk production. Warming could also lengthen the forage growing season but decrease forage quality, with important variations due to rainfall changes (Hoegh-Guldberg et al., 2019).

4.3.2.2. (Re)Emergence of viruses and bacteria

There is evidence that animal disease-carrying vectors such as midges advanced northwards from Africa as a result of increased humidity and temperature linked to global warming. Biting midges of the *Culicoides* genus are carriers of bluetongue, a viral disease affecting sheep, goats, cattle and deer. The movement of blood-feeding flies, mosquitoes and ticks is responsible for the spread of lumpy skin disease from the Middle East to south-east Europe.

New viruses, bacteria and parasites have emerged or re-emerged over the past years because of numerous causes (climate change, population increase, deforestation, urbanisation, irrigation, etc.). They have an impact on the habitat suitability of viruses, bacteria and parasites (e.g. making them appear in higher latitudes then before). In particular, viral emergence in marine organisms was linked to sea ice reduction[35] (VanWormer et al., 2019).

JRC has recently published a report on weak signals in Science and technology (Eulaerts et al., 2019) where the following weak signals related to (re)emerging viruses and bacteria were observed:

- acute hepatopancreatic necrosis disease (AHPND[36]);
- atypical porcine pestivirus;
- porcine circovirus 3 (PCV3)

In particular, AHPND has already become a huge issue for global shrimp and prawn culture and has required extensive research initiatives, in recognition on the increasing importance of emerging diseases in the aquatic sector and the rapid increase in global aquaculture (predicted to double by 2050 to meet global needs). In recent years it has become OIE-listed[37] ('AHPND is characterised by sudden, mass mortalities (up to 100%) usually within 30–35 days of stocking grow-out ponds with PLs or juveniles (FAO, 2013; Hong et al., 2016) Older juveniles may also be affected (de la Pena et al., 2015)'.

4.3.2.3. Ocean acidification

Food production from marine fisheries and aquaculture is becoming increasingly important for global food security but is facing increasing risks from ocean warming and the resulting ocean acidification (Hoegh-Guldberg et al., 2019). The world's oceans are absorbing carbon dioxide at an unprecedented rate. Increased ocean acidity interferes with the ability of clams, mussels and oysters and other shell-forming organisms to build and maintain their calcium carbonate shells. The planktonic larval stages of many species are also vulnerable. This may constitute a concern for hatcheries and wild populations of shellfish. Ocean acidification and warming may also affect skeletal mineralisation in marine fish.

[35] https://www.zmescience.com/ecology/climate-change-new-diseases-sea-creatures

[36] http://www.fao.org/3/ca2976en/CA2976EN.pdf . The report states that stated that the most relevant risk of introduction in free countries or zones is related to animal movement/trade. High water temperature is anyhow a predisposing factor.

[37] https://www.oie.int/index.php?id=171&L=0&htmfile=chapitre_diseases_listed.htm

4.3.2.4. Migrations

Migration in search of suitable conditions might change the spatial distribution of fish. For example, warm-water top predators like barracudas (*Sphyraena* spp.) are now frequently found in Northwest Mediterranean waters (Barange et al., 2018). The European Environment Agency reports that a northward migration of marine species has been observed and projected in many biogeographical regions in Europe (EEA, 2017).

4.3.2.5. Susceptibility to disease

Climate change may affect susceptibility to disease of animals, including biophysical reactions to thermal stress (UNEP, 2016).

4.3.3. Plant health

The EFSA PLH Panel has discussed in several circumstances the importance of addressing climate change scenarios in plant health risk assessment, particularly regarding changes in land use and cultivated crops. It recognises that climate change has a potential impact on the occurrence, dominance and persistence of various parasites, fungi, viruses, vectors and invasive species, harmful to plant health.

For the identified plant health issues identified by the CLEFSA crowdsourcing project, the Panel highlights that these issues are affected by a combination of climate change and changed global trade patterns which are difficult to separate. Some of the issues identified regarded a large group of plant pests (e.g. aphids) making the linkage to climate change difficult.

4.3.3.1. (Re)Emerging viruses

As described in the animal health remit, new viruses have emerged or re-emerged over the past years. The above-mentioned JRC report on weak signals in Science and technology (Eulaerts et al., 2019) includes the following:

- grapevine red blotch virus (GRBV)
- Orthotospovirus
- tomato mottle mosaic virus (ToMMV).

The grape red blotch virus is already included in the alert list of EPPO (Brunel et al., 2010). When finding Orthotospovirus, in which an insect vector is involved, climate can play a role but needs to be studied more in detail.

4.3.3.2. Water resilience: how a hotter planet could put pressure on our plants

The climate modelling from the JRC[38] reveals that unless warming is reduced to 2°C above pre-industrial levels by the end of the century, green water resilience will decline by 40% in some regions of the tropics, the Mediterranean (including Spain), South Africa, Australia, and regions of coniferous forests circling the northern hemisphere (e.g. Scandinavia). Resilient green water supply requires high levels of precipitation and low variability, and such conditions are the most favourable for plant yield and ecosystem stability. As rainfall is reduced and becomes more variable (higher number of both droughts and flooding events), plant growth will be compromised.

[38] https://ec.europa.eu/jrc/en/news/tracking-water-resilience-how-hotter-planet-could-put-pressure-our-plants, https://www.mdpi.com/2072-4292/11/22/2708/htm

4.3.3.3. Soil salinisation

Rising sea levels triggered by climate change increase seepage of saltwater into agricultural soils. This negatively affects plant health and in consequence global food production[39]. The EU-funded SalFar[40] project focuses on the degradation of farmland due to salinisation. Scientific research is conducted on the salt tolerance of various crops, aiming to propose alternative methods of farming under saline conditions.

4.3.3.4. Impact on plant growth

Increasing temperatures, changes in precipitation patterns, and rising atmospheric CO_2 concentrations could also play a direct role for crop growth and crop yield (Kimball, 2016). Researchers have found that most of the gains derived from elevated CO_2 on crop growth will be lost due to increasing temperatures (Asseng et al., 2015). In addition, an increase in the frequency of drought and heat stress might have serious impact on plant growth and crop yield (Semenov and Shewry, 2011; Witcombe et al., 2008). Further research on the mechanisms controlling growth at high temperatures could help to breed plants that are adapted to global warming.

4.3.3.5. Influence of the changing ultraviolet radiation, increasing or decreasing in a changing climate

There is a strong link between the greenhouse effect and the changes in the ozone layer. Increases in ultraviolet radiation (UV) may have both positive and negative effects on wild and farmed plants, e.g. the fibre content in crops may increase on increased UV. Conversely, UV causes the build-up of reactive oxygen species, which in high cellular levels leads to necrosis and ultimately plant death (Nawkar et al., 2013).

4.3.3.6. Lack of plant pollination due to mismatch of plant flowering and insect pollination caused by phenological changes

Many crops and wildflowers require insect pollination to produce fruit or set seed. Changes in phenology due to climate change may mean, for example that a crop flowers earlier in the year than previously, before a sufficient population of its pollinator (e.g. bees) is available, thus resulting in inadequate pollination.

4.3.3.7. Establishment of toxic plants and invasive weeds

Toxic plants are widespread in the tropical areas. Climatic changes (and increasing trade) may contribute to a shift and expansion of these plants' geographic ranges. In addition, climate change may create new biosecurity challenges by allowing establishment of new weeds that will outcompete local species.

4.3.3.8. Pathogen internalisation

Severe hail causing injury to the plant tissue, drought, sudden massive rain showers and changed absorption properties of soil, as well as vicinity of open-air sewage channels and non-insulated septic tanks can apply additional probability of spread of pathogens and their internalisation through root systems, leaf and plant injuries, as well as wider spread of pathogens between plants and fields through local floods.

[39]https://www.fastcompany.com/90435837/mit-scientists-have-figured-out-how-to-make-plants-grow-in-soil-that-should-be-too-salty-for-plants?partner=rss&utm_source=rss&utm_medium=feed&utm_campaign=rss+fastcompany&utm_content=rss; https://www.foodnavigator.com/Article/2019/09/06/Saline-farming-Unlocking-new-opportunities-for-food-through-an-innovative-response-to-climate-change?utm_source=newsletter_weekly&utm_medium=email&utm_campaign=From%2006-Sep-2019%20to%2013-Sep-2019&c=ab6wU2%2FJaXFgdZs1R37jwwaoUKjqVABd&p2=

[40] https://northsearegion.eu/salfar/

4.3.3.9. Susceptibility to disease/infestation

Climate change may affect susceptibility to disease/infestation of plants, including biophysical reactions to thermal stress and nutrient availability (UNEP, 2016).

4.3.3.10. Increased risks of plant phytopathogen and pest occurrence that affect plant fitness

Bacterial, viral, fungal infections can decrease plant fitness and product survival, and lead to secondary infections (Jones, 2016). Climate change is predicted to alter the severity of damage caused by 31 globally important pest species (Lehmann et al., 2020). The response of 31 major global pest species to climate warming suggests that the damage they cause will increase for nearly half of them. However, the majority show mixed responses (range expansion, life history, population dynamics, and trophic interactions) indicating that a population of single species can both increase and decrease in severity, depending on the context (Lehmann et al., 2020).

4.3.4. Contaminants

4.3.4.1. Harmful algal blooms

Surveys throughout the world demonstrate that the trends of harmful algal blooms (HABs) caused by marine and freshwater algae and bacteria producing toxins are changing[41]. It is hypothesised that global change (Gobler et al., 2017; Wells et al., 2015) and in particular, planet warming (Solomon et al., 2007; Stocker et al., 2013) may be responsible for the increase in frequency and intensity of HABs in all aquatic environments (marine, brackish and freshwater) (Paerl and Huisman, 2009). Still, many uncertainties exist, and an effort should be made to design strategies to prevent or alleviate the future negative impacts of these events. As an example, EFSA is involved in a 4-year framework partnership agreement, which will try, among other goals, to investigate the link between environmental parameters associated with climate change and the occurrence and toxicity of *Gambierdiscus*, the dinoflagellate genus producing the toxin (ciguatoxin) responsible of the outbreaks of ciguatera. Moreover, the recent detection of tetrodotoxin in European bivalve shellfish and marine gastropods has been linked to the spread of *Vibrio parahaemolyticus*, a marine bacterium responsible of shellfish poisoning whose growth is strongly dependent on rising seawater temperature.

The EFSA report on cyanotoxins (Testai et al., 2016) concludes that temperature seems to positively influence the production of the toxic rather than non-toxic fractions of freshwater cyanobacteria populations, both in field and in laboratory experiments. This result suggests that in a future scenario of global warming, we could expect an increase in exposure of humans and farmed animals to cyanotoxins. This issue has also received a lot of attention in the IPCC Special Report on Oceans and Cryosphere in a Changing Climate (SROCC[42], see section A8.2 in the summary for policymakers and chapter 6 on Extremes, Abrupt Changes and Managing Risks) and in FAO (2020).

4.3.4.2. Impacts of climate change on indirect human exposure to pathogens and chemicals from agriculture

Climate change may affect transport pathways, fate (including bioaccumulation and elimination), toxicity of and exposure to toxic compounds. The magnitude of the increases will depend on the type of contaminant. Risks from many pathogens and particulate and particle-associated contaminants could increase significantly.

Increasingly frequent flooding events due to more extreme weather conditions, acid rain and fertiliser-induced soil acidification can affect bioavailability and mobilisation of contaminants (heavy metals, Persistent Organic Pollutants) and faecal matter from soils and sediments. Through rivers, canals and

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[41] Special Issue on HABs and Climate Change in Harmful Algae available online: https://www.sciencedirect.com/journal/harmful-algae/vol/91/suppl/C ; *Toxins* Special Issue Freshwater HABs and Health in a Changing World publication: *How the Neurotoxin β-N-Methylamino-l-Alanine Accumulates in Bivalves*: *Distribution of the Different Accumulation Fractions among Organs* available online: https://www.mdpi.com/2072-6651/12/2/61/pdf

[42] https://www.ipcc.ch/srocc/

lakes they will be transported onto agricultural land and subsequently into food animals and crops. Permafrost thawing may also release heavy metals like mercury into our freshwater systems. Environmental factors associated with climate change influence the methylation process of mercury in aquatic systems, which may result in bioaccumulation of methylmercury in the aquatic food chain (FAO, 2020).

Climate change can also affect the fate and transport of chemical contaminants in agricultural systems. Increases in temperature and changes in moisture content are likely to reduce the persistence of chemicals, whereas changes in hydrologic characteristics are likely to increase the potential for contaminants to be transported to water supplies. Rising soil temperatures are expected to facilitate the uptake of heavy metals by plants (e.g. arsenic in rice[43]).

Climate change may also affect the patter of use (amount, type) of fertilisers, triggered by reduced nutrient availability and soil quality, affecting plant health and crop productivity.

4.3.5. Nutritional quality

4.3.5.1. Impact of climate change on crop quality

To date, the effects of extreme weather events at global level on nutrient supply have not been quantified (Park et al., 2019). In their study, Park et al. (2019) investigated micronutrient, macronutrient, and fibre supply changes during 175 extreme weather events within 87 countries in the year when a major extreme weather event occurred. The main finding is that the global effects of extreme weather events on nutrient supply are modest; however, in the context of nutrient needs for healthy child development in low-income settings, the effects observed are substantial. The recent IPCC report on 'Climate Change and Land' (IPCC, 2019), supported by (Hoegh-Guldberg et al., 2019) indicates that 'increased atmospheric CO_2 levels can also lower the nutritional quality of crops (high confidence)'. A growing number of studies describe climate change impacts on crop yield, but the impacts on the nutritional quality (intended as the level of micro and macronutrients) of the crops have received much less attention even though this is a critical aspect of food security. For example, grain protein content is an important characteristic affecting the nutritional quality but also the end-use value and baking properties of wheat flour (Asseng et al., 2019). Research has shown that elevated CO_2 concentrations in the atmosphere may lead to a significant decline in wheat grain protein content, reducing the grain quality with potential impacts on the nutritional value[44].

Overall, at CO_2 levels likely for the mid-21st Century, there is evidence of a small decline in grain Zn and Fe content, e.g. in wheat (−9% Zn), rice (−3% Zn) (Myers et al., 2014), likely to be due to yield dilution effects: when grown at elevated CO_2, crop biomass/yield tends to increase by about 15% (Ainsworth and Long, 2005) induced by increased atmospheric CO_2 (Reich et al., 2018a, 2018b; Wolf and Ziska, 2018). This decline in micronutrient quality has recently gained a lot of media attention, typically accompanied by media headlines such as 'nutrient collapse'. The media reporting seemed to focus on the dilution of grain Zn, Fe etc., due to CO_2 enrichment[45,46]. However, increased temperature or shifts in precipitation patterns could offset the yield-related decreases in grain quality. (Kohler et al., 2019) highlight the need to consider the complexity of predicting climate change effects on food and nutritional security when various environmental parameters change in an interactive manner.

4.3.5.2. Allergenicity of novel food proteins and increasing cases of food allergies

Understanding the potential allergenicity of new or modified proteins is crucial to ensure protection of public health. Exposure to new proteins may result in *de novo* sensitisation, with or without clinical allergy, or clinical reactions through cross-reactivity. The survey identifies the following two causes: (1)

[43] https://focusonfoodsafety.wordpress.com/

[44] http://incda-fundulea.ro/rar/nr37/rar37.29.pdf (through Medysis)

[45]https://www.thehindu.com/sci-tech/science/millions-in-india-may-face-nutritional-deficiencies-due-to-co2-rise-study/article24802266.ece

[46]https://www.theguardian.com/science/2018/aug/27/climate-change-will-make-hundreds-of-millions-more-people-nutrient-deficient

possible impact of high temperature and ample temperature fluctuations on body functions[47]; and (2) new plants extending their geographical range and bringing new protein sources in the European diet.

4.3.5.3. Tight coupling of selenium and sulfur

When the status of selenium (Se) in soils and its bioavailability with respect to plant uptake are assessed, also sulfur (S) needs to be taken into account. Uptake of Se and S by plants is largely controlled by their elemental speciation, i.e. the chemical form of the element, which, in turn, determines their bioavailability. The bioavailable forms of S are sulfate (SO_4^{2-}) and, to a lesser extent, amino acids. Selenium is taken up from soils mainly as selenate (SeO_4^{2-}) through SO_4^{2-} transporters (White, 2016). Due to the strong link between Se and S with respect to plant uptake, it has been shown that changes in SO_4^{2-} concentrations in soils can affect the Se status of plants (Stroud et al., 2010). Climate change likely leads to quantitative and qualitative changes in soil organic matter (SOM) stocks (Crowther et al., 2016). As both Selenium and Sulfur are strongly associated with SOM (Kirkby et al., 2011; Supriatin et al., 2015), these changes may also impact the availability of Se and S for plant uptake (Schoenau and Malhi, 2008). Changing levels of both S and Se in soils may affect their uptake by plants, but the extent of these changes and effects on combined Se and S status of plants has not been investigated on a broad scale. This needs further investigation.

4.4. Interaction with other drivers

The criteria for identification of emerging issues potentially affected by climate change include the identification of drivers interacting with climate change and indirectly driving the emergence of issues (see Section 2.2). The CLEFSA survey and the other sources listed in Section 2.3 has retrieved a list of such drivers, which are described in the sections below.

4.4.1. Impact for plant protection products

Climate change may drive the introduction and spread of new pests and diseases affecting plant health and crop productivity. This may trigger additional needs for pest management by farmers, including increasing the use of pesticides (Delcour et al., 2015) or changing patterns (amount, type) of pesticide use (FAO, 2020). Climate change will reduce environmental concentrations of pesticides at local level due to a combination of increased volatilisation and accelerated degradation, both strongly affected by a high moisture content, elevated temperatures and direct exposure to sunlight. However, for persistent pesticides the same process may increase medium and long-range transport, enhancing the potential impact on natural areas located at significant distance from those with intensive agriculture. Pesticide dissipation seems to also benefit from higher levels of precipitation. But again, the same process may increase runoff and the transfer to aquatic systems of pesticides that would usually remain in the soil. To overcome the changes in crops and pest prevalence, pesticide use might be changed. Adapted pesticide use may finally impact consumer exposure at the end of the food chain. Changes in habitat may trigger the need to consider new specific protection goals in the environmental risk assessment of pesticides.

From a health and environmental protection perspective, farmers are only permitted to use products authorised by the Member State, and always following the authorised good agricultural practice. It could be speculated that the increase in pests' pressure, or the outbreak of new pests/diseases in certain areas, due to climate change could trigger an increase of illegal trade and illegal uses of pesticides. However, the Member State enforcement systems should mitigate this pressure. The regulatory frame, requiring premarketing risk assessment and periodic re-assessments to update the evaluation to scientific knowledge, is suitable for addressing the expected changes in pesticide uses maintaining a high level of protection for human and the environment. However, considering the extensive timelines required for a proper evaluation of the active substances and the plant protection products, a possible consequence of climate change is the increase in the use by the MSs of the exceptional authorisation mechanisms. This will negatively affect the harmonisation achieved through the EU approval and zonal authorisation dual system.

[47] https://www.bafu.admin.ch/bafu/en/home/topics/climate/publications-studies/publications/klimabedingte-risiken-und-chancen.html

This section focuses on the current risk assessment methodology and its capacity for addressing climate changes. Although the focus of this section is on plant protection products, many of the principles and concerns may be applicable to other assessments for regulated products under the EFSA remit. In general, two complementary approaches are used for addressing the environmental variability anticipated for the values to be used for the different environmental parameters relevant for the fate and exposure assessments. The first approach focuses on the selection of (realistic) worst conditions, i.e. absolute worst case for the lower tiers and conditions covering the 90th or other higher percentiles for the refinements. The second approach, e.g. for the FOCUS water scenarios, was the selection of the values measured in existing locations distributed around Europe. Two complementary questions arise:

1. Are the climatic values appropriate for future assessments?
2. Are the conceptual models and implementing tools suitable for addressing the challenges of climate change?

The approach for lower tier assessments is based on the use of generic scenarios and (realistic) worst-case data. Considering the large variability in climatic and related environmental conditions in the EU, the impact is expected to be negligible for substances for which a clear low risk situation is identified with the current models. Several quantitative thresholds for lower tier environmental assessments are in the regulation on the Uniform Principles. Theoretically, in borderline cases minor modifications of some environmental parameters could influence the decision at the lower tier levels.

For more realistic and higher tier assessments, the connectivity among the different influencing factors does not allow straight conclusions. Even for a single parameter, such as increase in temperature, opposite forces and drivers are expected. If considered in isolation, an increase in the environmental temperature is expected to result in faster degradation, but also in reduced efficacy, which could trigger increases in the dose. The complexity increases when several parameters are put together, e.g. changes in degradation rates due to increased temperature associated to significant decrease in soil moisture; or to changes in runoff linked to modification of rainfall patterns, soil conditions and vegetation coverage. As pointed out by (EFSA PPR Panel, 2010) for realistic assessments it is essential to link exposure and effect assessments in terms of spatial and temporal scales, and to consider the relevance of ecological scenarios and the definition of specific protection goals. The analysis confirms that when higher tier assessments are needed, the current methods and tools may be insufficient for properly addressing the environmental and ecological variability in the EU. Consequently, current models and tools may be inadequate for addressing the challenges of climate change, and this gap cannot be addressed by updating the climatic data with current measurements or predictions. Some key aspects and proposals have been summarised in (Topping et al., 2020). Following a set of recommendations from the PPR Panel, the EFSA 2020 scientific strategy has included the development of new risk assessment strategies, considering the agricultural landscape structure in the risk assessment in addition to the in-field and edge-of-field assessments.

During the last decade, the EU has invested in the collection of environmental and agricultural data. This progress offers new possibilities for considering similarities and differences in Member States agricultural and environmental conditions, within and between Member States. EFSA is currently developing the methodology for adapting the environmental assessments to the different agricultural landscape characteristics of the EU, exploring the possibility for including climate and other factors as spatially explicit variables, following the example of Persistence in Soil Analytical Model) (PERSAM). The concept of landscape-based assessments has been mostly limited to the topographic representation of the land use and other structures in the agricultural environment. For example, generic scenarios describing the distribution of the crop to be treated with the pesticide, the surrounding crop and non-crop areas and major environmental structures such as ponds, streams and other water bodies have been proposed in some FOCUS scenarios. However, in order to address the large agri-environmental variability of the EU, landscape assessments should cover, in addition to the topographic description of the agro-environmental structures, two other factors: (1) the environmental and ecological characteristics including climate; and (2) the human management of the area, including the all farming activities, crop rotation, land use changes, the management of protected areas, etc.

Climate change will have direct consequences on weather conditions, locally and regionally and indirect consequences on agricultural management. Both sets of factors have been considered in a number of reports and studies predicting alternative scenarios. The development of a new risk assessment paradigm, including the variability of the parameters defining these landscape characteristics within the

EU would allow the consideration of observed and predicted changes in the risk assessment of pesticides. Some proposals for achieving a more integrative and flexible system were described in a dedicated report (EFSA, 2018a). The development of landscape-based methodologies for the risk assessment of pesticides is the current priority for offering a proper coverage of the European environmental variability, in order to produce more informative assessments connecting EFSA evaluations with the broader environmental impact assessments (Streissl et al., 2018). It will also allow for addressing the adaptation of the assessment scenarios and methods to climate change challenges. In the long-round, climate change may also affect the structural topographic component of agricultural landscape, however local changes are not directly relevant to the regulatory decision on authorisation of the product. Broader changes leading to significant changes in the topography at the Nomenclature of Territorial Units for Statistics (NUTS) 1 or 2 levels, could be covered within the renewal assessment process which has a maximum recurrence of 15 years.

4.4.2. Impact for veterinary drugs and additives

The risk of emerging zoonoses, changes in the survival of pathogens, and changes in distribution of vectors and parasites (and related vector-borne diseases) may necessitate the increased use of veterinary drugs and additives, possibly resulting in increased residue levels in foods of animal origin. This would pose not only acute and chronic risks to human health but could lead to the emergence of antimicrobial resistance (AMR) in human and animal pathogens. Due to increasing frequency of antibiotic resistant bacteria, humans are becoming more susceptible, with climate change contributing to this susceptibility (WHO, 2018a). Climate change considerations may drive the use of feed additives aiming at reducing the production of methane. In vitro research has shown that adding seaweed such as *Asparagopsis taxiformis* to rumen fluid can drastically reduce methane production by cows and sheep (FAO, 2020).

4.4.3. Constraints on natural resources, driving circular approaches

4.4.3.1. Availability of quality water for irrigation and food processing

The projected increase in human population, increased meat consumption (Petrovic et al., 2015) and climate change-disrupted water cycles may boost water demand for agriculture. Needs for water treatment are growing, and emerging processes are applied, such as water recycling along the food supply chain. However, reclaimed water for agriculture and food production might be contaminated with hazardous chemicals or biological agents that treatments failed to eliminate. Increased contamination of water used for irrigation can impact upon the safety of crops, and animals who consume the crops, and their resulting food output (WHO, 2018a). So far, there is still no clear idea about the potential consequences of long-term exposures (CRO Forum, 2016; OECD, 2017). Hazardous substances may also be applied during periods of drought as wastewater is increasingly used in the agricultural sector. However, more comprehensive understanding of long-term health risks requires future research and monitoring (Dickin et al., 2016)

4.4.3.2. Soil health

Climate change may affect soil processes and health, determining its agro-ecological potential and biomass production. The use of soil conditioners like compost may increase in the future. In addition, public policies may stimulate new land management strategies characterised by enhanced use of compost for mitigating climate change (Biala, 2011). Native soils are thought to take up more of the greenhouse gas methane than land used for farming, therefore the application of compost may compensate for loss of the methane sink function. This may trigger the emerging and dissemination of plant pathogens from municipal waste (including ornamental pruning remains for compost) to professional farming. Pathogenic microorganisms may survive the composting process in low numbers and subsequently regrow to high levels under favourable conditions.

4.4.4. New crops, breeds and food production systems

Increasing temperatures and changes in precipitation may induce farmers to apply various climate change adaptation measures such as crop diversification, mixed crop-livestock farming systems, changing planting and harvesting dates, using drought or temperature resistant varieties and high-yield water-sensitive crops. While such adaptations help maintain food production, the introduction of new crops (e.g. hemp) and cultivation methods also increase the risk of introducing food-borne diseases that people and health systems are not familiar with. For livestock, the introduction of breeds less susceptible to heat may be one way forward to reduce the effect of a global average temperature increase, but this change may increase susceptibility to certain pathogens. In some areas, more animals may be moved indoor to avoid heat exposure and stress, giving increased opportunity for transmission of disease. Conversely, increased temperatures will increase the length of the grass-growing season in some areas, which could allow more extensive livestock grazing and greater exposure to vectors and wildlife (WHO, 2018a).

The growing urban population, the shrinking of arable lands and the difficult food delivery to cities when extreme events occur is stimulating a re-design of the urban agricultural landscape. Novel food production systems are emerging like vertical farming, rooftop farms and floating cattle farms. Cellular agriculture and 3D printing technologies are also given more attention (FAO, 2020). Circular economy initiatives are increasing the attention given to the use of food waste as a food and feed source.

4.4.5. Novel food and feed sources

New sources of alternative food and feed are increasingly being used to cope with the growing demand and production of food and feed products, which is a consequence of the increased globalisation, the progressive increase of world population, and the need to reduce the high pressure on natural resources and the negative impact on the planet (e.g. environmental pollution, loss of biodiversity, climate change) attributable to the current conventional agro-zootechnical practices. Insects and algae are proposed as an alternative source of protein in food and feed. However, several food and feed safety issues require attention (see EFSA, 2015; Testai et al., 2016; FAO and WHO, 2019). Circular economy initiatives are increasing the attention given to the use of food waste as a food and feed source. Novel feed is also being designed from production technologies (e.g. biofuel by-products) and from the food market distribution (e.g.: former food products) (FAO and WHO, 2019). Circular economy initiatives are increasing the attention given to the use of food waste as a feed source (Pinotti et al., 2019).

4.4.6. Other drivers

Climate change may also indirectly affect food safety through other drivers like social behaviour, consumption patterns, practices associated with food handling and storage and new technologies (e.g. geoengineering and digitalisation; see FAO, 2020).

5. Conclusions

The CLEFSA project has:

- developed and tested new methodologies for ERI, characterisation and analysis;
- identified emerging issues/risks in EFSA's remit potentially affected by climate change.

Conclusions are provided in relation to these objectives identifying strengths, weaknesses and possible follow-up activities.

The interlinkages of the CLEFSA project with other initiatives at EU and global level are indicated in Appendix H.

5.1. Methodologies for emerging risks identification, characterisation and analysis

A methodology to identify, characterise and analyse the overall potential impact of a complex global disruptive change (climate change) on food safety, plant, animal health and nutritional quality was developed that:

- focuses on all areas of food and feed safety, animal health, plant health and nutrition;
- leads to the identification of a broad range of issues in all EFSA's areas, including weak signals retrieved through horizon scanning and engagement of scientists and the public at large (crowdsourcing);
- constitutes a transparent and structured procedure for identifying, characterising and analysing weak signals characterised by a limited evidence base;
- allows for quantitative analysis of expert assessments, addressing the lack of data and knowledge uncertainty;
- provides elements and a methodological framework to support risk managers, researchers and risk assessors working on food safety;
- informs on future efforts to further develop the methodology.

5.1.1. Identification of emerging issues through crowdsourcing

5.1.1.1. Strengths

Traditional data sources are often not enough for detecting the weak signals typical of potential emerging issues. New and non-traditional sources of data are required. Citizen science is an emerging example of a non-traditional data source. It has potential for identifying a broad range of emerging food safety risks covering all areas in the EFSA's remit.

It allows for detecting weak signals from specific regions and non-obvious connections (e.g. microplastics and climate change) which need to be studied in more detail.

It is useful if adequately screened, focused and complemented with additional information. It provides early information and weak signals not always found in established scientific publications (no evidence base).

5.1.1.2. Weaknesses

Using crowdsourcing for ERI requires resource-intensive human analysis. It has limitations in data reliability and completeness, detail and accuracy thus requiring expert verification and review. Crowdsourcing could be affected by data bias including temporal, demographic and selection bias. It is generally characterised by information noise.

5.1.2. Characterisation of the identified issues by an expert network

5.1.2.1. Strengths

The identified emerging issues have been characterised through a MCDA and a scoring system. The characterisation methodology combines quantitative and qualitative criteria and provide a detailed criteria structure. An expert network was used to characterise the identified emerging issues and identify relevant ones from the vast and often incomplete information provided in the crowdsourcing exercise. The nature of the characterisation exercise supports the establishment of networks of experts relevant for future cooperation initiatives.

5.1.2.2. Weaknesses

The main weakness of the characterisation is the different interpretation by the experts of the issue description, used the requirements of the criteria used to characterise the issues (in particular, the qualitative description of the criterion 'impact') and how to use the climate change scenarios. Another relevant weakness is the low average number of experts scoring each issue and, in some cases, the limited expertise for specific criteria. Finally, the restricted scale (scores from 1 to 5) may have led to 'middle score' preference by experts.

5.1.3. Analysis of the expert data

5.1.3.1. Strengths

The analysis methodology provides indicators for potential impacts of climate change on food safety. It allows a consistent treatment of information coming by several sources, translating qualitative information into scores and indicators values. It makes it possible to summarise the information provided by the experts involved in the characterisation. It stimulates new approaches and offers a systematic way of analysing different emerging issues related to climate change.

The CLEFSA project addresses the issue of characterising uncertainty in data-poor environment. Variance has been used to measure the spread of the individual uncertainty distribution or the aggregated (over all contributing experts) uncertainty distribution for each sub-criteria or criteria.

The impact–likelihood diagrams concentrate relevant information in an easy to understand and readily communicable diagram. Notwithstanding the ambiguity of the impact criteria, the small number of experts and the weaknesses raised in earlier sections, scoresheets were designed to summarise and visualise the outcome of the characterisation and analysis exercise and to provide different layers of information for various end users and stakeholders. Once the methodology is improved, they could report useful information for risk managers, and help them prepare for the future challenges related to climate change. The structure and type of information provided in the scoresheets could also address a broader target audience including risk assessors, managers, policymakers and the general public, therefore it was crucial to ensure transparent communication of results. Due to lack of detailed bibliography the scoresheets are expected to be less useful for scientists. The way the scoresheets are designed attempts to set up a bridge with the IPCC reporting cycle. Finally, the methodology could provide a methodological framework for prioritisation of emerging risks for food safety.

5.1.3.2. Weaknesses

The impact–likelihood diagrams cannot fulfil the ambition of being comprehensive and some relevant information or indicators may be missed. It is not possible to compare and prioritise issues simply on the basis of their positions on these diagrams, especially when they belong to different areas. Additional information is needed to characterise the confidence level. Detailed uncertainty analysis is required to fully describe and quantify different sources of uncertainty affecting the assessment.

The analysis methodology does not consider the reduced number of experts and their level of expertise. If all issues were assessed by a similar number of experts and expertise was comprehensively scored (as opposed to self-assessment), this would allow for more meaningful comparisons between issues and using expertise as a weighing factor.

5.2. Climate change as a driver of emerging risks

The CLEFSA methodology contributes to building a more systemic, overarching and global approach to food safety, considering the food system in a wider context where various environmental, social, economic and technological factors and their interactions can drive a plethora of potential changes. It does not address a single hazard in a single area but rather, multifaceted effects. Climate change and its implications for food safety demand complex scientific work, given the number and diversity of hazards to be considered, the large uncertainties involved and the interconnections between the different areas. The effects of climate change are characterised by a multidisciplinary nature (human–plant–animal health and environmental sciences) and go beyond the recognition of specific emerging risks.

CLEFSA has identified numerous generic issues (described in Section 4.3 and Appendix D) that are driven by climate change and affect food safety. These issues indicate that climate change has the potential of causing, enhancing or modifying the occurrence and intensity of some food-borne diseases and the establishment of invasive alien species harmful to plant and animal health. It has an impact on the occurrence, intensity and toxicity of blooms of potentially toxic marine and freshwater algae and bacteria, on the dominance and persistence of various parasites, fungi, viruses, vectors and invasive species, harmful to plant and animal health. Climate change may also affect:

- susceptibility to disease/infestation of animals and plants, including biophysical reactions to thermal stress and nutrient availability;
- transport pathways in the environment, fate (including bioaccumulation and elimination), toxicity of and exposure to toxic compounds;
- use patterns (amount, type) of pesticide and fertilisers, triggered by the introduction and spread of new pests and diseases as well as reduced nutrients availability and soil quality, affecting plant health and crop productivity;
- patterns (amount, type) of veterinary drugs (potentially contributing to antibiotic resistance) and additives use, triggered by the introduction and spread of new pests and diseases;
- sewer overflow into rivers and coastal environment due to heavier and more frequent rainfalls and flooding (concurrently with higher human pressures in this area);
- food hygiene, in primary production, storage, transport and distribution;
- other drivers (social behaviour, societal changes, global trade patterns or increasing pollution, novel food/feed sources, consumption patterns, farming practices and technologies), which are difficult to separate from climate change.

The CLEFSA survey has stressed the importance of extreme weather events (heat waves, drought, heavy rainfall and flooding) as driver of emerging issues for food safety.

Climate change is likely to drive the (re)emergence of new hazards, increase the exposure or the susceptibility to known hazards and change the levels of micronutrients and macronutrients in food and feed items. The CLEFSA project has identified, characterised and statistically analysed over 100 emerging issues for food and feed safety, plant, animal health and nutritional quality (Section 3.3), fourteen of which were characterised for their impacts on both human and animal health.

A large number of issues identified by the CLEFSA survey (Section 2.3) is related to plant health, suggesting a public concern and sensitivity to potential effects of climate change in this area. The analysis of the characterisation information provided by the experts indicates that climate change may affect the emergence of specific risks in food and feed safety, animal and plant health and nutritional quality. It may increase severity, duration and/or frequency of the potential effects of the hazard considered in the identified issue. However, it shows a more pronounced effect on the likelihood of emergence, for which the confidence level is also higher. It is difficult to draw a general conclusion applicable to all EFSA's areas. Focusing on the parameter with the highest confidence level, likelihood, under the climate change scenario most of the EFSA's areas include issues distributed along all ranges of likelihood. However, plant health shows a gathering of its issues at the highest ranges of likelihood of emergence (66–90%) followed by the cluster of contaminants issues (with marine biotoxins at the highest likelihood values).

6. Recommendations

6.1. Methodological development

The CLEFSA project has contributed to the identification and characterisation of the overall interacting effect of climate change across various areas. Crowdsourcing and 'unsupervised' expert elicitation and characterisation were used to widen the scope of the exercise to several areas and capture possible interlinkages across them. The limited evidence base confers high uncertainty and broad descriptions to each individual issue. The information summarised in the scoresheets is not a thorough assessment of the risk and should not be used in isolation. Furthermore, an integrated approach is recommended to characterise issues affecting different areas (e.g. human and animal health) as part of the same assessment exercise rather than separate assessments. In order to achieve comparability and prioritisation between different issues, the scope of the assessment needs to be narrowed and focused on specific areas (e.g. contaminants) or even issues within the same area (e.g. marine biotoxins). This would be facilitated by:

- well defined criteria question, specifying hazard and context (time, geographic area and scenario) and disentangling variability and uncertainty;
- definition of quantitative criteria and ranges;
- a more interpretable way to aggregate criteria into metric relevant for comparability and prioritisation;
- a more harmonised structure, amount and type of information describing each issue;
- a more harmonised structure, type and amount of information requested from the experts for the issue characterisation;
- homogeneous number of experts across the issues.

The limited number of issues and their improved description can facilitate recruitment of a larger number of experts for each issue and their 'supervision' through more detailed specifications. The uncertainty linked to a different understanding of the issues and the criteria to assess them would be reduced.

6.2. Emerging issues follow-up

The wide variety of issues identified and characterised in this report emphasises the need for policymakers and other relevant players in the food system to consider adjusting surveillance and monitoring to prepare for emerging risks caused by climate change.

The interconnections shown by the different areas and between issues stimulate the envisaging of integrated food system policies in multiple sectors and foster closer collaboration among policymakers, risk managers, risk assessors and researchers. It urges the development of innovative adaptation strategies, innovative technologies, investments in transdisciplinary research and data sharing among scientists.

This report highlights knowledge gaps in the current understanding of how climate change affects the areas in the EFSA's remit and encourages researchers to endeavour to fill them. Environmental sciences need to be linked with human nutrition and epidemiology with a 'One Health' vision. The identified emerging issues contain some useful input for researchers and risk assessors and pave the way to possible collaboration opportunities.

The characterised list of emerging issues could aid decision makers to make informed decisions and use the correct resources to handle potential emerging risks. Further research on the generic issues described in Appendix D will help specify the affected species, geographical areas etc. Breaking down these generic issues into more concrete, actionable ones will allow for detailed characterisation and, finally, risk assessment.

6.3. Revisiting risk assessment approaches

Climate change considerations can substantially impact the assessment of the risks to human, plant, animal health and to the environment. Consequently, for risk assessment to remain relevant, climate change needs to be accounted for. In addition, holistic approaches to deal with multiple stressors (including climate change) are becoming of increasing importance in the food and feed safety area. EFSA is exploring them first in the bee health area[48].

Climate change could be addressed in risk assessment through the following means:

- In the problem formulation phase, climate change should be considered for two main aspects:
  - As part of 'emerging risks', leading to new hazards or conditions increasing existing risks (e.g. increased exposure or incidence); this covers risk assessments for human, plant and animal health under EFSA remits, and may lead to the formulation of additional risk assessment questions (e.g. covering new hazards).
  - Climate change scenarios could be considered in the conceptual model when describing the exposure scenario and the exposed entities. For environmental risk assessments, climate change-related modifications could be incorporated through the ecosystem services framework[49]. Climate change scenarios could be considered when determining the representative biogeographical zones/receiving environments, the relevant ecosystem services, the service providing units and the various parameters of protection (magnitude of effects and their spatial and temporal scale, which also includes an assessment of the impact of climate change on 'vulnerability' and 'recovery potential of valued non-target organisms'). The relevance of default assumptions, such as representativeness of focal species and their biology/ecology, interspecies variability and coverage of ecosystem functions through structural indicators, might need to be re-assessed.
- Beyond the problem formulation phase: when implementing the conceptual model developed as part of the problem formulation, climate change should be considered in the hazard and exposure assessment:
  - As indicated above, in the hazard identification phase, climate change considerations may lead to the inclusion or prioritisation of specific hazards. In the hazard characterisation, climate change scenarios could be considered when evaluating trends in prevalence or incidence over time or geographic areas. Environmental stress linked to climate change may also lead to increased susceptibility.
  - For exposure assessment, climate change scenarios could be considered when assessing fate and distribution in the environment, (including the representativeness of the applied environmental fate parameters). In the plant health remit, climate change scenarios could be used to evaluate the potential area of establishment of a quarantine pest.

Climate change should be part of the uncertainty analysis when the information or available knowledge is insufficient for addressing it as part of the scenarios. EFSA Panels could consider, where relevant, the opportunity of regularly including climate change in their risk assessments

[48] https://www.efsa.europa.eu/en/topics/topic/bee-health

[49] https://www.efsa.europa.eu/en/efsajournal/pub/4499

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Glossary

Driver/driving force. Generally, the energy providing impetus to a development. In futures research, frequently used as internal/external factors influencing developments, decisions, policies etc., helping to define possible future scenarios. Often used in parallel to or overlapping with the term 'trends'. More specifically used in this report for describing the phenomena underlying trends and other developments that finally lead to the emergence of risks. They may act as modifiers of effect on the onset of emerging risks, namely they can either amplify or attenuate the magnitude or frequency of risks arising from various sources.

Emerging issue. 'An issue that could be a food or feed safety risk that has very recently been identified and merits further investigation, and for the information collected is still too limited to be able to assess whether it meets the requirements of an emerging risk. Thus, emerging issues are identified at the beginning of the emerging risks identification process as subjects that merit further investigation and additional data collection. Emerging issues can include specific issues (e.g. a specific chemical substance or pathogen, or a specific susceptible group of the population), as well as general issues, called drivers (e.g. climate change), that could result in emerging risks'.

Emerging risk. an emerging risk is associated with the probability of harm to human, animal and/or plant health, resulting from:

a newly identified hazard (which may be an agent of physical, chemical or biological nature) to which a significant exposure of the target organism may occur, or from:

an unexpected new or increased significant exposure; and/or

new or increased susceptibility to a known hazard;

changed composition of food items or environmental matrices, determining the possibility of a changed intake of micro and macronutrients.

through the food chain for humans, through the feed chain and the environment for animals and through the environment for plants.

Granularity. Level at which the characterisation of the prioritisation criteria does not vary across the various groups of a certain agent/process. It will be up to the experts in a specific field to identify the necessary granularity level, e.g. the specific groups of mycotoxins and specific cereals and the most serious agent within a certain category.

Weak signals. Signals defined as unclear observable trends or patterns that warn about the possibility of future events. They illustrate potential future developments (i.e. emerging issues) for which limited and scattered evidence is currently available. Often there is ambiguous interpretations of the origin, meaning and/or implications of weak signals[50]

[50] http://wiwe.iknowfutures.eu/what-is-a-weak-signal/

Abbreviations and acronyms

AHAW	Animal Health and Welfare
AHPND	acute hepatopancreatic necrosis disease
AHPNS	acute hepatopancreatic necrosis syndrome
AMR	antimicrobial resistance
BIOHAZ	biological hazards
CC	climate change
CFP	Ciguatera fish poisoning
CLEFSA	CLimate change and Emerging risks for Food SAfety
CLN	corn lethal necrosis
CMCC	Euro-Mediterranean Centre on Climate Change
CONTAM	Contaminants in the Food Chain
DG-AGRI	Directorate-General for Agriculture and Rural Development
DG-CLIMA	Directorate-General for Climate Action
DG-ENV	Directorate-General for Environment
DG-RTD	Directorate-General for Research and Innovation
DG-SANTE	Directorate-General for Health and Food Safety
EAP	Environmental Action Programme
EASAC	European Academies Science Advisory Council
EC	European Commission
ECDC	European Centre for Disease Prevention and Control
ECHA	European Chemical Agency
ECMWF	European Centre for Medium-Range Weather Forecasts
EEA	European Environmental Agency
EFSA SC	European Food Safety Authority Scientific Committee
Eionet	European Environment Information and Observation Network
EKC	Environmental Knowledge Community
EKE	Expert Knowledge Elicitation
EMM	Europe Media Monitoring
EMS	Early Mortality Syndrome
EPPO	European and Mediterranean Plant Protection Organization
ERA	environmental risk assessment
EREN	Emerging Risk Exchange Network
ERI	Emerging Risks Identification
ESA	European Space Agency
ETC	European Topic Centre
EU	European Union
FAO	Food and Agriculture Organisation
FDA	Food and Drug Administration
FSA	Food Standards Agency
GASCA	Global Alliance for Climate Smart Agriculture
GMO	genetically modified organisms
HAB	harmful algal bloom
HPAI	Highly pathogenic avian influenza
INFOSAN	International Food Safety Authorities Network
IOI	Island of Ireland
IPB	Institute for Plant Biochemistry
IPCC	Intergovernmental Panel on Climate Change
IPM	Integrated Pest Management
IPMA	Instituto Português do Mar e da Atmosfera
IPPC	International Plant Protection Convention
IRAT	Influenza Risk Assessment Tool
IRSA-CNR	Istituto Ricerca sulla Acque
ISPRA	Istituto Superiore Protezione e Ricerca Ambientale
ISS	Istituto Superiore di Sanità
JRC	Joint Research Centre
LPAI	Low pathogenic avian influenza
LSD	Lumpy skin disease
MCDA	Multi-Criteria Decision Analysis
MCMoV	Maize Chlorotic Mottle Virus
MDMV	Maize Dwarf Mosaic Virus
MediSys	Medical Information System
MERS	Middle East respiratory syndrome

MLND	Maize Lethal Necrosis Disease
MLT	Machine Learning Tool
MLU	Martin Luther University Halle-Wittenberg
OIE	World Organisation for Animal Health
PLH	Plant Health
PPP	Plant Protection Product
PPR	Peste des Petits Ruminants
RCP	Representative Concentration Pathway
RMM	Risk management measures
SAM	Scientific Advice Mechanism
SCOR	Scientific Committee on Ocean Research
SDM	Species distribution model
SOM	Soil organic matter
StaDG-ER	Stakeholder Discussion Group on Emerging Risks
STEC	Shiga toxin-producing Escherichia coli
TEEB	The Economics of Ecosystems and Biodiversity
TIM	Tools for Innovation Monitoring
TM	Text mining
TMA	Text Mining and Analysis
TNO	Netherlands Organisation for Applied Scientific Research (English)
ToMMV	Tomato mottle mosaic virus
UCLA	University California Los Angeles
UNEP	United Nations Environment Programme
UNESCO-IOC	The Intergovernmental Oceanographic Commission of UNESCO
WSMV	Wheat Streak Mosaic Virus
WHO	World Health Organization
WMO	World Meteorological Organization
WSMV	Wheat Streak Mosaic Virus

Appendix A – List of experts for the characterisation

The table below contains the list of experts involved in the characterisation exercise. Some cells are blanked as, at the time of finalising this report, the related experts had not sent their consent to publish names and affiliations yet.

Table 26: Expert name, affiliation, country, email and expertise

Expert	Institution	Country	Email	Field of expertise
Miguel Ángel Miranda-Chueca	University of the Balearic Islands	Spain	ma.miranda@uib.es	Animal health and welfare, Plant health, Biological hazards to human health
Adrian Ioan Ardelean	Institute for Diagnosis and Animal Health-IDAH	Romania	ardeleanadriandvm@gmail.com	Animal health and welfare, Biological hazards to human health
Dominique Bicout	Laue-Langevin Institute and VetAgro Sup	France	bicout@ill.fr	Animal health and welfare
Iain Lake	School of Environmental Sciences, UEA	United Kingdom	i.lake@uea.ac.uk	Biological hazards to human health
Peeters Luc	Copa-Cogeca	Belgium	luc.peeters@belorta.be	Plant health, Contaminants
	BVL-Federal office of consumer protection and food safety	Germany		Contaminants
Anne Wilstermann	Julius Kuehn Institute	Germany	anne.wilstermann@julius-kuehn.de	Plant health
	Julius Kuehn Institute	Germany		Plant health
Elisabetta Suffredini	Istituto Superiore di Sanità	Italy	elisabetta.suffredini@iss.it	Biological hazards to human health
Julio Álvarez Sánchez	VISAVET Health Surveillance Centre, Universidad Complutense	Spain	jalvarez@visavet.ucm.es	Animal health and welfare
Stefano Messori	World Organisation for Animal Health (OIE)	France	s.messori@oie.int	Animal health and welfare
	Swedish Royal Academy of Sciences	Sweden		Biological hazards to human health
Ákos Jóźwiak	University of Veterinary Medicine	Hungary	Jozwiak.Akos@univet.hu	Biological hazards to human health
Mariangela Caroprese	University of Foggia	Italy	mariangela.caroprese@unifg.it	Animal health and welfare
Elisa Berdalet	GlobalHAB & ICM-CSIC	Spain	berdalet@icm.csic.es	Contaminants

Keya Mukherjee, Vittorio Fattori	Food and Agriculture Organization of the United Nations (FAO)	Italy	Keya Mukherjee, Vittorio Fattori	Biological hazards to human health, Contaminants
Patrick Mulder	Wageningen Food Safety Research, Wageningen University and Research	Netherlands	Patrick.mulder@wur.nl	Contaminants
Maura Manganelli	Istituto Superiore di Sanità	Italy	maura.manganelli@iss.it	Biological hazards to human health, Contaminants
Emanuela Testai	Istituto Superiore di Sanità	Italy	emanuela.testai@iss.it	Contaminants
	Wageningen Food Safety Research, Wageningen University and Research	Netherlands		Contaminants
Johanna Takkinen	ECDC	Sweden	johanna.takkinen@ecdc.europa.eu	Biological hazards to human health
Kalila Hajjar	FEDIOL	Belgium	khajjar@fediol.eu	Animal health and welfare, Plant health, Contaminants, Nutritional quality
Ana Allende	CEBAS-CSIC	Spain	aallende@cebas.csic.es	Biological hazards to human health
Marianne Chemaly	ANSES	France	marianne.chemaly@anses.fr	Biological hazards to human health
Ilaria Di Bartolo	Istituto Superiore di Sanità	Italy	ilaria.dibartolo@iss.it	Animal health and welfare; Biological hazards to human health
Michele Dottori	IZSLER	Italy	michele.dottori@izsler.it	Animal health and welfare
Bryony Jones	Royal Vet College	United Kingdom	bajones@rvc.ac.uk	Animal health and welfare
Michael Baron	The Pirbright Institute, UK	United Kingdom	michael.baron@pirbright.ac.uk	Animal health and welfare
Bruno Garin-Bastuji	ANSES	France	bruno.garin-bastuji@anses.fr	Animal health and welfare
	FLI	Germany		Animal health and welfare
	Centre for Environment, Fisheries and Aquaculture Sciences	United Kingdom		Animal health and welfare
Saraya Tavornpanich	Norwegian Veterinary Institute	Norway	saraya.tavornpanich@vetinst.no	Animal health and welfare
Lucy Robertson	Norwegian University Life Sciences	Norway	lucy.robertson@nmbu.no	Biological hazards to human health

Mieke Uyttendaele	University of Ghent	Belgium	Mieke.Uyttendaele@UGent.be	Biological hazards to human health
	ETH	Switzerland		Nutritional quality
Marco Vinceti	University of Modena and Reggio Emilia	Italy	marco.vinceti@unimore.it	Nutritional quality
Cristina Tirado	UCLA	United States	cristinatirado@g.ucla.edu	Biological hazards to human health; Contaminants; Nutritional quality
Panos Milonas	Benaki Phytopathological Institute	Greece	p.milonas@bpi.gr	Plant health
Jessika Giraldi	EC JRC		jessika.giraldi@ec.europa.eu	Contaminants
Georges Kass	EFSA	Italy	Georges.KASS@efsa.europa.eu	Contaminants
Hans-Martin Füssel	European Environment Agency	Denmark	martin.fuessel@eea.europa.eu	Animal health and welfare; Plant health; Biological hazards to human health; Contaminants; Nutritional quality
Martina Cirlini	University of Parma	Italy	martina.cirlini@unipr.it	Contaminants
Antonella Penna	University of Urbino	Italy	antonella.penna@uniurb.it	Contaminants
Jane Kilcoyne	Marine Institute	Ireland	Jane.Kilcoyne@Marine.ie	Contaminants
Isabelle Oswald	INRA	France	isabelle.oswald@inra.fr	Contaminants
Marco Pelin	University of Trieste	Italy	mpelin@units.it	Contaminants
Luc Ingenbleek	FAO	Italy	Luc.Ingenbleek@fao.org	Contaminants
Paola Bordin	Italian health authority and research organisation for animal health and food safety	Italy	pbordin@izsvenezie.it	Contaminants
Juan Navas-Cortes	Institute for Sustainable Agriculture – CSIC	Spain	j.navas@csic.es	Plant health
Nathalie Arnich	ANSES	France	nathalie.arnich@anses.fr	Contaminants
Isabelle Villena	University Hospital Centre of Reims	France	ivillena@chu-reims.fr	Biological hazards to human health
Antonio Velarde	IRTA Institute of Agrifood Research and Technology	Spain	antonio.velarde@irta.cat	Animal health and welfare
	ANSES	France		Biological hazards to human health
Alfonso Siani	Institute of Food Sciences, Italian	Italy	alfonso.siani@isa.cnr.it	Nutritional quality

	National Research Council (CNR)			
John Kearney	Technological University Dublin	Ireland	john.kearney@TUDublin.ie	Nutritional quality
Jacqueline Castenmiller	Netherlands Food and Consumer Product Safety Authority	Netherland	j.j.m.castenmiller@nvwa.nl	Nutritional quality
Stefaan De Henauw	Universiteit Gent	Belgium	stefaan.dehenauw@ugent.be	Nutritional quality
Androniki Naska	School of Medicine, University of Athens	Greece	anaska@med.uoa.gr	Nutritional quality
Kristina Pentieva	Ulster University	United Kingdom	k.pentieva@ulster.ac.uk	Nutritional quality

Appendix B – Issue scoresheets

The collection of 27 scoresheets produced for the issues with the highest number of experts is available as supplementary information in the Wiley landing page. Explanatory information is presented in Section 3.3.4.

Appendix C – List of uncharacterised issues

Some of the collected issues have not been characterised because of expert's unavailability. They are listed below.

Table 27: List of identified issues per EFSA's area and category, description, source, support information and impact on other area

Area	Category	Issue	Description	Source	Supporting information	Impact on other area in the remit of EFSA
Plant health	Pest and other arthropods	Risks to plant health posed by *Bemisia tabaci* species complex and viruses it transmits for the EU territory	The EFSA Scientific Opinion shows that a +2°C increase in average temperatures determines: – expansion of the outdoor area currently invaded by *B. tabaci* – increase in population density – expansion of the northernmost limit of distribution. In regions where *B. tabaci* is established, viruses transmitted by this insect, especially those affecting tomato and cucurbits (courgette, pumpkin, cucumber, watermelon and melon) and also beans, pepper and aubergines, are responsible for severe diseases that have a strong negative impact on crop yield.	EFSA	https://www.efsa.europa.eu/en/efsajournal/pub/3162	
		Spread of pests typical of sub-tropical areas such as locust	Climate change conveys desertification and occurrence of extreme weather phenomena such as flooding, which may cause increased growth and expansion of desert locust. Global warming may transform southern EU areas in a suitable environment for desert locust. In fact, Spanish island and Greek territories were affected by locust plagues in the past. The FAO is closely monitoring how climate change is affecting locust migration patterns, and populations are currently reaching the borders of the Mediterranean costs of the EU. We already have some pests in New Zealand which are isolated to small pockets like locusts and armyworms. These are known as sleeper pests because under warmer conditions have the potential to spread and multiply, devastating pastures and crops.	Survey	http://www.fao.org/news/story/en/item/343656/icode/ ; http://www.fao.org/ag/locusts/en/activ/1307/climate/index.html ; http://www.nzherald.co.nz/the-country/news/article.cfm?c_id=16&objectid=11993587 ; https://en.wikipedia.org/wiki/Desert_locust	
		Fall army worm (FAW)	Crop pests and diseases developed in sub-tropical regions are moving or threatening to move into S Europe, such as fall armyworm. These can cause significant crop loss and are difficult to control due to restrictions on pesticide use in EU. We already have some pests in New Zealand which are isolated to small pockets like armyworms. These are known as sleeper pests because under warmer conditions have the potential to spread and multiply, devastating pastures and crops. In Kenya fall armyworm attack on and Lethal Necrosis (NLD) on staple maize production is observed. This is a recent (i.e.	Survey	http://www.nzherald.co.nz/the-country/news/article.cfm?c_id=16&objectid=11993587	

			about two years) disease and pest attack s which have been developing/spreading from neighbouring countries.			
		Increased area of potential establishment and spread of *Frankliniella occidentalis* and the viruses it transmits	The thrips *Frankliniella occidentalis* transmits many viruses to many crops and here are no control measures available to protect against viruses. this includes important food products like glasshouse crops as tomato, sweet pepper, eggplant, beans. but also outdoor vegetable crops like leak, onion, cabbage and also soft fruit crops like strawberries, blueberries.	Survey		
		Glassy winged sharpshooter	With 2016 our hottest year on record and this January the hottest month recorded, it is difficult to ignore that our climate is changing. Temperatures are predicted to further increase, making frosts a thing of the past for us in the Waikato. [..] Sub-tropical insects will have the potential to devastate horticulture and legume crops. Insects like the glassy winged sharpshooter and giant sapsucking whitefly which is known to infest at least 35 plant families, including New Zealand native plants.	Survey	http://www.nzherald.co.nz/the-country/news/article.cfm?c_id=16&objectid=11993587	
		Giant sapsucking whitefly	With 2016 our hottest year on record and this January the hottest month recorded, it is difficult to ignore that our climate is changing. Temperatures are predicted to further increase, making frosts a thing of the past for us in the Waikato. [..] Sub-tropical insects will have the potential to devastate horticulture and legume crops. Insects like the giant sapsucking whitefly which is known to infest at least 35 plant families, including New Zealand native plants.	Survey	https://www.nzherald.co.nz/the-country/news/article.cfm?c_id=16&objectid=11993587	
		Aphids	In parallel to climate change, a change in the area of distribution of many vectors can be anticipated (e.g. aphids). Many plant viruses are transmitted by such vectors. For overview, plant viral textbooks can be consulted (e.g. Plant Virus, Vector by CRC Press, 2017; or the classical textbook on Plant Virology (5th edn), edited by: Roger Hull ISBN: 978-0-12-384871-0, 2014).	Survey	https://www.elsevier.com/books/plant-virology/hull/978–0-12–384871–0 ; https://www.crcpress.com/Plant-Virus-Vector/Mukhopadhyay/p/book/9781138112018	
		Leaf hoppers, for example *Orientus ishidae*	In parallel to climate change, a change in the area of distribution of many vectors can be anticipated (e.g. leaf hoppers). A large number of plant viruses is transmitted by such vectors. For overview, plant viral textbooks can be consulted (e.g. Plant Virus, Vector by CRC Press, 2017; or the classical textbook on Plant Virology (5th edn), Edited by: Roger Hull ISBN: 978-0-12-384871-0, 2014). The study in the link provides the first data on the occurrence of the mosaic leaf hopper *Orientus ishidae* (Matsumura, 1902) (Hemiptera: Cicadellidae) in Poland. This species is native to Southeast Asia,	Survey, TIM	https://content.sciendo.com/view/journals/jppr/57/2/article-p107.xml ; https://www.crcpress.com/Plant-Virus-Vector/Mukhopadhyay/p/book/9781138112018	

			adventive in Europe and feeds on cultivated plants. *Orientus ishidae* is a well known carrier of grapevine flavescence dorée phytoplasma which causes the grapevine yellows disease. Symptoms of phytoplasma diseases of grapevine include deformations, leaf chlorosis and withering of plants. The appearance of this species in Poland might be caused by observed climate variations and insufficient plant health controls in the international trade of plants.			
		Plant hoppers	In parallel to climate change, a change in the area of distribution of many vectors can be anticipated (e.g. plant hoppers). Many plant viruses are transmitted by such vectors. For overview, plant viral textbooks can be consulted (e.g. Plant Virus, Vector by CRC Press, 2017; or the classical textbook on Plant Virology (5th edn), edited by: Roger Hull ISBN: 978-0-12-384871-0, 2014).	Survey	https://www.elsevier.com/books/plant-virology/hull/978–0-12–384871–2 ; https://www.crcpress.com/Plant-Virus-Vector/Mukhopadhyay/p/book/9781138112018	
		Beetles	In parallel to climate change, a change in the area of distribution of many vectors can be anticipated (e.g. beetles). Many plant viruses are transmitted by such vectors.	Survey	https://www.uni-wuerzburg.de/en/news-and-events/news/detail/news/scientists-alarmed-by-bark-beetle-boom/ ; https://www.crcpress.com/Plant-Virus-Vector/Mukhopadhyay/p/book/9781138112018	
		Mites	In parallel to climate change, a change in the area of distribution of many vectors can be anticipated (e.g. mites). Many plant viruses are transmitted by such vectors. For overview, plant viral textbooks can be consulted (e.g. Plant Virus, Vector by CRC Press, 2017; or the classical textbook on Plant Virology (5th edn), Edited by: Roger Hull ISBN: 978-0-12-384871-0, 2014).	Survey	https://www.elsevier.com/books/plant-virology/hull/978-0-12-384871-4 ; https://www.sciencedirect.com/science/article/pii/S0169534719301673; https://www.crcpress.com/Plant-Virus-Vector/Mukhopadhyay/p/book/9781138112018	
		Grapevine moth (*Lobesia botrana*)	The grapevine moth *Lobesia botrana* (Lepidoptera: Tortricidae) is the principal native pest of grape in the Palearctic region. In the present study, we assessed prospectively the relative abundance of the moth in Europe and the Mediterranean Basin using linked physiologically based demographic models for grape and *L. botrana*. The model includes the effects of temperature, day-length and fruit stage on moth development rates, survival and fecundity. The effects of climate warming on grapevine and *L. botrana* were explored using regional climate model projections based on the A1B scenario of an average +1.8°C warming during the period 2040–2050 compared with the base period (1960–1970). Under climate change, grape yields increase northwards and with a higher elevation but decrease in hotter areas. Similarly, *L. botrana* levels increase in northern areas but decrease in the hot areas where summer temperatures approach its upper thermal limit.	Literature	https://onlinelibrary.wiley.com/doi/full/10.1111/afe.12256	

		Potential geographical distribution of the agricultural invasive pest, *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae)	Climate change is a major factor driving shifts in the distribution of invasive pests. The oriental fruit fly, *Bactrocera dorsalis*, native to mainland Asia, has spread throughout Southeast Asia and sub-Saharan Africa. Recently, the species has extended its Asian range northward into regions previously thought unsuitable which presents a major new risk to temperate zone agriculture and has invaded Italy.	Literature	https://link.springer.com/article/10.1007%2Fs10584–019–02460–3	
		Pink bollworm *Pectinophora gossypiella*	Four global warming scenarios were examined to estimate the effects on the potential geographic range of pink bollworm (PBW). Average observed daily temperatures were increased 1.0, 1.5, 2.0 or 2.5°C, respectively, in the four scenarios. Scenarios with average increases of 1.5–2.5°C predicted that the range of PBW would expand into the Central Valley of California and the severity of the pest would greatly increase in areas of current infestation. Studies on the overwintering of pink bollworm *Pectinophora gossypiella* in cotton plants in Egypt are also found in the literature.	Literature	https://link.springer.com/chapter/10.1007/698_2018_311 ; https://www.researchgate.net/publication/248535979_Climatic_limits_of_pink_bollworm_in_Arizona_and_California	
		Alternanthera philoxeroides in several crops (irrigated rice, wheat, sweat potato, corn, lettuce)	The risk of establishment will potentially increase with temperature increases. Those areas which are currently unsuitable for the occurrence of *A. philoxeroides* may become more suitable with increased number of day degrees. Extreme weather events, flooding etc., will increase the occurrence and potential areas of establishment for the plant. Of importance, *A. philoxeroides* is highly tolerant to submergence – even though growth is supressed survival rates remain high. *A. philoxeroides* can tolerate high levels of seawater salinity (10–30%).	Literature	https://www.researchgate.net/publication/282292544_Pest_Risk_Analysis_for_Alternanthera_philoxeroides ; https://link.springer.com/content/pdf/10.1007%2Fs12230–019–09739–2.pdf	
	Fungi	Botryosphaeriaceae	Increased risk of establishment of new plant pests and diseases and increased risk of spread of some existing plant pests and diseases towards the north: *Botryosphaeria dothidea* and other fungi from the family Botryosphaeriaceae due to severe droughts. Latent endophytic fungi can pose a pathogenic threat under changed climatic conditions (e.g. Botryosphaeriaceae). See for example Slippers and Wingfield (2007) Fungal Biology Reviews; Marsberg A, et al. Molecular Plant Pathology, 2017, 18, 477–488.; Piškur B, et al. European Journal of Forest Research, 2011, 130, 235–249.	Survey	http://www.davidmoore.org.uk/21st_Century_Guidebook_to_Fungi_PLATINUM/REPRINT_collection/Slippers_Wingfield_endophytes_as_latent_pathogens.pdf ; https://www.researchgate.net/publication/235651236_Diversity_and_pathogenicity_of_Botryosphaeriaceae_on_declining_Ostrya_carpinifolia_in_Slovenia_and_Italy_following_extreme_weather_conditions	
	Virus	Lethal Necrosis disease (NLD) viruses	The Maize Lethal Necrosis Disease (MLND) is a result of a combination of two viruses, the Maize Chlorotic Mottle Virus (MCMoV) and any of the cereal viruses in the Potyviridae group, like the Sugarcane Mosaic Virus (SCMV), Wheat Streak Mosaic Virus (WSMV) or Maize Dwarf Mosaic Virus (MDMV). The double infection of the two viruses gives rise to what is known as MLND, also referred to as Corn Lethal Necrosis (CLN). In Kenya this is a recent (i.e. about	Survey		

			two years) disease on staple maize which have been developing/spreading from neighbouring countries.			
		Potato virus Y, Pepino mosaic virus and Potato spindle tuber viroid	Water is reused more and more, it is known that bacteria and viruses/viroids could be easily transmitted that way and can by chance infect few plants but then the pathogen can be rapidly transmitted from infected plant mechanically or via vectors to cause epidemics.	Survey	https://www.ncbi.nlm.nih.gov/pubmed/22871317 q https://aem.asm.org/content/80/4/1455	
	Nematodes	Increased risk of plant nematode damage	In parallel to climate change, a change in the area of distribution of many vectors can be anticipated (e.g. nematodes, aphids, leaf hoppers, plant hoppers, beetles, mites, flies). A large number of plant viruses is transmitted by such vectors. For overview, plant viral textbooks can be consulted (e.g. Plant Virus, Vector by CRC Press, 2017; or the classical textbook on Plant Virology (5th edn), Edited by: Roger Hull ISBN: 978-0-12-384871-0, 2014). Due to higher temperatures, global warming will promote the development rate and thus increase population densities of plant nematodes. Conditions favouring the herbivore populations can drive them to surpass the economic threshold levels and becoming new emerging pests. Also, this involves the expansion of the geographical ranges to north.	Survey	https://www.researchgate.net/publication/216848810_Climate_changes_and_nematodes_Expected_effects_and_perspectives_for_plant_protection	
Biological hazards to human health	Virus	Nipah virus	Nipah virus introduction in wild boar.	Survey		Animal health and welfare
		Animal-origin influenza A viruses	Identification of animal-origin influenza A viruses not currently circulating among humans. Although the Influenza Risk Assessment Tool (IRAT) is not intended to predict the next pandemic influenza A virus, it has provided input into prepandemic preparedness decisions. Source: Use of Influenza Risk Assessment Tool for Prepandemic Preparedness. Planning and preparation for influenza pandemics are major challenges to public health authorities for many reasons, not the least of which is the inherent variability and unpredictability of the influenza virus. IRAT with the goal to systematically evaluate influenza A viruses that are not circulating in humans but potentially pose a pandemic risk. The aspects that the experts considered for the development of the IRAT tool are based on the	Survey	https://wwwnc.cdc.gov/eid/article/24/3/17–1852_article	Animal health and welfare

			epidemiologic and ecologic evidence: infection in humans, infections in animals and global distribution in animals. This last could be affected/linked to climate changes. Although the IRAT is not intended to predict the next pandemic influenza A virus, it has provided input into prepandemic preparedness decisions. In regard to the evaluation of animal-origin influenza viruses for their potential human pandemic risk, two specific questions were developed related to the potential risk for emergence and consequent potential impact: (1) What is the risk that a virus not currently circulating in humans has the potential for sustained human-to-human transmission? (emergence question); and (2) If a virus were to achieve sustained human-to-human transmission, what is the risk that a virus not currently circulating among humans has the potential for substantial impact on public health? (impact question) In developing the IRAT, a working group of international influenza experts in influenza virology, animal health, human health and epidemiology identified 10 risk elements and definitions. The final three elements are based on the epidemiologic and ecologic evidence: infection in humans, infections in animals and global distribution in animals. These elements are used to answer the two risk questions to evaluate an influenza virus of interest. The 10 elements are ranked and weighted based on their perceived importance to answering the specific risk questions and an aggregate risk score is generated.			
		Usutu virus	Usutu is an exotic mosquito-borne arbovirus that has been imported into Europe and has been involved in local transmission to humans. It is mentioned for potential mosquito-borne risks as a result of climate change.	EREN	https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/371103/Health_Effects_of_Climate_Change_in_the_UK_2012_V13_with_cover_accessible.pdf ; https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6186058/; https://onlinelibrary.wiley.com/doi/full/10.1111/tbed.13351?campaign=woearlyview	

	Bacteria	*Stenotrophomonas maltophilia*	An emerging opportunist pathogen for cultured channel catfish, *Ictalurus punctatus*, in China. Overcrowding, fighting and changes in the environment and diet are believed to be predisposing factors for the fish infection. However, the role of this bacterium in animal diseases is less clear than in humans, and its control poses great challenges because of its high resistance to most authorised antibiotics.	EREN		
	Abiotic factors	Biogenic amines (histamine) in fishery products	Temperature effects the multiplication of implicated commensal bacteria, their expression of the enzyme histidine decarboxylase, and the activity of that enzyme. Risk of this most common seafood hazard, increases with temperature. Temperature control problems can arise around harvest, notably with long-line soak-times where dead/dying fish can lie in/on water for several hours on hook awaiting retrieval by boat. Subsequent refrigeration does not reduce risk of already-produced histamine.	Survey, EFSA	https://www.efsa.europa.eu/en/supporting/pub/en-1301	
Contaminants	Macrophytes biotoxins	Cyanogenic glucosides	Interactive effects of temperature and drought on cassava growth and toxicity: toxic cyanogenic glucosides like amygdalin contained in apricot kernels. Cassava is an important dietary component for over 1 billion people, and its ability to yield under drought has led to it being promoted as an important crop for food security under climate change. Despite its known photosynthetic plasticity in response to temperature, little is known about how temperature affects plant toxicity or about interactions between temperature and drought, which is important because cassava tissues contain high levels of toxic cyanogenic glucosides, a major health and food safety concern. Findings confirm that cassava is adaptable to forecast temperature increases, particularly in areas of adequate or increasing rainfall; however, in regions forecast for increased incidence of drought, the effects of drought on both food quality (tuber toxicity) and yield are a greater threat to future food security and indicate an increasing necessity for processing of cassava to reduce toxicity.	Survey	https://onlinelibrary.wiley.com/doi/full/10.1111/gcb.13380 ; https://www.sciencedirect.com/science/article/pii/S0035378719306745; https://www.news-medical.net/news/20191026/Some-plant-foods-causing-paralysis-death-in-malnourished-populations.aspx	

	Cucurbitacin	Food poisoning due to squashes and other cucurbits. Possibly due to climate change and dryness which can trigger a higher production of cucurbitacin in cucumbers and squashes. However, if there is a stronger link to climate change proven, it may become an emerging issue.	EREN, survey	https://www.ncbi.nlm.nih.gov/pubmed/29323540	
Anthropogenic contaminants	Perchlorates	Potential increase in the risk of perchlorate contamination of food. Environmental variables such as temperature, moisture level, salinity, pH, etc. can be influenced by climate change. This can alter the behaviour of chemicals in the environment and maybe their toxicokinetics in living systems. Perchlorate is present in the environment from both natural and man-made sources. At high concentrations, it is thyrotoxic to humans and animals. It has been detected in water and other media such as soil and milk. Climate change-related increased rainfall (both in frequency and intensity) could lead to increases in surface runoff and waterlogging in certain areas. This may lead to an increased availability of perchlorate in the ruminant diet with possible transfer to milk (which may affect the kinetics of other milk components such as iodine). This may lead to increased exposure of humans, particularly in utero and in infancy.	Survey	http://www.safefood.eu/SafeFood/media/SafeFoodLibrary/Documents/Publications/Research%20Reports/M10039-SAFEFOOD_Climate-Change-on-the-Dairy-Production-Report-24-02-2017.pdf ; https://www.dairyreporter.com/Article/2019/09/13/Chlorate-is-an-emerging-residue-of-concern-within-the-dairy-F-B-industries/?utm_source=Newsletter_Subject&utm_medium=email&utm_campaign=Newsletter%2BSubject&c=ab6wU2%2FJaXHZEPz8kwU1NBRe%2FOAY6UnO ; https://onlinelibrary.wiley.com/doi/full/10.1111/gcb.13667	
	Acids	Pollution produces the acid rains, that means H_2SO_4, H_2CO_3 and HNO_3. So, when the acid rain falls, the particles of N precipitates with rain and reach not only pollute the air, soil and water as well as – and, in conclusion – the food.	Survey	Protein	

Appendix D – List of generic issues

Table 28: List of issues for which no specific hazard or agent was specified, as received by the EU survey

Area	Issue	Description
Animal health	Influence of the changing ultraviolet radiation, increasing or decreasing in a changing climate	There is a strong link between the greenhouse effect and the changes in the ozone layer. Increases in ultraviolet radiation (UV) may have both positive and negative effects on wild and farmed plants and animals. For example the fibre content in crops may increase on increased UV while sun damage has been observed in farmed animals such as fish in shallow waters. Decreases in the UV irradiance to the surface of the Earth can in certain regions be brought about by changes in the atmosphere such as more cloudiness. The decrease can be regarded as beneficial in terms of less chance of sun damage, but may have a negative influence also through less production of vitamin D in organisms.
	New and re-emerging vector-borne zoonotic diseases and parasitic diseases	Climate change affecting directly the ecology and evolution of the infectious agents, their vectors and hosts giving rise to emerging and re-emerging threats.
	Introduction of new crop and animal pests and diseases into Europe and northward movement of pests and diseases.	Introduction of new crop and animal pests and diseases into Europe and northward movement of pests and diseases. Crop pests and diseases developed in sub-tropical regions are moving or threatening to move into South Europe, such as fall armyworm. These can cause significant crop loss and are difficult to control due to restrictions on pesticide use in EU. Some animal pests and pathogens are also invading or becoming more prevalent in larger areas of Europe.
	Impact on the development of molluscs and fish by acidification of the oceans	Acidification facilitates dissolution of calcium carbonate, a key compound of marine shells and skeleton structures. Thus, acidification cause fragility on these organisms.
Plant health	How climate change alters plant growth	Global warming affects more than just plant biodiversity—it even alters the way plants grow. A team of researchers at Martin Luther University Halle-Wittenberg (MLU) joined forces with the Leibniz Institute for Plant Biochemistry (IPB) to discover which molecular processes are involved in plant growth. In Current Biology, the group presents its latest findings on the mechanism controlling growth at high temperatures. In the future, this could help breed plants that are adapted to global warming.
	More frequent flooding events, therefore more contaminated waters reaching crops different cultivars being introduced due to raised temperatures and having an impact on local flora and local diets	
	Influence of the changing ultraviolet radiation, increasing or decreasing in a changing climate	There is a strong link between the greenhouse effect and the changes in the ozone layer. Increases in ultraviolet radiation (UV) may have both positive and negative effects on wild and farmed plants and animals. E.g. the fibre content in crops may increase on increased UV while sun damage has been observed in farmed animals such as fish in shallow waters. Decreases in the UV irradiance to the surface of the Earth can in certain regions be brought about by changes in

	the atmosphere such as more cloudiness. The decrease can be regarded as beneficial in terms of less chance of sun damage, but may have a negative influence also through less production of vitamin D in organisms.
Northward expansion of toxic plants	Toxic plants are widespread in the tropical areas. Climatic changes and increasing trade may contribute to an expansion of the plants.
Increased spread or changed pattern of vector transmitted plant viruses due to a change in vector distribution	this is a generic issue linked to vector transmitted plant viruses, expanding on the already inserted emerging issue on a change of spread of *Bemisia tabaci* and the viruses it transmits. In parallel to climate change, a change in the area of distribution of many vectors can be anticipated (e.g. nematodes, aphids, leaf hoppers, plant hoppers, beetles, mites, flies). A large number of plant viruses is transmitted by such vectors. For overview, plant viral text books can be consulted (e.g. Plant Virus, Vector by CRC Press, 2017; or the classical text book on Plant Virology (5th edn), Edited by: Roger Hull ISBN: 978-0-12-384871-0, 2014).
Introduction of new crop and animal pests and diseases into Europe and northward movement of pests and diseases, due to climate change, globalisation of agriculture and human assisted movement (trade)	Crop pests and diseases developed in sub-tropical regions are moving or threatening to move into Europe, such as fall armyworm. These can cause significant crop loss and are difficult to control due to restrictions on pesticide use in EU. Some animal pests and pathogens are also invading or becoming more prevalent in larger areas of Europe. Range shift (north and south) has been faster for pest than non-pest species. Partly due to climate change and also globalisation of agriculture as human assisted movement has broken many natural dispersal barriers. http://www.downtoearth.org.in/blog/how-is-climate-change-affecting-crop-pest-and-diseases--54199 http://www.ilsiindia.org/PDF/internationalconferenceonclimatechangeandimplicationforwaterresourcesandnutritionsecurity/Dr.%20Vellingiri%20Geethalakshmi%20Indirect%20Impacts%20Pest%20and%20Disea.pdf
Losses of agricultural yields from climate change-derived impacts	Decreases of agricultural yields from different impacts of climate change (water scarcity, losses of fertility, etc.).
Emerging and dissemination of plant pathogen from municipal waste (including ornamental pruning remains for compost) to professional farming	Pathogenic microorganisms may survive the composting process in low numbers and subsequently regrow to high levels under favourable conditions. The objective of this study would be to investigate the regrowth potential of emerging plant pathogens and their dissemination through compost uses in professional farm.
Increased risks of plant phytopathogen and pet occurrence that affect plant fitness	Bacterial, viral, fungal infections can decrease the plant fitness and products survival, secondary infections. Climate change is predicted to alter the severity of damage caused by 31 globally important pest species (doi.org/10.1002/fee.2160)
Lack of plant pollination due to mismatch of plant flowering and insect pollination caused by phenological changes	Many crops and wild flowers require insect pollination to produce fruit or set seed. Changes in phenology due to climate change may mean, for example that a crop flowers earlier in the year than previously, before a sufficient population of its pollinator (e.g. bees) is available, thus resulting in inadequate pollination.
Pathogen internalisation	Severe hail causing injury to the plant tissue, drought, sudden massive rain showers and changed absorption properties of soil, as well as vicinity of open-air sewage channels and non-insulated septic tanks can apply additional probability of spread of pathogens and their internalisation through root systems, leave and plant injuries, as well as wider spread of pathogens between plants and fields through local floods.

	Increased area of potential establishment, spread and impact of invasive alien species	Invasive alien species represent an important driver for biodiversity loss, alteration of ecosystem function and degradation of ecosystem services. Furthermore, non-native species could also threat human health and wellbeing. Under the influence of climate change the area of potential establishment and spread of many alien species are expanding. Also population abundance that is considered the main driver of risk associated pest is known to be affected by change in the environmental drivers (e.g. temperature and rainfall). *Ceratitis capitata* represents one of the many examples that can be considered to show the effects of climate change on the northward expansion of species with potential impacts on EU plant health.
Biological hazards to human health	Increased exposure to biological hazards	This rising water demand intensifies emerging risks due to greater chances of water contamination, spread of infectious parasites, pathogenic microorganisms and insect larvae through water, and burst of liability issues and political conflicts. The probability of occurrence is expected to expand soon due to climate change disrupting water cycles (Jiménez Cisneros et al., 2014). Interconnected drivers are: The Earth's population is projected to reach 11.2 billion by 2100 (Roser and Ortiz-Ospina, 2017) which intensifies water demand, for example, due to expanding urbanisation, scarce rain (The Guardian, 2017), more water-thirsty crops (WWF, 2017) and increased meat consumption (Worldwatch Institute, 2017). The extent of its impact of pollutants, toxins and micro-particles in water on human and animal health is yet to be assessed. References: Jiménez Cisneros, B.E., T. Oki, N.W. Arnell, G. Benito, J.G. Cogley, P. Döll, T. Jiang and S.S. Mwakalila. 2014. 'Freshwater resources'. In: IPCC, 2014. Climate Change 2014: Impacts, Adaptation and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. [C.B. Field, V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press, pp. 229–269. Roser, M., Ortiz-Ospina, E., 2017: World Population Growth https://ourworldindata.org/world-population-growth/ . WWF, 2017: Living Waters, Conserving the source of life. Thirsty crops: Our food and clothes: eating up nature and wearing out the environment? http://wwf.panda.org/about_our_earth/about_freshwater/freshwater_problems/thirsty_crops/ The Guardian, 2017: Rome facing water rationing as Italy suffers driest spring for 60 years. https://www.theguardian.com/world/2017/jul/24/rome-water-rationing-italy-suffers-driest-spring-60-years-fountain Worldwatch Institute, 2017: Global Meat Production and Consumption Continue to Rise. http://www.worldwatch.org/global-meat-production-and-consumption-continue-rise
	New and increased exposure to hazardous agents as adverse consequences of failures in technological advances (i.e. water treatment)	Due to climate change needs for water treatment are growing, and emerging processes are applied such as water recycling along the food supply chain. However, reclaiming water for agriculture and food production might be contaminated with hazardous agents that treatments failed to eliminate. So far, there is still no clear idea of the potential consequences of long-term exposures (CRO Forum, 2016). Hazardous substances may also be applied during periods of drought as wastewater is increasingly used in the agricultural sector. However, a more comprehensive understanding of long-term health risks requires future research and monitoring (Dickin et al. 2016). References: CRO Forum, 2016: Water Risks. Emerging Risk Initiative-Position paper November 2016. https://www.thecroforum.org/2016/11/28/water-risk/ Dickin, S.K., Schuster-Wallace, C.J., Qadir, M., Pizzacalla, K. A Review of Health Risks and Pathways for Exposure to

	Wastewater Use in Agriculture Environm. Health Perspect. 2016 Jul; 124(7): 900–909. doi: 10.1289/ehp.1509995. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4937861/ OECD (2017), Water Risk Hotspots for Agriculture, OECD Studies on Water, OECD Publishing, Paris. http://dx.doi.org/10.1787/9789264279551-en
Increase in rapid and massive spread of infectious diseases due to water crisis	A rising demand intensifies emerging risks due to greater chances of water contamination, spread of infectious parasites, pathogenic microorganisms and insect larvae through water. The probability of occurrence is expected to expand soon due to climate change disrupting water cycles (Jiménez Cisneros et al., 2014). The extent of its impact of pollutants, toxins and micro-particles in water on human and animal health is yet to be assessed. Published: 28 January 2018; First report of extreme drought is plaguing a city of millions (metropolis) – Cape Town/Kaapstad (South Africa) releases a water restriction rationing 87 L pppd. Cause: no rainfall in the last three years due to climate change. Source: Dutch newspaper TROUW 76 (no. 22464), p. 20 (Economy) Published: 24 July 2017: Rome facing water rationing as Italy suffers driest spring for 60 years. The Guardian available at: https://www.theguardian.com/world/2017/jul/24/rome-water-rationing-italy-suffers-driest-spring-60-years-fountain Interconnected triggers (drivers) are e.g. 1) earth's population is projected to reach 11.2 billion by 2100 (Roser and Ortiz-Ospina, 2017) which intensifies water demand, for example, due to expanding urbanisation, 2) scarce rainfall (Trouw, 2018; The Guardian, 2017), 3) more water-thirsty crops (WWF, 2017) and 4) increased meat consumption (Worldwatch Institute 2017). Why: The rising demand (i.e. access to water supply) intensifies emerging risks due to an increase in water-borne diseases/pollution including a burst of political conflicts. Heatwaves are the most deadly weather-related hazard in Europe (https://ec.europa.eu/jrc/en/news/europe-be-hit-hard-climate-related-disasters-future). If decisive actions do not greenhouse gas emissions, deaths from weather disasters, heatwaves most of all, could increase 50-fold by the start of the next century (published 29 August 2017; source: http://www.euractiv.com/section/climate-environment/opinion/europes-dramatic-summer-gives-a-foretaste-of-super-heatwaves-to-come/) References: CRO Forum, 2016: Water Risks. Emerging Risk Initiative-Position paper November 2016. https://www.thecroforum.org/2016/11/28/water-risk/ Jiménez Cisneros, B.E., T. Oki, N.W. Arnell, G. Benito, J.G. Cogley, P. Döll, T. Jiang and S.S. Mwakalila. 2014. 'Freshwater resources'. In: IPCC, 2014. Climate Change 2014: Impacts, Adaptation and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. [C.B. Field, V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press, pp. 229–269. Roser, M., Ortiz-Ospina, E., 2017: World Population Growth https://ourworldindata.org/world-population-growth/ . Worldwatch Institute, 2017: Global Meat Production and Consumption Continue to Rise. http://www.worldwatch.org/global-meat-production-and-consumption-continue-rise
Increased exposure to hazardous agents as adverse consequences of limitations in technological advances (i.e. water treatment)	Needs for water treatment are growing, and emerging processes are applied such as water recycling along the food supply chain. However, reclaiming water for agriculture and food production might be contaminated with hazardous agents that advanced treatments failed to eliminate. So far, there is still no clear idea of the potential consequences of long-term exposures (CRO Forum 2016). More frequent liability claims due to allegations of unsafe delivery of water. For example, Jordan seeks to become an oasis of water-saving technology: wells are running dry, groundwater is

	increasingly polluted. Source: http://www.nature.com/news/jordan-seeks-to-become-an-oasis-of-water-saving-technology-1.22598 Why: Hazardous substances may be applied during periods of drought as reclaimed as well as wastewater is increasingly used in the agricultural sector. However, a more comprehensive understanding of long-term health risks requires future research and monitoring (Dickin et al., 2016). References: Dickin, S.K., Schuster-Wallace, C.J., Qadir, M., Pizzacalla, K. A Review of Health Risks and Pathways for Exposure to Wastewater Use in Agriculture Environm. Health Perspect. 2016 Jul; 124(7): 900–909. doi: 10.1289/ehp.1509995. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4937861/ UN-Water, 2014: A Post-2015 Global Goal for Water: Synthesis of key findings and recommendations from UN-Water. http:/www.un.org/waterforlifedecade/pdf/27_01_2014_un-water_paper_on_a_post2015_global_goal_for_water.pdf
Increased exposure to infectious diseases as consequences of large-scale involuntary migration of 1 billion in the Asia-Pacific area by 2100	The article 'Health and healthcare provision to asylum seekers and refugees in Germany' published in the Journal of Health Monitoring (2017) noted the insufficient representative data on the health and healthcare of asylum seekers and refugees in Germany or their impact amongst the general public. However, the article acknowledged that the prevalence of 'particular communicable diseases is higher among asylum seekers than among the resident population'. The number of reported cases of hepatitis B, for example, increased nearly fourfold between 2014 and 2016. Many of the infected individuals were unvaccinated migrants from Afghanistan, Iraq and Syria. Publication: August 22, 2017 Source: Joseph Klein Mass Migration Risks Major Public Health Crisis Germany provides a case study of the health consequences of uncontrolled migration. Available at: https://www.frontpagemag.com/fpm/267655/mass-migration-risks-major-public-health-crisis-joseph-klein Why: large-scale involuntary migration from Asia-Pacific territories importing/spreading (rare) exotic infectious agents. Source: 26 July 2017 climate change will force mass immigration consulted on http://www.eco-business.com/news/climate-change-will-force-mass-migration-of-1-billion-by-2100/. Rising sea levels could make one-fifth of the worlds population refugees by 2100 http://amp.weforum.org/agenda/2017/06/one-fifth-of-the-worlds-population-could-be-a-refugee-by-2100 In a worst-case scenario, 1.4 billion people living in low-elevation coastal zones might become involuntary migrants by 2060 due to rising sea levels (source: 'Impediments to inland resettlement under conditions of accelerated sea level rise, available at: http://www.sciencedirect.com/science/article/pii/S0264837715301812?via%3Dihub). If present climate trends continue, by 2100, some 1 billion people are forced to move (source: Region at Risk: the Human Dimensions of Climate Change in Asia and the Pacific; available at: https://www.adb.org/sites/default/files/publication/325251/region-risk-climate-change.pdf). Asia and the Pacific might experience a temperature increase of 6 degrees Celsius above pre-industrial times (i.e. heat waves become daily occurrences). Climate change affects the region's weather systems (i.e. drought), agriculture and fisheries (i.e. flood-prone and acidification) , biodiversity, trade and urban development, therefore trigger massive migration. The Robert Koch Institute's Infectious Disease Epidemiology Annual Report for 2016 reported that a proportion of the increase in the number of cases of such diseases as Hepatitis B, HIV, and tuberculosis in 2015/2016 can be attributed to the migratory movements as compared with previous years. Hence, WHO replies that in spite of the common perception of an association between migration and the importation of infectious diseases (http://www.euro.who.int/en/health-topics/health-determinants/migration-and-health/migrant-health-in-the-european-region/migration-and-health-key-issues), there is no systematic association. The risk for importation of exotic and rare infectious agents into Europe, such

	as Ebola, Marburg and Lassa viruses or Middle East respiratory syndrome (MERS), is extremely low. WHO's experience has shown that, when importation occurs, it involves regular travellers, tourists or health care workers rather than refugees or migrants. Although the risk that refugees and migrants will bring cholera to Europe exists, but travellers returning from cholera-endemic countries pose a similar risk. WHO replies 'Should a rare exotic infectious agent be imported, Europe is well prepared to respond, as shown over the past 10 years in responses to imported cases of Lassa fever, Ebola virus disease, Marburg virus disease and MERS, as countries have good laboratory capacity, treatment facilities equipped with isolation wards, a trained health workforce and systems for contact tracing. While countries should remain vigilant, this should not be their main focus'.
Increased exposure to zoonotic pathogens as the impact of climate change on the emergence and spread is underestimated previously	The impact of climate change on the emergence and spread of infectious diseases could be greater than previously thought, according to new research by the University of Liverpool. Publication: 2 August 2017 Source: https://www.genengnews.com/gen-news-highlights/spread-of-infectious-disease-due-to-climate-change-may-be-greater-than-previously-thought/81254752 Gene news highlights a study published in Scientific Reports (available at https://www.nature.com/articles/s41598–017–06948–9.pdf) assessing at a large-scale how climate affects bacterium, viruses or other microorganisms and parasites (pathogens) threatening health of humans or animals in Europe. Why: Prioritisation of pathogens that may respond to climate change. Currently, most models examining climate effects only consider a single or at most two climate drivers, so our results suggest that this should change if we really want to understand future impacts of climate change on health. Zoonotic pathogens – those that spread from animals to humans – were also found to be more climate sensitive than those that affect only humans or only animals. As 75% of emerging diseases are zoonotic, emerging diseases may be particularly likely to be impacted by climate change. However, their response to climate change will also be dependent on the impacts of other drivers, such as changes to travel and trade, land use, deforestation, new control measures and the development of antimicrobial resistance. References: FORENV – Foresight /December 2017 weak signal no. 67: EU DG-ENV pilot New technologies in urban environment).
Climate change could drive a third of parasites to extinction by 2070	As many as one in three parasites could become extinct as a result of climate change by 2070, new research suggests. This may sound like good news, but the loss of parasites could destabilise many of the world's ecosystems, the lead author tells Carbon Brief. Parasites play a critical role in maintaining food webs and, in their absence, a diverse range of animals could be threatened with extinction. Rising global temperatures could also drive parasites into cooler regions, such as the UK and Canada, the study finds, which will have a significant, but unpredictable, effect on the diseases they carry. Source: https://www.carbonbrief.org/climate-change-drive-third-parasites-extinction-2070
Use of antibiotics in conventional farm animals can lead to increased risk of antibiotic-resistant bacteria	Livestock which is fed in giant halls in many numbers usually were given antibiotics in their food as prevention or growth stimulation. In EU countries it has been forbidden since 2006 to do carry out this practice due to higher risk of antibiotic (ATB)-resistant bacteria. But outside EU this practice still may occur. Due to safety I would recommend using antibiotics only for treatment and globally focus on regulating ATB use in livestock.
Variation (+/−) in 'outside' temperatures and influence on pathogens (and hazards)	Influence on systems for hazards control (risk/cost/benefit analysis) in production and marketing.

development and growth in food and feed products	
Increased potential for growth of sea lice and jellyfish	Reported cases of sea lice attacks on swimmers in Australian waters www.abc.net.au/localstories/2015/02/03/4173206 www.theguardian.com/Australianews/video/2017/Aug07/sea-lice-feast on-fresh-meat-in Australia-after Teenager left bloodied-video
Increase in diarrheal illness from microbial pathogens	Microbial food-borne illness is typically a seasonal phenomenon. Therefore, if summers are longer and hotter, we anticipate an increase in illnesses from bacteria such as Salmonella. https://www.globalchange.gov/browse/reports/impacts-climate-change-human-health-united-states-scientific-assessment
Challenges to the integrity of the refrigeration chain	The safety of food chains, in particular in global supply chains, relies heavily on maintaining the integrity of the cold chain in order to ensure that the product is safe for consumption when it reaches the end consumer. Increasing complexity puts a burden on safeguarding the necessary integrity of the refrigeration chain. Climate Change puts further stress on the system and the danger increases that the cold chain becomes compromised with considerable potential impact on the processor and the consumer sphere.
Risk of exposure to zombie pathogens (viruses) in the thawing permafrost	Higher temperatures have been found to disproportionately affect northern land areas, particularly the Arctic, which has already experienced fallout from climate change. In the past few years, there has been a growing fear about a possible consequence of climate change: zombie pathogens. Specifically, bacteria and viruses — preserved for centuries in frozen ground — coming back to life as the Arctic permafrost starts to thaw. Publication data: 24 January 2018 Source: https://www.npr.org/sections/goatsandsoda/2018/01/24/575974220/are-there-zombie-viruses-in-the-thawing-permafrost – Goat and soda; https://www.npr.org/programs/all-things-considered/2018/01/24/580170816 Until yet, no virulent species (that could grow in the lab) have been excavated such as the 1918 flu virus in Norway, Anthrax or smallpox from bodies in the 1990s by Russian scientists. Why: Last year 2017, a 25-year-old teacher was helping archaeologists excavate an 800-year-old log cabin, high above the Arctic Circle on the northern coast of Alaska. He claimed that his knee got infected by Seal finger bacterium, a 800-year-old strain of a seal hunters disease that was trapped in ice. The doctors never tested Petersons infection to see if it really was seal finger. It responded well to simple antibiotics — the treatment for seal finger. In her blog Michaeleen Doucleff warns about the dangers of human curiosity. I was convinced that the only way pathogens would rise up from the permafrost was if a scientist bent over backward to resurrect the creatures in the lab. The chance of it happening naturally seemed infinitesimally small.
Increased microbiological contamination of costal waters, farm and human environment	Changes in the levels of rain falling during storms provide evidence that the water cycle is already changing. Water quality could suffer in areas experiencing increases in rainfall. Heavy rain can increase the levels of runoff into rivers and lakes, washing sediment, nutrients, pollutants, trash, animal waste and other materials into water supplies, making them unusable or unsafe. Climate change models predict increased rainfall in some areas which may lead to severe flooding. Severe flooding events may overwhelm waste water treatment plants resulting in contamination of the human and animal or farm environment with bacteria present in human sewage, including bacteria which are resistant to antimicrobials, contaminating those environments. Such contamination allows a point of exposure of animals or food crops to bacteria (including resistant bacteria) present in untreated waste water/sewage of human origin.

Increased expansion and occurrence of zoonoses and other food-borne diseases affecting animals and humans	
Northwards expansion of vector-borne diseases affecting animals and or humans	Diseases as the blue tongue of sheep, the west Nile virus of Horses, the Crimean–Congo haemorrhagic fever of humans and livestock among others, are transmitted by mosquitoes/ticks vectors. The spread of these vectors depends on climatic conditions.
Death of bees and pollinating insects due to antibiotics and to microbial resistance	Very serious and disastrous consequences on the pollination of plants with disappearance of plant essences, their seeds, fruits, food and feed. If antibiotics were also registered for the beekeeping sector, we could not rule out that antibiotics or even worse the resistant antimicrobial bacteria can be transported by the bees on each flower, to the heart of the fruit for 3 km radius from each hive. Considering that in every beehive there are at least 30,000 bees touching thousands of flowers a day and multiplying this number by the number of hives present in Europe, one would create a huge network of contaminations. The bees could therefore turn out to be the amplifying vector of the phenomenon of the antimicrobial resistance, from which no one could defend itself. Making antibiotics to bees means making them environmentally collapse of biodiversity and biological death of the planet.
Increased food safety risk from the use of untreated wastewater through contamination of pathogens (including antimicrobial-resistant strains) in irrigated agriculture	Many parts of the world is facing water shortages and under climate change, it is expected to become worse. Agriculture may need to rely more on untreated wastewater. That poses a range of food safety risks including contamination of irrigated produced by different types of pathogens (including antimicrobial-resistant strains) and chemical pollutants, e.g. heavy metals. See Thebo et al. (2017) A global, spatially explicit assessment of irrigated croplands influenced by urban wastewater flows. Environmental Research Letters, 12, 074008.
Increased food safety risk from the use of untreated wastewater through contamination of chemical pollutants (e.g. heavy metals) in irrigated agriculture	
Pesticides or antibiotics as adverse consequences of floods and excessive rainfalls	Environmental change is evident e.g. extreme weather events, drought, floods, storms etc. (Source: https://www.wired.com/story/climate-change-fueled-storms-could-leave-less-water-for-drinking). To aggravate occurrences, uneven consequences around the globe like droughts, floods and unsound water management (i.e. discharging untreated sewage), risks are expected to emerge in new places and to worsen (CRO Forum, 2016; World Economic Forum, 2018). In general, the level of precipitation is increasing but also the kind of precipitation is changing: rain rather than snow; shorter periods covered by snow, more spring rain and faster snow melt combines to release large amounts of runoff. Publication: 11 September 2017 Source : https://www.eurekalert.org/pub_releases/2017–09/uoc--ucc091117.php; 28 August 2017: Source: https://www.livescience.com/60253-hurricane-harvey-flood-public-health.html Why: Floods and excessive rainfalls leach chemicals and microorganisms that enter surface or ground waters (Sandin, 2017). Examples are *Escherichia coli* (*E. coli*) bacteria carrying Shiga-toxin genes (STEC) in a number of water-borne

		outbreaks (USGS 2017a) , presence of oestrogenic or androgenic compounds, pesticides or antibiotics (USGS 2017b) or nanosized material (Mattsson et al. 2017). Blooming of toxic blue-green algae (cyanobacteria) may be caused by nitrate fertilisers entering waters through leaching (e.g. flushed nutrients from over-fertilised farms into its canals and reservoirs; more rain in already-wet agricultural areas will leach away even more nutrients, causing more blooms, leading to more water shortages—impacting fisheries, agriculture and public health. Source: http://science.sciencemag.org/cgi/doi/10.1126/science.aan2409) Considerable pollution flows into rivers due to floods and storm water that results in water containing chemicals responsible for soil contamination of agricultural fields with subsequent threads to food safety. In fact, flooding and heavy rainfall may cause sewage overflow into drinking water supplies or agricultural areas (Levin 2017). Flooding events can also carry to agricultural fields pollutants that are more typical from other land uses (example metals such as As and Hg in the UK and PBB in Baltic sea). Centers for Disease Control and Prevention notes a slew of risks related to floodwater and standing water, including wound infections and the spread of infectious diseases and chemicals in the water (https://www.cdc.gov/healthywater/emergency/extreme-weather/floods-standingwater.html)
Contaminants	Increase of toxic algal blooms responsible for shellfish poisoning and fish mortality	Expansion of areas affected by HABs incidences; Emerging HABs species in some regions; increase frequency and intensity of HABs and areas of occurrence.
	Flooding as a mechanism for transporting pathogens and chemicals onto agricultural land	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2679592/ Environ Health Perspect. 2009 Apr; 117(4): 508–514. Published online 2008 Dec 10. doi: 10.1289/ehp.0800084 PMCID: PMC2679592 Review Impacts of Climate Change on Indirect Human Exposure to Pathogens and Chemicals from Agriculture
	Increased range and concentration of veterinary drug residues in food	Many factors influence the emergence of animal diseases and subsequent treatments which may lead to harmful drug residues in food. Climate change is predicted to influence the biology, distribution and occurrence of animal diseases. However, precise forecasting of disease emergence is problematic. Animal transportation will continue to be a distribution route for emerging diseases. Increased disease burden in food producing animals and drug resistance in pathogenic organisms may necessitate alterations in the veterinary medicine regime. This may in turn lead to an increase in the range and concentration of veterinary drug residues in food. Relevant document can be accessed at: http://www.safefood.eu/SafeFood/media/SafeFoodLibrary/Documents/Publications/Research%20Reports/Climate-Change-Impact-on-Food-Safety_.pdf
	Impact of increased flooding events on contaminant levels in food	Increasingly frequent flooding events due to more extreme weather conditions may lead to more mobilisation and transfer of contaminants (heavy metals, pesticides, persistent organic pollutants) from sediment in rivers, canals and lakes onto agricultural land and subsequent uptake into food animals and crops. As an example, previous relevant Food Standards Agency (FSA) research (with further references in reports and papers) available at: https://www.food.gov.uk/science/research/chemical-safety-research/env-cont/fs231030.
	Increased heavy metal contamination of feed in areas of increased rainfall and land contamination via	The more frequent and intense rainfall that is predicted could result in greater contamination of both silage and grazing pasture by heavy metals. These contaminants may originate from geochemical sources, such as the soil or bedrock, or even anthropogenic sources, such as human pollution. Given that cattle production on the island of Ireland (IOI) is primarily grass-based, the risks of consuming heavy metals is predictably high. Transmission into milk may become an

	anthropomorphic or geological activities	emerging food safety issue.
	Wetter conditions leading to the proliferation of parasites and survival of pathogenic bacteria requiring increased use of veterinary drugs and risk of residues	In wetter conditions such as those predicted for the IOI, animal diseases may become more of a problem. Increased use of veterinary medicines and anthropogenic (man-made) chemicals may be necessary. This creates the potential for transmission of chemical residues into the food chain. Climate change on IOI is likely to increase the disease burden on some agricultural livestock. With the exception of parasitic helminth infections, there is little published data on the subject. Administration of veterinary medicines to food animals is likely to increase, encroaching drug resistance may lead to administration of greater quantities of medications or alternative drugs being used inappropriately. There is the potential for more and different residues of veterinary medicines to appear in locally produced foods. As approximately 75% of food-borne diseases are zoonotic the effect of climate change on livestock must be considered. With higher ambient temperatures livestock may become stressed (Miraglia et al., 2009), more likely to become ill and therefore possibly discharge larger numbers of pathogens (Keen et al.,2003)
	Increase contamination of watersheds during hottest periods	Increase of temperature induce more use of water (irrigation, industry, urban...) and we will observe water stress in many places mainly during summer. Because wastewaters continue to be discharged in watersheds, we will observe an increase of the concentration level of chemicals in raw waters. This will induce toxic effects on fauna and more contamination of fish but also a higher risk of chemical contamination for tap water production (if we consider drinking water associate with food).
	Increased food safety risk from the use of untreated wastewater through contamination of biological and chemical pollutants (e.g. heavy metals) in irrigated agriculture	‘Many parts of the world is facing water shortages and under climate change, it is expected to become worse. Agriculture may need to rely more on untreated wastewater. That poses a range of food safety risks including contamination of irrigated produced by different types of pathogens (including antimicrobial-resistant strains) and chemical pollutants, e.g. heavy metals.
Nutrition	Increasing cases of food allergies	The high temperature, and especially fast temperature fluctuations, affect the human body and put it under stress and that is a reason for increase the number of food allergy cases51.
		Allergenicity of novel food protein, e.g. due to new plants extending their geographical range and bringing new protein sources in the European diet. The development and introduction of new dietary protein sources has the potential to improve food supply sustainability. Understanding the potential allergenicity of these new or modified proteins is crucial to ensure protection of public health. Exposure to new proteins may result in *de novo* sensitisation, with or without clinical allergy, or clinical reactions through cross-reactivity.
	Effect of soil management systems on erosion and nutrition loss in vineyards on steep slopes	

[51] https://www.bafu.admin.ch/bafu/en/home/topics/climate/publications-studies/publications/klimabedingte-risiken-und-chancen.html

	Increased C/N ratio of food and feed crops	
	impact of wetter soils and weather on crop quality (that is nutrient status, taste and physical appearance)	
Pesticides	Increased risk of pest diseases in a context of less available plant protection products	The food chain needs a diversified range of plant protection products to protect their crops and deliver the quality and quantity of safe food required by EU consumers. If these are not available, not only yields will drop, agricultural raw material supply will decrease and food prices will rise. But it will also be increasingly difficult to grow safely some crops in some EU countries, in particular in a context of climate change that is expected to increase the presence of pests. With the reduced availability of pesticides which are being phased out and with few alternatives or few new pesticides being chemical or natural, an increased susceptibility of resistance and/or risk of spreads of further diseases could be seen in liaison with climate change. It could be useful to investigate it in general to understand and map its possible impacts. Many scientific and press articles have been published on the subject: https://www.nature.com/news/crop-pests-advancing-with-global-warming-1.13644 http://science.time.com/2013/09/02/a-warmer-world-will-mean-more-pests-and-pathogens-for-crops/ http://www.fao.org/3/a-ai785e.pdf https://ageconsearch.umn.edu/bitstream/20722/1/sp01am02.pdf A third conference on agriculture and impacts of climate change will take place next year. https://www.elsevier.com/events/conferences/agriculture-and-climate-change-conference
	Change in the use pattern and environmental risks of pesticides	Climate is a key factor in the biology of the crops, as well as the biology and ecology of pests and plant pathogens. Climate change is leading to a new geographical distribution of crops but also affecting the distribution and relevance of plant pests and diseases. As a consequence changes in pesticides-based and integrated pest and weed management strategies are expected. Within the EFSA role for assessing the risk for pesticides the following emerging issues could be considered: The environmental risk assessment methodology used by EFSA (based on scenarios developed in the last century) becomes obsolete and no longer addresses the real risk for non-target organisms (e.g. obsolete environmental scenarios, focal species, etc.).
	Influence of climate change on pesticide and herbicide use and prevalence	Under the impact of climate change, drivers such as temperature, humidity, precipitation, drought, flood can influence directly and indirectly the use of pesticide, herbicide and fungicides in order to manage insects, weeds and diseases. These drivers also influence the transport, dispersal and degradation of insecticides/herbicides in the environment including agricultural and aquaculture areas.
	Challenge for farmers to ensure food supply and adapt to the changes in precipitation patterns (droughts or floods) and in the growth of crops	Changes in the precipitation pattern (causing draughts or floods) will challenge irrigation systems and plant protection strategies, resulting in different use of pesticides and, potentially, different efficacy. Changes in crops growing seasons will challenge fertilisation and harvest practices. Known pests could increase their prevalence in altered temperature and humidity conditions, leading to a different use of pesticides. Additionally, new plant and animal pathogens, not previously considered a hazard, could develop in modified habitats, triggering the need for new pesticides.
	Increased prevalence of plant and animal parasites that results in increased	Changes in the precipitation pattern (causing draughts or floods) will challenge irrigation systems and plant protection strategies, resulting in different use of pesticides and, potentially, different efficacy. Changes in crops growing seasons will challenge fertilisation and harvest practices. Known pests could increase their prevalence in altered temperature and

occurrence of new plant and animal pests	humidity conditions, leading to a different use of pesticides. Additionally, new plant and animal pathogens, not previously considered a hazard, could develop in modified habitats, triggering the need for new pesticides.
Changed frequency of occurrence of organisms harmful to plants requiring different pesticide solutions	Changes in the precipitation pattern (causing draughts or floods) will challenge irrigation systems and plant protection strategies, resulting in different use of pesticides and, potentially, different efficacy. Changes in crops growing seasons will challenge fertilisation and harvest practices. Known pests could increase their prevalence in altered temperature and humidity conditions, leading to a different use of pesticides. Additionally, new plant and animal pathogens, not previously considered a hazard, could develop in modified habitats, triggering the need for new pesticides.
Migrations and new biological hazards coming from new products or risk of pesticides not used in Europe	Migrations and new biological hazards coming from new products or risk of pesticides not used in Europe.
Pesticides or antibiotics as adverse consequences of floods and excessive rainfalls	Environmental change is evident e.g. extreme weather events, drought, floods, storms etc. (Source: https://www.wired.com/story/climate-change-fueled storms-could-leave-less-water-for-drinking). To aggravate occurrences, uneven consequences around the globe like droughts, floods and unsound water management (i.e. discharging untreated sewage), risks are expected to emerge in new places and to worsen (World Economic Forum 2018, CRO Forum 2016). In general, the level of precipitation is increasing but also the kind of precipitation is changing: rain rather than snow; shorter periods covered by snow, more spring rain and faster snow melt combines to release large amounts of runoff. Publication: 11 September 2017 Source : https://www.eurekalert.org/pub_releases/2017–09/uoc--ucc091117.php; 28 August 2017: Source: https://www.livescience.com/60253-hurricane-harvey-flood-public-health.html Why: Floods and excessive rainfalls leach chemicals and microorganisms that enter surface or ground waters (Sandin, 2017). Examples are *Escherichia coli* (*E. coli*) bacteria carrying Shiga-toxin genes (STEC) in a number of water-borne outbreaks (USGS 2017a) , presence of oestrogenic or androgenic compounds, pesticides or antibiotics (USGS 2017b) or nanosized material (Mattsson et al., 2017). Blooming of toxic blue-green algae (cyanobacteria) may be caused by nitrate fertilisers entering waters through leaching (e.g. flushed nutrients from over-fertilised farms into its canals and reservoirs; more rain in already-wet agricultural areas will leach away even more nutrients, causing more blooms, leading to more water shortages—impacting fisheries, agriculture and public health. Source: http://science.sciencemag.org/cgi/doi/10.1126/science.aan2409) Considerable pollution flows into rivers due to floods and storm water that results in water containing chemicals responsible for soil contamination of agricultural fields with subsequent threads to food safety. In fact, flooding and heavy rainfall may cause sewage overflow into drinking water supplies or agricultural areas (Levin 2017). Flooding events can also carry to agricultural fields pollutants that are more typical from other land uses (example metals such as As and Hg in the UK and PBB in Baltic sea). Centers for Disease Control and Prevention notes a slew of risks related to floodwater and standing water, including wound infections and the spread of infectious diseases and chemicals in the water (https://www.cdc.gov/healthywater/emergency/extreme-weather/floods-standingwater.html)
Northwards expansion of noxious plant or other species that cause more intensive	Herbicides and pesticides have been used for a long time, their accumulation routes are not well known in the long term. Climate warming causes Northwards invasion of noxious plant and other species and the increased usage of herbicides and pesticides. Their residues may accumulate in soil and food.

	pesticide usage and hence pesticide residues in the environment and food	
	Development of human resistance towards triazoles	The use of azole fungicides is causally related to the development of resistance towards triazoles in human medicine. https://www.ncbi.nlm.nih.gov/m/pubmed/29376938/?i=2&from=rivero-menendez Garcia-Rubio R et al. Triazole Resistance in Aspergillus Species: An Emerging Problem Drugs (2017) 77:599–613 Meis JF, et al. Clinical implications of globally emerging azole resistance in Aspergillus fumigatus. Philos Trans R Soc Lond B Biol Sci. 2016.
	Changes in pesticide usage	Due to the climate change there will possibly arise a change in pesticide usage. If the pesticide persistence in the environment change that can lead to two different scenarios: 1) the pesticide will persist shorter and will not have the efficacy as before, so the change in the way or the quantity it is used will become necessary or the change of the pesticide; 2) the pesticide will stay longer in the environment and the problem of residual content can surface.
	Increased use of fungicides	The other type of problem can be that due to the climate change and higher mycotoxin problem the increased quantities of fungicides will be necessary in all stages of plant food production, so the increased control of fungicide residues may be needed, as well as re-evaluation of the risk that fungicide present to the population.
	Increased use of dangerous pesticides	As disease and insect pest outbreaks increase in frequency or spread to new regions lacking knowledge of effective control measures, farmers may increasingly turn away from safer (cultural) control measures and increasingly begin using pesticides to control new pests with which they are unfamiliar. This may be exacerbated if companies promoting pesticide sales are quicker on the uptake to promote their products in newly susceptible regions than farmer groups are to disseminate traditional control techniques. E.g.: https://www.sciencedirect.com/science/article/pii/S0963996914006309 (2015) https://link.springer.com/article/10.1007/s11027–017–9755-y (2017)
Genetically Modified Organisms	Increased use of innovative products with faster adoption rates (e.g. drought tolerant, cold tolerant and more effectively growing GM plants)	How will risk managers respond to climate change and hopefully will allow solutions that are existing and offered by newest technologies e.g. like drought tolerant, cold tolerant and more effectively growing GM plants and animals. This question is related to food provision in a sustainable way, and therefore also reflects on risk assessments. the emerging risk is that the risk managers are not swift enough to adopt novel products that can offer solutions – I think risk governance and regulatory preparedness remain important for a risk assessment body like EFSA.
	More cultivation of soybean, including GM	
Veterinary drugs	Changed use of veterinary medicines	Due to climate change animals could face other diseases or more diseases which could lead to another or increased use of veterinary drugs.
	Increase in the impact of drug residues due to the acidification of the oceans	

Appendix E – Risk management measures

The following recommendations for risk management measures indicate the information submitted by the experts involved in issue characterisation under the qualitative criterion 'risk management measures'. It has not been reviewed by EFSA.

Biological hazards to human health

As numerous hazards to human health are interconnected with animal and plant health, proposed remediation measures are at the cross-section of these areas. Good sanitation standards for workers in agriculture and horticulture, monitoring the population of animal vectors and outbreaks in animals and deworming pets will reduce the risk of outbreaks. Moreover, global systems for monitoring disease spread should be implemented. Food and feed need to be tested for pathogens and efforts must be made to control the cold chain in food supply and storage. Good sanitation and water management, also as a part of disaster management, will reduce the probability of outbreaks. Research efforts should concentrate on development of vaccines and antimicrobial treatments. In parallel, pathogen populations should be genotyped to detect any potentially harmful mutations. Antimicrobial resistance should also be monitored. Finally, the general public should be informed about the food sources and cooking practices that might increase the risk of infection.

Plant health

If plant pathogens are concerned, Integrated Pest Management (IPM) is recommended. It involves a combination of using resistant cultivars and biological methods of controlling pest populations. Integrated monitoring should focus on early detection of disease outbreaks, vector and alternate host control and removal. Monitoring and inspection at borders should focus on commodities associated with the pests and certification programmes that would allow for importing only pest-free crops. Moreover, emphasis should be placed on educating farmers about proper hygiene in farms and surveillance of their crops in order to spot pests.

Animal health

The interconnectedness among human, animal and plant health emphasise the need for greater collaboration and communication between public health professionals, veterinarians, plant pathologists and scientists. There is a need for a monitoring effort to trace vector (both domesticated and wild) population expansion and genotypic variation of pathogens. Disaster management should also aim to prevent outbreaks after extreme events. Research ought to focus on identifying all relevant vectors and reservoirs for animal diseases and assessing whether humans can also be reservoirs for animal pathogens. There is also a need for vaccine and antibiotic development, but the latter two might cause resistance in the pathogen populations which needs to be monitored. Thus, emphasis must be placed on rational use of antimicrobials and repellents and not exceeding the recommended doses. Habitat preservation is a powerful tool that will prevent both migrations (and in consequence disease spread) and wildlife loss. Since heat stress results in lower yields of milk cattle and affects their wellbeing, rearranging the pastures to provide more shade and increase water availability is strongly advised. On the other hand, breeding should be directed towards increasing the animals' resistance to heat stress. Awareness campaigns should aim to 1) teach farmers to recognise early disease symptoms 2) increase collaboration between authorities and citizens 3) promote knowledge about vector-related risks and importance of good personal hygiene, especially when in contact with animals.

Contaminants

Surveys throughout the world demonstrate that the occurrence, intensity and toxicity of blooms of potentially toxic marine and freshwater algae and bacteria ('harmful algal blooms'- HABs) is changing. The growing interest in aquaculture and mariculture to meet the increased demand for food and a new public awareness on sustainability brings significant food safety concerns related to algal toxins. Still, many uncertainties exist, and an effort should be made to design strategies to prevent or alleviate the future negative impacts of these events.

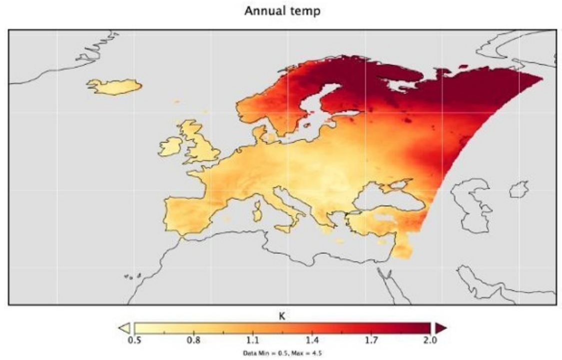
It is necessary to revisit and expand the present regulatory framework and design and implement appropriate monitoring and surveillance systems for early detection, prevention, mitigation, analysis and control of HABs and their negative health and economic effects. Citizen involvement could be used to boost reporting HABs in regions where less infrastructure for monitoring is available. HAB modelling and forecasting also plays a relevant role. The high degree of temporal and spatial patchiness and heterogeneity in species composition make these tools extremely challenging. This complexity is enhanced by the nonlinearity in the relationship between algal biomass and toxin production and the numerous environmental factors influencing bloom dynamics (often acting in opposing directions). Accurate models for predicting algal bloom formation and outbreaks of seafood poisoning diseases need to be developed, considering future climate change scenarios. Artificial intelligence and deep learning models could also support these predictions (FAO, 2020). Data sharing plays a fundamental role for preparedness. Omics approaches (genomics, transcriptomics, proteomics and metabolomics) can complement laboratory and field techniques for analytical detection of algal toxins and improved comprehension of the environmental and genetic control of toxin production. Importantly, prevention should go hand in hand with preparedness, and the most efficient method for avoiding HABs is improved water management and monitoring, which will prevent eutrophication.

Heavy metals also require urgent attention from public health authorities. The implementation of innovative biological, physical and chemical (or better, mixed) remediation approaches together with revisited regulatory standards should be considered. Methylated mercury is an especially dangerous derivative of Hg due to its ability to permeate biological membranes and its concentrations in the environments are increasing. Its interactions with other components of ocean ecosystems require further research and harmonised monitoring efforts are needed. Several follow-up steps are recommended to mitigate risks related to contaminants. Detailed toxicity assessments need to be performed, if not already conducted, especially for microplastics whose impact on human health is still not properly characterised. More research is needed on the transfer of toxins in the food chain and the impact of environmental conditions on toxin concentrations. Furthermore, analytical detection methods should be improved, which will allow for controlling contaminant levels in food and feed and implement large-scale monitoring programmes. Finally, education campaigns will improve the awareness of: (1) food sources that may contain harmful contaminants (aimed at consumers and sellers); and (2) symptoms of poisoning and treatment strategies (aimed at health professionals)

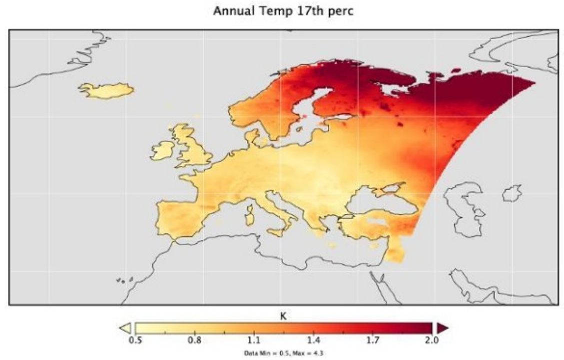
Nutritional quality

It is important to improve monitoring of micronutrients in current food systems. Research is needed aiming at understanding the relative contribution of climate change and yield-related shifts, different crop varieties (e.g. HarvestPlus and CGIAR breeding) and crop production system (soil type, climate smart agriculture, crop choice, livestock, fertiliser use) on crop quality. The IFPRI group and their IMPACT foresight model (PIMS programme) could be useful in this regard, it encompasses future climate, demographic, e.g. demand scenarios. Preliminary informal dialogues with experts lead to the appreciation of the lack of expertise and knowledge on the potential effects of climate change on micro and macronutrients availability in environmental matrices and food items. This is an area where further investigation could be needed. However, at the moment this is not perceived as a relevant issue in Europe also considering the observed overexposure to those nutrients. The experts warrant that caution is needed in interpreting what these data are showing. These changes in nutritional quality, intended as changes in the content of micro and macronutrients (e.g. zinc, iron, proteins) in food items, driven by climate change (according to the 'driver' definition provided in Section 1.1) may, in the long term, stimulate the development and introduction of novel foods (fortified foods, novel food proteins or breeding plant varieties less sensitive to climate-influenced variations in nutritional quality (Broadley et al., 2006)) or the emergence of new consumer habits. New foods and new habits will only be successfully introduced when appropriate education and awareness campaigns about nutrition are launched.

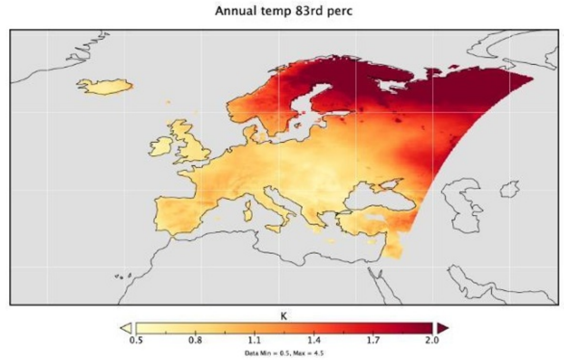
Appendix F – Climate change scenarios



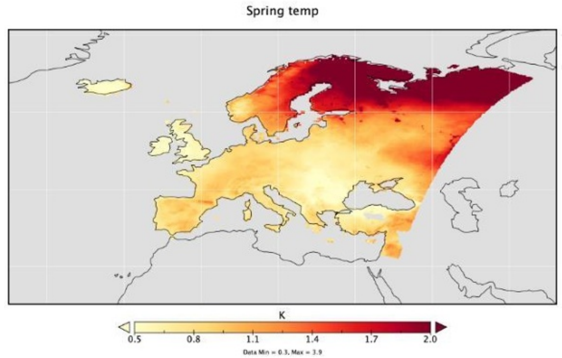
Annual unweighted average change in 2-metre air temperature (deg. C) between 'reference' (1981–2010) and 'near future' (2021–2050) periods.



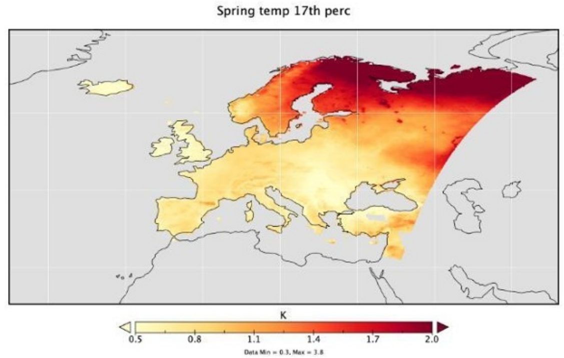
Annual 17th percentile change in 2-metre air temperature (deg. C) between 'reference' (1981–2010) and 'near future' (2021–2050) periods.



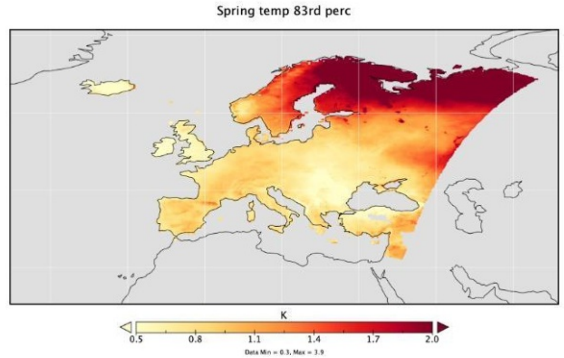
Annual 83rd percentile change in 2-metre air temperature (deg. C) between 'reference' (1981–2010) and 'near future' (2021–2050) periods.



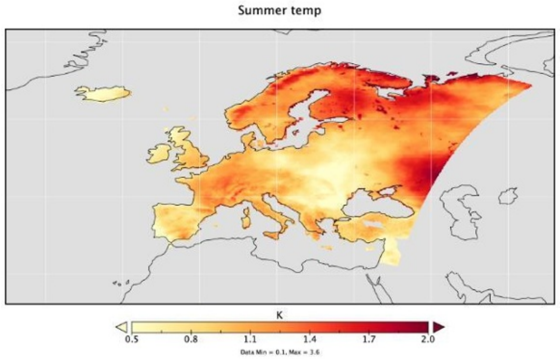
Spring unweighted average change in 2-metre air temperature (deg. C) between 'reference' (1981–2010) and 'near future' (2021–2050) periods.



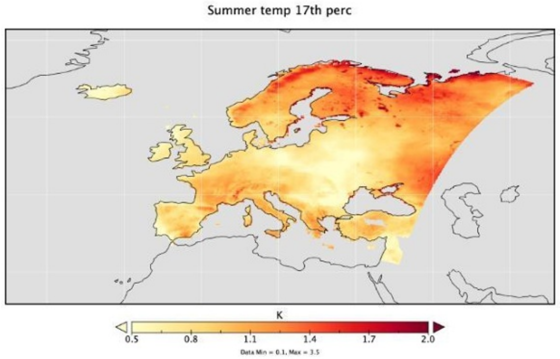
Spring 17th percentile change in 2-metre air temperature (deg. C) between 'reference' (1981–2010) and 'near future' (2021–2050) periods.



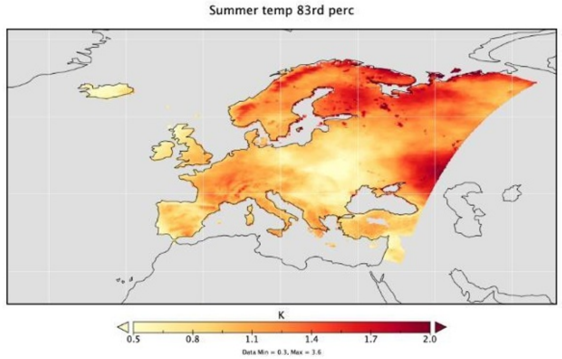
Spring 83rd percentile change in 2-metre air temperature (deg. C) between 'reference' (1981–2010) and 'near future' (2021–2050) periods.



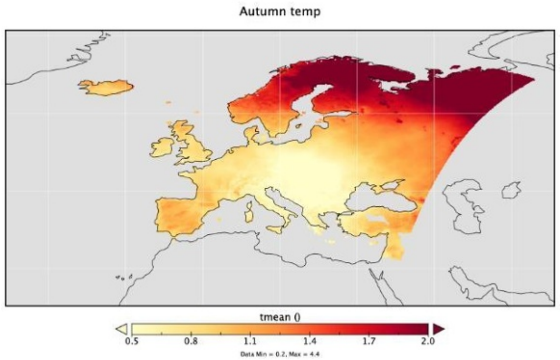
Summer unweighted average change in 2-metre air temperature (deg. C) between 'reference' (1981–2010) and 'near future' (2021–2050) periods.



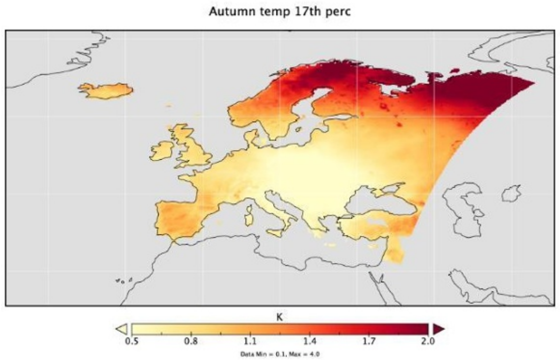
Summer 17th percentile change in 2-metre air temperature (deg. C) between 'reference' (1981–2010) and 'near future' (2021–2050) periods.



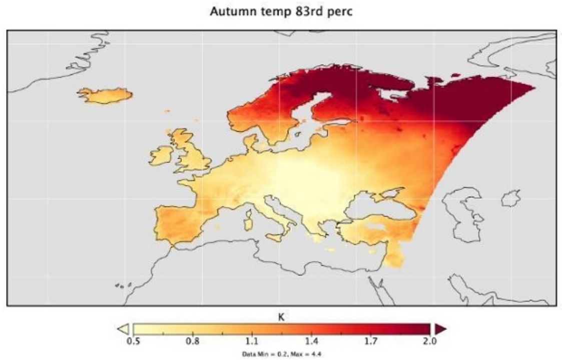
Summer 83rd percentile change in 2-metre air temperature (deg. C) between 'reference' (1981–2010) and 'near future' (2021–2050) periods.



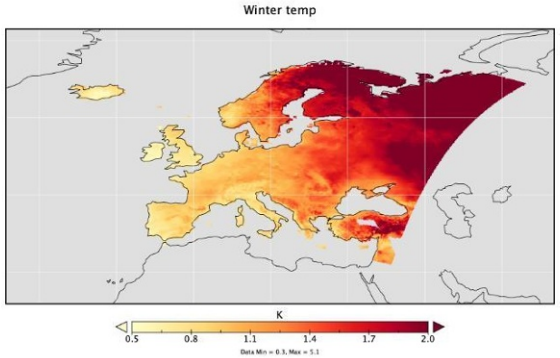
Autumn unweighted average change in 2-metre air temperature (deg. C) between 'reference' (1981–2010) and 'near future' (2021–2050) periods.



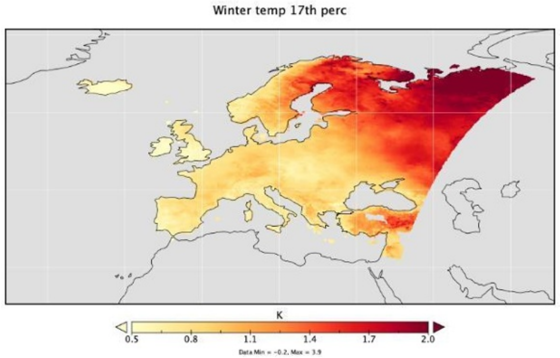
Autumn 17th percentile change in 2-metre air temperature (deg. C) between 'reference' (1981–2010) and 'near future' (2021–2050) periods.



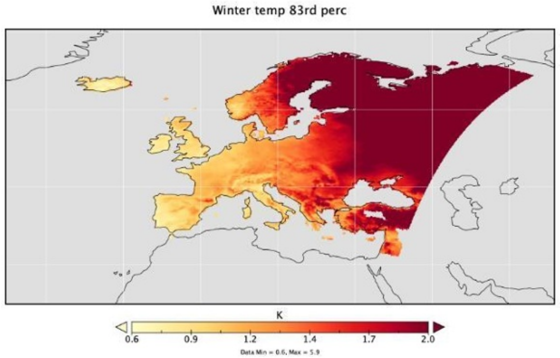
Autumn 83rd percentile change in 2-metre air temperature (deg. C) between 'reference' (1981–2010) and 'near future' (2021–2050) periods.



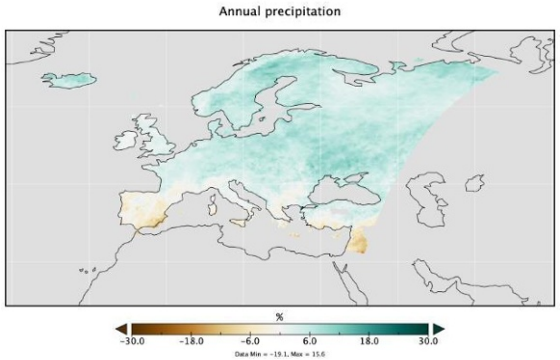
Winter unweighted average change in 2-metre air temperature (deg. C) between 'reference' (1981–2010) and 'near future' (2021–2050) periods.



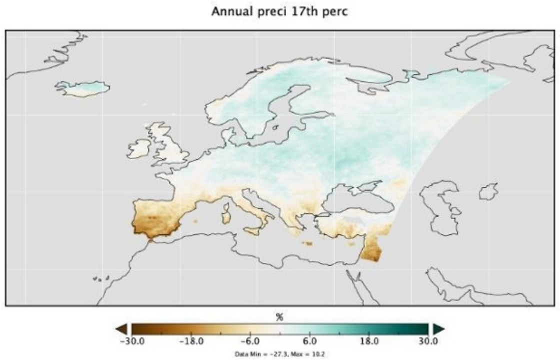
Winter 17th percentile change in 2-metre air temperature (deg. C) between 'reference' (1981–2010) and 'near future' (2021–2050) periods.



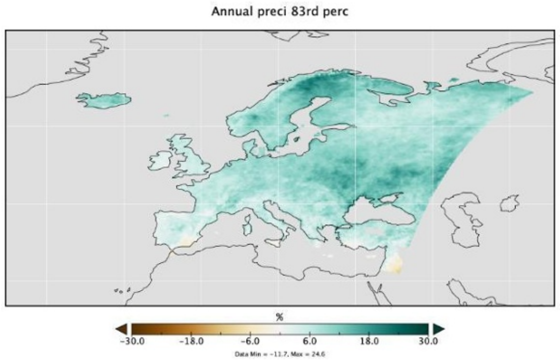
Winter 83rd percentile change in 2-metre air temperature (deg. C) between 'reference' (1981–2010) and 'near future' (2021–2050) periods.



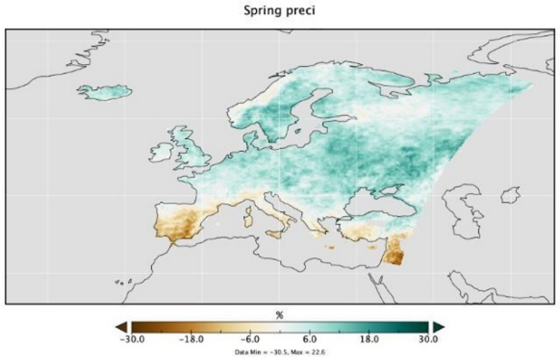
Annual unweighted average change in precipitation between 'reference' (1981–2010) and 'near future' (2021–2050) periods. Precipitation change is expressed in %.



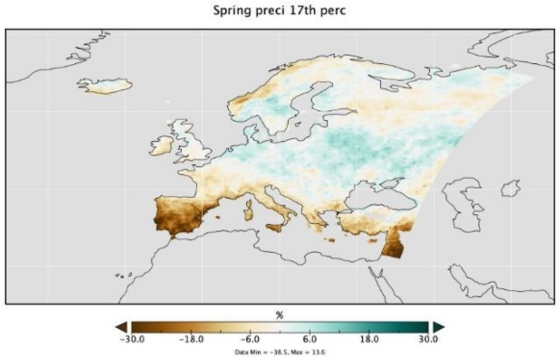
Annual 17th percentile change in precipitation between 'reference' (1981–2010) and 'near future' (2021–2050) periods. Precipitation change is expressed in %.



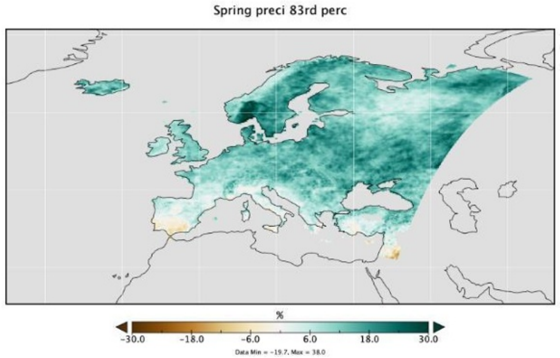
Annual 83rd percentile change in precipitation between 'reference' (1981–2010) and 'near future' (2021–2050) periods. Precipitation change is expressed in %.



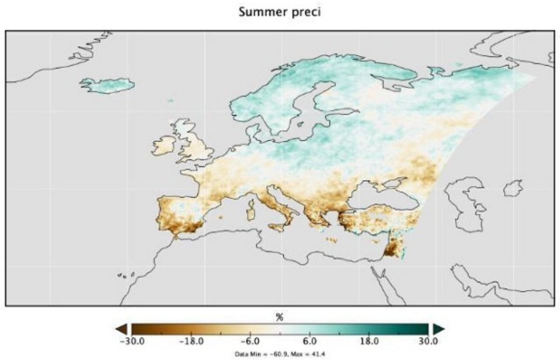
Spring unweighted average change precipitation between 'reference' (1981–2010) and 'near future' (2021–2050) periods. Precipitation change is expressed in %.



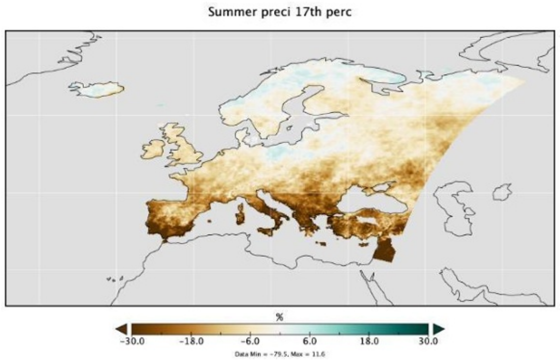
Spring 17th percentile change precipitation between 'reference' (1981–2010) and 'near future' (2021–2050) periods. Precipitation change is expressed in %.



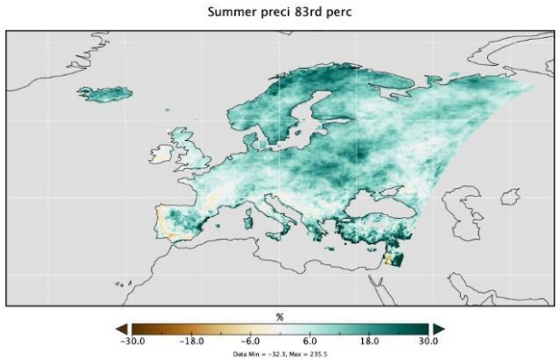
Spring 83rd percentile change precipitation between 'reference' (1981–2010) and 'near future' (2021–2050) periods. Precipitation change is expressed in %.



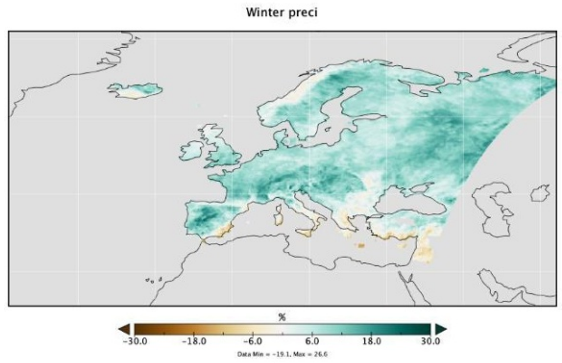
Summer unweighted average change precipitation between 'reference' (1981–2010) and 'near future' (2021–2050) periods. Precipitation change is expressed in %.



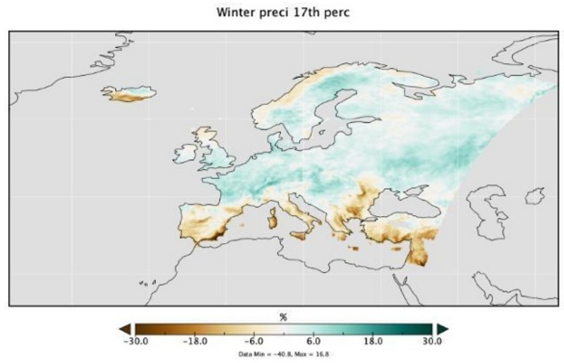
Summer 17th percentile change precipitation between 'reference' (1981–2010) and 'near future' (2021–2050) periods. Precipitation change is expressed in %.



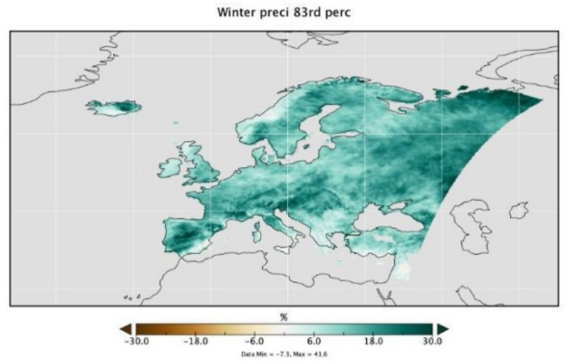
Summer 83rd percentile change precipitation between 'reference' (1981–2010) and 'near future' (2021–2050) periods. Precipitation change is expressed in %.



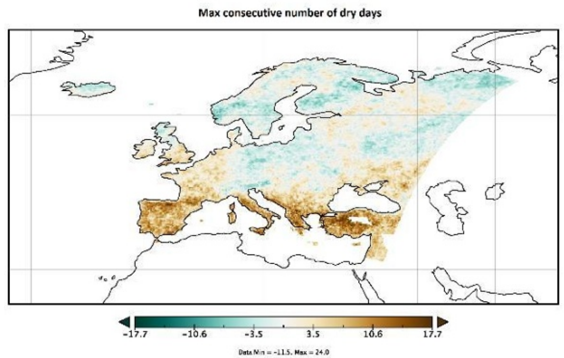
Winter unweighted average change precipitation between 'reference' (1981–2010) and 'near future' (2021–2050) periods. Precipitation change is expressed in %.



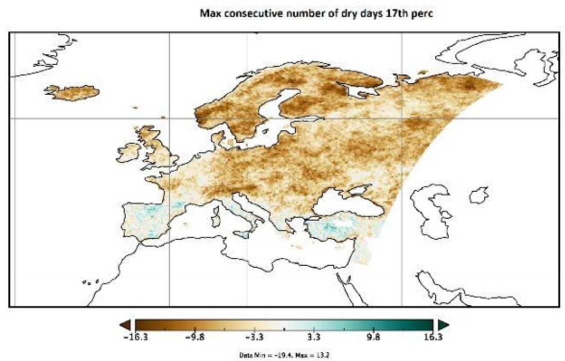
Winter 17th percentile change in precipitation between 'reference' (1981–2010) and 'near future' (2021–2050) periods. Precipitation change is expressed in %.



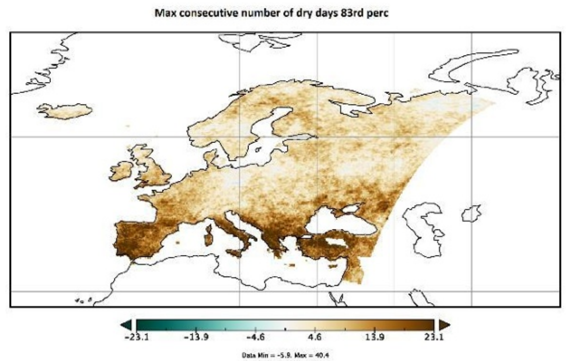
Winter 83rd percentile change in precipitation between 'reference' (1981–2010) and 'near future' (2021–2050) periods. Precipitation change is expressed in %.



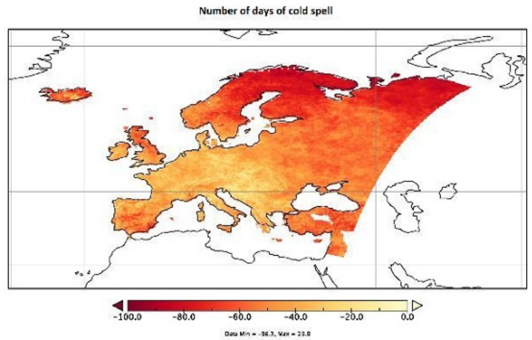
Unweighted average change in max consecutive number of dry days between 'reference' (1981–2010) and 'near future' (2021–2050) periods. The change is expressed in %. Dry day is defined as a day with precipitation less than 1 mm.



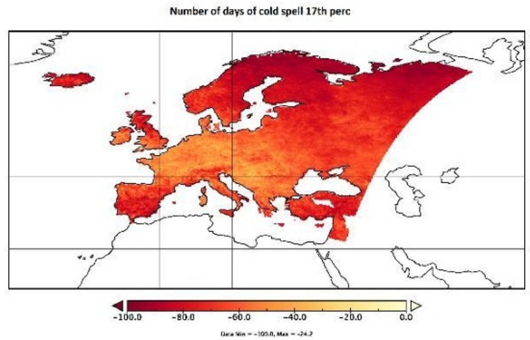
17th percentile of the ensemble changes in max consecutive number of dry days between 'reference' (1981–2010) and 'near future' (2021–2050) periods. The change is expressed in %. Dry day is defined as a day with precipitation less than 1 mm.



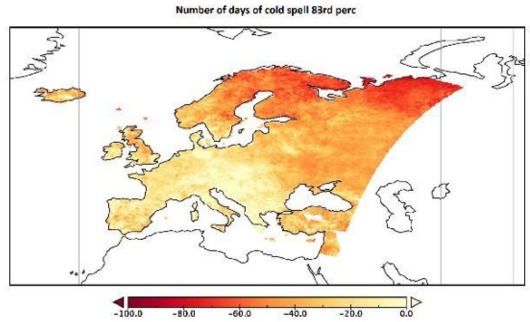
83rd percentile of the ensemble changes in max consecutive number of dry days between 'reference' (1981–2010) and 'near future' (2021–2050) periods. The change is expressed in %. Dry day is defined as a day with precipitation less than 1 mm.



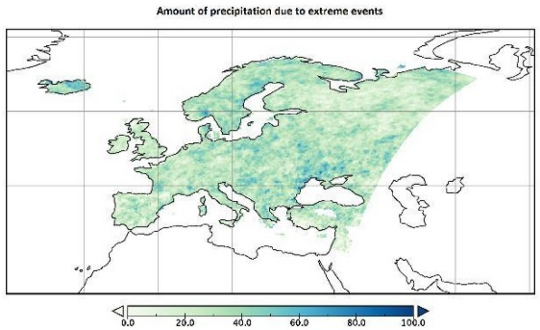
Unweighted average change in number of days of cold spell between 'reference' (1981–2010) and 'near future' (2021–2050) periods. The change is expressed in %. Cold spell is defined as at least 6 days with minimum temperature lower than its 10th daily percentile.



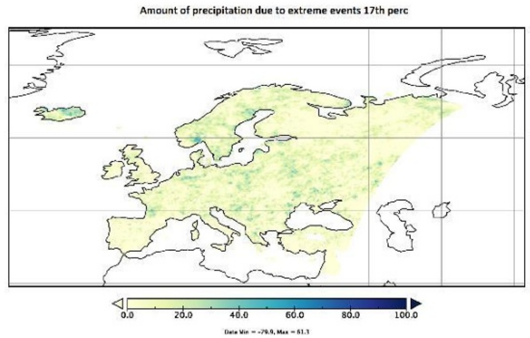
17th percentile of the ensemble changes in number of days of cold spell between 'reference' (1981–2010) and 'near future' (2021–2050) periods. The change is expressed in %. Cold spell is defined as at least 6 days with minimum temperature lower than its 10th daily percentile.



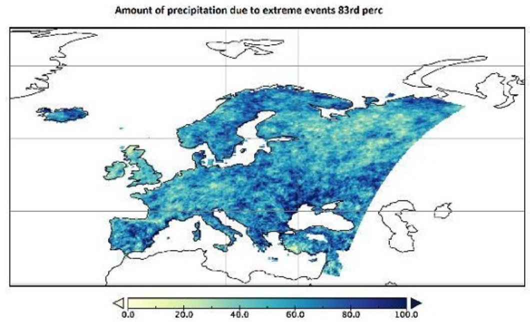
83rd percentile of the ensemble changes in number of days of cold spell between 'reference' (1981–2010) and 'near future' (2021–2050) periods. The change is expressed in %. Cold spell is defined as at least 6 days with minimum temperature lower than its 10th daily percentile.



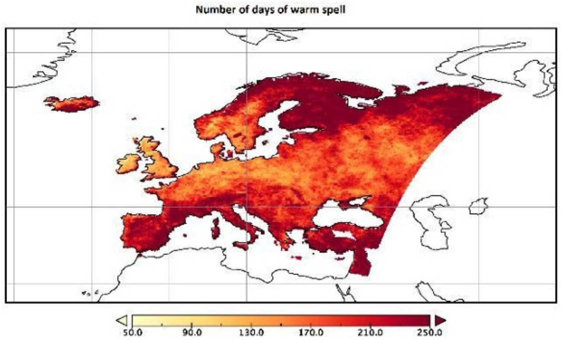
Unweighted average change in extreme precipitations between 'reference' (1981–2010) and 'near future' (2021–2050) periods. The change is expressed in %. Extreme precipitation events are defined as days having daily total precipitation higher than 99th daily percentile.



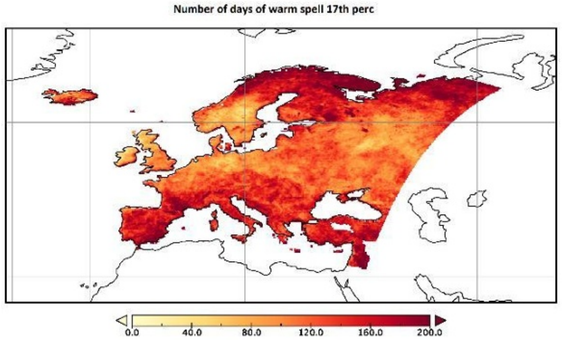
17th percentile of the ensemble changes in extreme precipitations between 'reference' (1981–2010) and 'near future' (2021–2050) periods. The change is expressed in %. Extreme precipitation events are defined as days having daily total precipitation higher than 99th daily percentile.



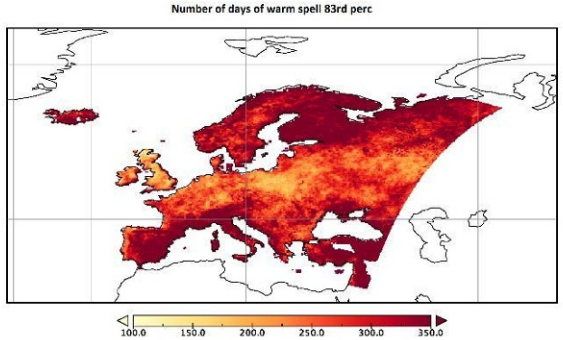
83rd percentile of the ensemble changes in extreme precipitations between 'reference' (1981–2010) and 'near future' (2021–2050) periods. The change is expressed in %. Extreme precipitation events are defined as days having daily total precipitation higher than 99th daily percentile.



Unweighted average change in number of days of warm spell between 'reference' (1981–2010) and 'near future' (2021–2050) periods. The change is expressed in %. Warm spell is defined as at least 6 days with maximum temperature higher than 90th daily percentile.



17th percentile of the ensemble changes in number of days of warm spell between 'reference' (1981–2010) and 'near future' (2021–2050) periods. The change is expressed in %. Warm spell is defined as at least 6 days with maximum temperature higher than 90th daily percentile.



83rd percentile of the ensemble changes in number of days of warm spell between 'reference' (1981–2010) and 'near future' (2021–2050) periods. The change is expressed in %. Warm spell is defined as at least 6 days with maximum temperature higher than 90th daily percentile.

Appendix G – EFSA's work related to climate change

Table 29: EFSA's past work related to climate change

EFSA's area	Organisms addressed by EFSA	Main EFSA products	Status	Link with climate change
Contaminants/Biotoxins	Dinoflagellates (in general) – *Gambierdiscus*	'Risk characterisation of ciguatera food poisoning in Europe' (http://www.aecosan.msssi.gob.es/AECOSAN/web/ciguatera/home/aecosan_home_ciguatera.htm)	Framework Partnership Agreement (2016 – ongoing)	Ciguatera fish poisoning (CFP) is typical of tropical and sub-tropical areas. Since 2008, CFP outbreaks have been reported in Spain (Canary Islands) and in Portugal (Madeira). Climate change could be one of the factors explaining the emergence of the outbreaks in Europe. The contractors will conduct a literature search and collection of data on environmental factors affecting bloom occurrence and toxicity, useful to the future development/calibration/validation of models aiming at predicting blooms of Gambierdiscus species, bioaccumulation in fish, CFP outbreaks in climate change scenarios.
	Cyanobacteria	'Review and analysis of occurrence, exposure and toxicity of cyanobacteria toxins in food' (https://www.efsa.europa.eu/en/supporting/pub/998e)	Procurement (2014)	Cyanobacterial blooms are expected to be more frequent, longer and more intense because of a combination of factors associated with climate change. The report analyses the environmental factors affecting the dominance, persistence and toxicity of cyanobacterial populations, for future development of predictive models. Temperature seems to positively influence the toxic fraction of the populations both in-field and in lab experiments, more than non-toxic fraction; this result suggests that in a future scenario of global warming, we could expect an increase in the toxic fraction of cyanobacteria population.
	Vibrio and other proteobacteria	'Risks for public health related to the presence of tetrodotoxin (TTX) and TTX analogues in marine bivalves and gastropods' (https://www.efsa.europa.eu/en/efsajournal/pub/4752)	Scientific Opinion (2017)	The recent detection of tetrodotoxin in European bivalve shellfish and marine gastropods has been linked to the spread of Vibrio parahaemolyticus, a marine bacterium responsible of shellfish poisoning whose growth is strongly dependent on rising seawater temperature.
	Aspergillus flavus and *A. parasiticus*	'Modelling, predicting and mapping the emergence of aflatoxins from Aspergillus flavus and A. parasiticus in maize, wheat and rice due to climate change'	Grant (2012)	Climate change affect the growth and metabolic activity of *Aspergillus flavus* and *Aspergillus parasiticus*, crop phenology and fungi-crop infection cycle. EFSA has developed maps of predicted aflatoxins risks in the EU in different temperature increase scenarios. The risk for aflatoxin contamination is expected to increase in maize in a +2°C temperature scenario

		(https://www.efsa.europa.eu/en/supporting/pub/en-223)		
	Various fungi	'Mycotoxin mixtures in food and feed: holistic, innovative, flexible risk assessment modelling approach'	Grant (2017 – ongoing)	This grant will study the impact of environmental variables related to climate change (temperature, pest attack, nutrient availability etc.) on mycotoxins production and their occurrence in food.
Biological hazards	Norovirus	'Technical specifications for a European baseline survey of norovirus in oysters' (https://www.efsa.europa.eu/en/efsajournal/pub/4414)	Scientific Report (2016)	Sewage network runoffs caused by heavy rainstorm and flooding. The link with climate change is possible, but not explicitly addressed by EFSA.
	Salmonella, *Campylobacter* and other zoonotic agents	'The European Union summary reports on trends and sources of zoonoses, zoonotic agents and food-borne outbreaks in 2017' (https://www.efsa.europa.eu/en/efsajournal/pub/5500)	Scientific Report (2018)	Many environmental variables such as temperature, rainfall, humidity levels and soil have been identified as relevant factors that explain partially the distribution and survival of zoonotic agents.
		'Analysis of the baseline survey on the prevalence of *Campylobacter* in broiler batches and of *Campylobacter* and *Salmonella* on broiler carcasses in the EU, 2008 – Part A: *Campylobacter* and *Salmonella* prevalence estimates' (http://www.efsa.europa.eu/en/efsajournal/pub/1503)	Scientific Report (2010)	Climatic conditions affect the reservoirs or vectors of *Campylobacter* in the environment such as, for example, insects and arachnids in the broiler production environment.
	Anthrax	'Fatal human case of *Bacillus anthracis* infection and bovine meat contamination in Bulgaria' (http://www.efsa.europa.eu/en/supporting/pub/en-863)	Technical report (2015)	

	Histamine	'Assessment of the incidents of histamine intoxication in some EU countries' (https://efsa.onlinelibrary.wiley.com/doi/epdf/10.2903/sp.efsa.2017.EN-1301)	Technical report (2017)	
Plant health		EFSA Scientific Colloquium XVI on Emerging Risks in Plant Health – from plant pest interactions to global change (http://www.efsa.europa.eu/sites/default/files/event/documentset/colloque110609sr.pdf)	Summary Report (2011)	The Colloquium was organised through four discussion groups dealing with the emergence of plant health risks at different scales: changes in pests, vectors and/or plants and their interactions as drivers of emerging plant health risks; changes in agriculture and forestry practices as drivers of emerging plant health risks; changes in trade, food consumption and land use as drivers of emerging plant health risks; climate change as a driver of emerging plant health risks.
	Arthropod vectors (*Culicoides* midges) and associated viruses	'Risks to plant health posed by *Bemisia tabaci* species complex and viruses it transmits for the EU territory' (https://www.efsa.europa.eu/en/efsajournal/pub/3162)	Scientific Opinion (2013)	Expansion of the outdoor area invaded by *B. tabaci* and increase in population density. EFSA has developed physiologically based population dynamics model with biodemographic T-dependent functions (physiologically based demographic models) to assess the area of potential establishment and spread under current climatic conditions and scenarios of climate change (T increase).
	Pomacea canaliculata and *P. maculata*	'Assessment of the potential establishment of the apple snail in the EU' (http://www.efsa.europa.eu/en/efsajournal/pub/3487)	Scientific Opinion (2014)	Natural spread occurs via rivers and canals, in which the snails crawl, drift, raft and float on floating material. Extreme weather events and flooding increase spread.
		'Pest risk assessment of *Spodoptera frugiperda* for the European Union' (https://www.efsa.europa.eu/en/efsajournal/pub/5351)	Scientific Opinion (2018)	The potential for establishment of *S. frugiperda* in Europe was modelled using ensemble predictions generated with a platform encompassing eight species distribution model (SDM) techniques that assessed the effects of climate and habitat on the distribution of the pest.
	Emerging risks in plant health	EFSA Scientific Colloquium N°16: Emerging Risks in Plant Health: from plant pest interactions to global change (https://www.efsa.europa.eu/it/events/event/colloque110609; https://efsa.onlinelibrary.wiley.com/doi/epdf/10.2903/sp.efsa.2011.EN-199)	EFSA Scientific Colloquium summary report (2011)	

	Pantoea stewartii subsp. *stewartii*	Risk assessment of the entry of *Pantoea stewartii* subsp. *stewartii* on maize seed imported by the EU from the USA (https://efsa.onlinelibrary.wiley.com/doi/epdf/10.2903/j.efsa.2019.5851)	Scientific Opinion (2019)	The PLH Panel highlights that the impacts of Stewarts's wilt in the USA are higher in growing seasons following mild winters. This implies that, should the pest establish and spread in the EU, impacts might worsen in the coming decades due to ongoing climate warming.
Animal health	Arthropods	'Vectornet: European network for sharing data on the geographic distribution of arthropod vectors, transmitting human and animal disease agents' (https://vectornet.ecdc.europa.eu)	2014	Changes in the distribution of vectors and pathogens in vectors. VectorNet is a joint initiative of EFSA and the European Centre for Disease Prevention and Control (ECDC). The project supports the collection of data on vectors and pathogens in vectors, related to both animal and human health. The link with climate change is possible but not explicitly addressed by EFSA.
	Arthropod vectors (*Culicoides* midges) and associated viruses	'bluetongue monitoring and surveillance' (https://www.efsa.europa.eu/en/efsajournal/pub/2192)	Scientific Opinion (2011)	Numerous and intensive vector surveillance programmes have mapped in detail the presence of *Culicoides imicola* in Morocco, Portugal, Spain, southern France, Italy, Bulgaria and Greece. The northernmost records of *C. imicola* are from just below 45°N. In the 1980s, *C. imicola* was identified in countries located to the north of the Mediterranean Sea. This finding is interpreted in some publications as evidence for its recent invasion of Europe, northwards from Africa and that it will continue to advance northwards under the influence of climate change.
		'Bluetongue: control, surveillance and safe movement of animals' (https://www.efsa.europa.eu/en/efsajournal/pub/4698)	Scientific Opinion (2017)	The seasonality of the vectors is influenced by climate and specific factors, such as conditions related to breeding sites. Since immature stages of *Culicoides* require humid conditions for developments, humidity and temperature appear to be the main regulating factors. *C. imicola* has been considered often as an expanding species, particularly related to climate change consequence, changes in the environment due to farm practices (i.e. irrigation) and/or climate change, may create new favourable breeding sites and increase the spread of this species in Europe.
	Avian Influenza virus	'Effect of biosecurity measures and early detection systems, mitigation measures and surveillance strategies on the spread of highly pathogenic avian influenza (HPAI) and low pathogenic avian influenza (LPAI) between farms' (https://www.efsa.europa.eu/it/supporting/pub/1142e)	External scientific report (2016)	In the past 20 years, climate change might have been a factor behind avian flu outbreaks and might play an even greater role in the future. Correlations have been reported between the occurrence of the virus in wild birds and environmental factors. Climate change might also favour conditions leading to virus mutation.

Blood-feeding insects, such as certain species of flies and mosquitoes, or ticks	'Lumpy skin disease: I. Data collection and analysis' (https://www.efsa.europa.eu/en/efsajournal/pub/4773)	Scientific report (2017)	The disease is present in many African countries. Since 2012, it has been spreading from the Middle East to south-east Europe, affecting EU Member States (Greece and Bulgaria) and several other countries in the Balkans. The risk of further spread of the disease is high. (Temperature and humidity and related vector abundance are among the main risk factors for lumpy skin disease (LSD) spread)
Bees	'Specifications for field data collection contributing to honeybee model corroboration and verification' (https://www.efsa.europa.eu/en/supporting/pub/en-1234)	Technical report (2017)	Collecting data from different years and sites within these zones will be made to ensure a variation in abiotic parameters (climate and weather).

Appendix H – Contribution to other initiatives

The CLEFSA project has contributed and intends to contribute to a wide range of initiatives at EU and UN level taking part or stimulating interagency and interinstitutional collaboration exercises. It has supported better informed decision making, identifying gaps in knowledge, facilitating vulnerability assessments and proposing methodologies for enhancing preparedness to current and future climate impacts. It falls within a global commitment in preventing, mitigating and responding to the health impacts of climate change (WHO, 2017).

A list of these activities is provided below:

- WHO activities and global strategy on health, environment and Climate Change[52,53,54,55] (WHO, 2018b, 2019).
- G7 Initiatives on 'Impact of Climate Change on food security and safety'.
- EU adaptation strategy[56] and the European Climate Adaptation Platform 'Climate-ADAPT'[57]. In particular, CLEFSA could contribute to enhance preparedness and capacity to respond to the impacts of climate change. It could support a better informed decision making, by improving the knowledge base on climate change impacts and raising awareness on impacts on food safety, as a fundamental health determinant.
- The IPCC activities, in particular its upcoming Sixth Assessment Report (AR6), Chapter 7: Health, wellbeing and the changing structure of communities (IPCC, 2019).
- EEA Reporting: 'Climate Change, impacts and vulnerability in Europe', 'Environment, health and wellbeing' and 'The European environment — state and outlook', 'Climate change adaptation in the agricultural sector in Europe (EEA, 2019)'.
- EEA European Environment Information and Observation Network (Eionet).
- FAO activities on Climate Change and Climate Smart Agriculture;.
- The development of collaborative initiatives like those proposed within the EU Risk Assessment Agenda, including the identification of priority areas for thematic grants.
- Priority Objective 5 of the 7th Environmental Action Programme (EAP) setting up the need to improve the knowledge and evidence base for Union environment policy, to ensure, *inter alia*, 'that (by 2020) the understanding of, and the ability to evaluate and manage, emerging environmental and climate risks are greatly improved'.
- The activities of the European Academies Science Advisory Council (EASAC) on climate change-related health impacts in Europe (EASAC, 2019).
- The activities of the EC Scientific Advice Mechanism (SAM) on Climate change and health.
- The activities of the EC agricultural European Innovation Partnership (EIP-AGRI)[58].
- The UN adaptation gap report on effectiveness of adaptation strategies (UNEP, 2018).
- The CLEFSA exercise could be incorporated into the EU Environmental Foresight System (FORENV).
- CLEFSA could contribute to the implementation of the European Green Deal 'Act on climate change'.

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[52] https://www.who.int/en/news-room/fact-sheets/detail/climate-change-and-health

[53] https://www.who.int/globalchange/mediacentre/news/cop24-event5Dec2018/en/
[54] http://apps.who.int/gb/ebwha/pdf_files/WHA72/A72_15-en.pdf
[55] http://www.euro.who.int/__data/assets/pdf_file/0004/355792/ProtectingHealthEuropeFromClimateChange.pdf?ua=1
[56] https://ec.europa.eu/clima/policies/adaptation/what_en#tab-0-0
[57] Climate-ADAPT is a partnership between the European Commission and the European Environment Agency. It is maintained by the EEA with the support of the European Topic Centre on Climate Change Impacts, Vulnerability and Adaptation (ETC/CCA). See https://climate-adapt.eea.europa.eu/
[58] https://ec.europa.eu/eip/agriculture/en

- CLEFSA could provide useful information for supporting the IPCC reporting cycle.
- CLEFSA initiative has contributed to the implementation of the GlobalHAB Science and Implementation Plan to visualise the need to understand and minimise the risks of HAB impacts to human and animal health related to climate change.

The CLEFSA project contributes to the elaboration of the EFSA Strategy 2027, in particular in envisaging the future of environmental risk assessment in EFSA, contributing to the climate action portfolio of the European Green Deal[59]. The newly envisaged strategic directions of the European Green Deal 'Act on climate change' may impact on the development of new strategies in the environmental risk assessment (ERA). While climate change has an impact on food safety, agriculture sectors also contribute to climate change with almost a quarter of total greenhouse gas (GHG) emissions (IPCC, 2019). Addressing the potential *impact on climate change* of regulated products in the EFSA's remit (application of plant protection products, deliberate release into the environment of GMOs, use of feed additives) and of quarantine pests harmful to plant health can also be achieved by advocating a comprehensive implementation of the Ecosystem Services approach in the problem formulation phase. Carbon sequestration and storage is one of the Regulating services. According to the Economics of Ecosystems and Biodiversity (TEEB)[60] classification of ecosystem services, carbon sequestration and storage can be defined as:

'Ecosystems regulate the global climate by storing and sequestering greenhouse gases. As trees and plants grow, they remove carbon dioxide from the atmosphere and effectively lock it away in their tissues. In this way forest ecosystems are carbon stores. Biodiversity also plays an important role by improving the capacity of ecosystems to adapt to the effects of climate change'. In order to address the impact on climate change in the ERA through the ecosystem services framework, it is therefore possible to:

- evaluate the impact on carbon sequestration and storage (EFSA PLH Panel, 2014);
- identify relevant units (e.g. plant species) providing this service for which to derive Specific Protection Goals options.

In relation to the use of feed additive, indirect effects could be considered like the emission of greenhouse gases (GHG) from livestock animals, where air quality could play the role of environmental protection goal. In the context of the 'farm-to-fork' and 'green deal' strategies envisaged by the European Commission, the ambition could be potentially raised, in cooperation with other relevant players, in order to:

- support in the elaboration of methodologies for comparatively assessing the impact of different 'agricultural practices' and 'diets', in terms of impacts on climate change (e.g. GHG emissions/abatement, land use etc.);
- life cycle assessment of regulated products;
- 'farm-to-fork' ERA of food items.

[59] https://ec.europa.eu/commission/sites/beta-political/files/mission-letter-frans-timmermans-2019_en.pdf
[60] http://www.teebweb.org/resources/ecosystem-services/