European Commission

JRC EXTERNAL STUDY REPORT

Risks and vulnerabilities in the EU food supply chain

Mapping and analysis based on a stakeholder survey

Bertolozzi-Caredio, D., Severini, S., Pierre, G., Zinnanti, C., Rustom, R., Santoni, E., Bubbico, A.

2023

Contact information
Name: Juan Tur Cardona
Address: C/ Inca Garcilaso, 3, 41092 Seville, Spain
Email: juan.tur-cardona@ec.europa.eu

EU Science Hub
https://joint-research-centre.ec.europa.eu/jrc

JRC135290

PDF ISBN 978-92-68-08066-5 doi:10.2760/171825 KJ-04-23-968-EN-N

Luxembourg: Publications Office of the European Union, 2023

How to cite this report: Bertolozzi-Caredio, D., Severini, S., Pierre, G., Zinnanti, C., Rustom, R., Santoni, E. and Bubbico, A., *Risks and vulnerabilities in the EU food supply chain*, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/171825, JRC135290.

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Abstract

This study investigates the risks and vulnerabilities affecting food supply and food security in the EU, including differences across Member States, sectors and stages of the EU food supply chain. The study uses data from a systematic literature review, semi-structured interviews and an online survey of key stakeholders, and employs qualitative and quantitative methods to analyse risks and vulnerabilities. It finds that the EU food supply chain faces a broad range of risks and sheds light on the factors that make it vulnerable to these risks. The analysis identifies key characteristics of risks, such as origin, time horizon, likelihood of occurrence, potential impact and exposure. Key risks to food supply and food security are highlighted, as are the main risks threatening different Member States (including the outermost regions) and the different sectors and stages of the EU food supply chain. Emerging risks that warrant further attention are also identified. The study provides a basis for strategic decision-making by highlighting the sources of risks and potential areas of intervention to reduce the vulnerabilities of the food supply chain. Its findings will support EU policymakers, particularly within the European Food Security Crisis Preparedness and Response Mechanism, in improving the preparedness of the EU food supply chain for future crises.

Acknowledgements

The authors of this study would like to acknowledge the productive coordination with, and the continuous support provided by, the European Commission, and particularly by the Joint Research Centre and the Directorates-General for Agriculture and Rural Development, Maritime Affairs and Fisheries, and Health and Food Safety, during the implementation of the study.

The authors would also like to acknowledge the valuable contribution provided by the members of the Expert Group on the European Food Security Crisis preparedness and response Mechanism and by all other stakeholders that participated in the study.

Lastly, the authors would like to thank their colleagues involved in the organisation and conduction of interviews, notably Francesco Iadecola, Ines Pacheco, Hannah Wille, Pol Diestre, Joshua Wilson, Alexandre Mohamedaly, Nedyalka Dimitrova, Monika Sochaczewska and Preslav Petkov. The authors also thank Olivier Chartier and Vladimir Cvijanovic for conducting the quality control of this report.

Authors

Daniele Bertolozzi-Caredio ([1]), Simone Severini ([2]), Guillaume Pierre ([1]), Cinzia Zinnanti ([2]), Ralph Rustom ([1]), Eleonora Santoni ([1]) and Antonio Bubbico ([1]).

([1]) *Ecorys Brussels NV*

([2]) *Università degli Studi della Tuscia, Department DAFNE (Viterbo, Italy)*

Executive Summary

Policy context

In response to the increasing uncertainty and challenges threatening EU food systems, the European Commission adopted the Contingency plan for ensuring food supply and food security in times of crisis, with the aim of setting up the coordination of a common European response to crises. The European Commission established the European Food Security Crisis preparedness and response Mechanism (EFSCM), a group of Member States representatives, stakeholder organisations from the EU food supply chain and experts from neighbouring and non-EU countries, coordinated by the Commission to exchange data and practices and strengthen coordination. As part of the contingency plan, the European Commission requires the mapping of the risks and vulnerabilities, including structural issues, in the EU food supply chain and its critical infrastructures through a dedicated study. This study aimed to provide a comprehensive picture of the range of perceived risks and vulnerabilities that may affect food supply and security in the EU. The findings of this study lay down the basis for further discussion and analysis of the risks and vulnerabilities in the EU food supply chain. In particular, they will support the EFSCM in formulating recommendations to address or mitigate risks and vulnerabilities.

Key conclusions

A wide range of risks can affect the food supply. Based on our Risk Index, Economic and market and Biophysical and environmental risk types stand out as prominent threats to the EU food supply overall. However, relatively novel risks emerge from the stakeholder perspective. For instance, risks related to cybersecurity, new technologies, pests and diseases, are being increasingly recognised by stakeholders, even though they are less studied in the literature than other risk types. These emerging risks will require further attention in the future.

Risks are perceived beyond the 'usual' segments of the supply chain that are typically affected by them. Risks related to climate, water scarcity and degradation concern several stakeholders other than food producers, whereas stakeholders at different stages of the supply chain flag risks related to generational renewal, which so far has been mostly linked to agricultural and fishery production. Risk perceptions differ across EU countries, sectors, and stakeholders, highlighting the complexity of setting up a coordinated and comprehensive preparedness strategy in the EU. For example, while southern Europe appears to be more affected by Biophysical and Environmental risks, eastern Europe and island Member States seem to be more affected by Supply chain performance risks, and the south-eastern part of the EU is more affected by Socio-cultural and Demographic risks.

The EU food supply chain seems to be vulnerable to the risks identified to varying extents. While nine structural factors determining such vulnerability were identified, none of them appears to be the most relevant overall. Instead, the relevance of each structural factor is contingent on the type of risk.

The significant diversity among the risks identified suggests that an array of strategies could be needed to prevent, prepare for, or cope with future risks and crises. Strategies such as diversification, strategic autonomy or shorter supply chains can play a role. Given the unique risk profiles of the outermost regions of the EU, an ad hoc strategic approach may be required for these regions, while emerging and rapidly growing risks may need increasing efforts and novel instruments.

Future work

This study built on stakeholders' perceptions elicited through interviews and surveys. To complement this study, future research may focus on measurements of objective risks and their impacts. Moreover, this study focused on risk identification and assessment, but did not analyse the possible risk management strategies and interventions. Future work may focus on the risk management and strategic actions to build the preparedness of EU food systems. Importantly, the new or emerging risks identified in this study may deserve increasing attention, as they may translate into major threats in the medium term. This is the case, for example, for cybersecurity and technological risks. Finally, future research should evaluate the risks and vulnerabilities impacting diverse food systems, such as those reliant on local, short supply chains versus globalized, long supply chains.

Quick guide

The methodology of this study relied on qualitative and quantitative analytical methods using data collected through a systematic literature review, semi-structured interviews, and an online survey. Content and frequency analyses were conducted on the reviewed literature and the interviews. Quantitative analyses, including

frequency analysis, perception-based Likert-scale analysis, and econometrics, were conducted on data from the online survey. Based on the survey data, risk indicators were constructed to assess and prioritise risks.

The first step of the study was to define a risk typology based on the reviewed literature and interviews. This resulted in 28 risk categories, which were further grouped into six risk types. For all risk categories, risk characteristics including origin, time horizon of occurrence and relative importance were measured through frequency analyses, whereas the potential impact of, likelihood of occurrence of and degree of vulnerability to risks were measured using numerical scales. Linear regression analyses were employed to assess the correlation between the factors of vulnerability and the degrees of vulnerability to the different risk types. A risk exposure indicator was obtained by combining potential impact and likelihood of occurrence, while an overall Risk index was derived by combining risk exposure and degree of vulnerability in order to identify key risks warranting more attention. The findings from the analyses of quantitative indicators were triangulated with those from the content analysis of the interviews, and the review of the literature.

The study relied on the collection of qualitative and quantitative data based on stakeholders' perceptions. Therefore, the analysis was affected by some limitations. In particular, the sample of participants had a heterogeneous composition, whereas the perceived risks cannot measure objective risks, and perceptions can be influenced by recent events.

1 Introduction

1.1 Context of the study

With the growing impact of climate change and environmental degradation on food production, as well as risks related to public health, cyber threats and geopolitical shifts threatening the functioning of the global food supply chain, EU initiatives to ensure food supply and security in the EU are ever more relevant. The strategic importance of food security and the resilience of EU food systems is acknowledged in the European Commission's 2022 strategic foresight report (European Commission, 2022a). Growing attention has been paid to understanding the risks affecting food systems and to setting up effective risk management instruments (Poljansek et al., 2021; European Commission, 2018). More recently, a study by the European Parliamentary Research Service (2022a) highlighted relevant risks and issues for food supply and security, such as the COVID-19 pandemic, the Russia's unprovoked invasion of Ukraine, the disruption of supply chains and extreme weather events. In addition, a recent discussion paper by the European Policy Centre (European Policy Centre, 2022) casts light on the relationship between the energy and food crises in the context of the Russian war of aggression against Ukraine.

Preparing the food supply chain for future challenges is now at the top of the EU's policy agenda. Following the Farm to Fork strategy and building on the lessons learned from the COVID-19 pandemic, in November 2021 the Commission adopted the Communication "Contingency plan for ensuring food supply and food security in times of crisis" (European Commission, 2021a) with the aim of setting up the coordination of a common European response to crises affecting food supply and food security. This contingency plan embraces a collaborative approach between all public and private parties that are part of the food supply chain.

To this end, the European Commission established the European Food Security Crisis preparedness and response Mechanism (EFSCM), a group of Member State representatives, stakeholder organisations from the EU food supply chain and experts from neighbouring and non-EU countries, coordinated by the Commission to exchange data and practices and strengthen coordination. The contingency plan is being rolled out by the EFSCM.

The EFSCM focuses on specific activities and a set of actions to be completed between mid 2022 and 2024, including: (i) foresight, risk assessment and monitoring to improve preparedness by making use of available data (including on weather, climate, markets) and further analysis of vulnerabilities and critical infrastructure of the food supply chain; and (ii) coordination, cooperation and communication by sharing information, best practices and national contingency plans; developing recommendations to address crises; and coordinating and cooperating with the international community.

As part of the contingency plan, the Commission requires the mapping of the risks and vulnerabilities, including structural issues, in the EU food supply chain and its critical infrastructures through a dedicated study.

1.2 Objectives and scope of the study

Various studies are available in the literature on the analysis of crises affecting the food supply chain (for an overview, see Matthews, 2021). However, the relevant literature lacks a systematic review of threats and vulnerabilities, their likelihood of occurrence and their potential impact on the EU food supply chain. This study aims to narrow the current knowledge gap on risks and vulnerabilities in the EU food supply chain that threaten food supply and security in the EU, by outlining a profile of the heterogeneity of risk and vulnerabilities across different sectors and stages of the food supply chains. Ultimately, the study will support the EFSCM and the European Commission in increasing the preparedness of EU food systems for future challenges. This study serves as a basis for deeper analyses and to provide relevant insights for the policy-making process.

The objective of this study is to map and assess risks and vulnerabilities affecting EU food supply and safety and their heterogeneity across sectors, stages of the supply chain, and Member States. The study pursues three specific objectives, namely:

I. to identify and characterise potential risks affecting EU food supply and security across sectors, stages of the supply chain, and Member States, and define a risk typology;

II. to assess the vulnerability of the EU food supply chain in relation to the risks identified and define the factors determining such vulnerability;

III. to identify the key risks threatening the most the EU food supply chain.

It is important to highlight that this study intends to provide a mapping and assessment of perceived risks, and not to identify and evaluate the strategies to deal with them. As such, the study does not cover risk management.

The geographical scope of the study covers the EU-27, including the outermost regions ([1]). However, the study also involved stakeholders from associated or neighbouring countries, such as Kosovo ([2]), Norway, Switzerland, Ukraine the United Kingdom, as well as international organisations.

The respondents targeted in the study were food supply chain' stakeholders, including private companies and stakeholders' organisations, national and EU competent authorities, researchers and academics, non-governmental organisations (NGOs) and international organisations.

The study covers all relevant sectors of the food supply chain: fishery and aquaculture products; dairy and other animal products (including eggs, honey); meat products and their preparations; fruits and vegetables and their preparations; beverages and alcoholic drinks; cereals, legumes and oleaginous products and their preparations; sugar and miscellaneous products (including cocoa, coffee, tea and spices) and their preparations. It also covers the following stages of the food supply chain: input suppliers; primary producers (farmers and fishers); food processors; packaging operators; logistics operators (including transport and storage operators); wholesalers and traders; and retailers.

1.3 Definitions: key concepts underpinning the study

This study seeks to map and analyse risks and vulnerabilities threatening food supply and security in the EU. The concepts of risk, vulnerability and food security underpin the analyses performed in this study and are defined as follows:

Risk and crisis

A risk is an uncertain circumstance that can result in negative consequences for a potential outcome (Hardaker et al., 2015; Chavas, 2004). Risk involves exposure to potential losses during the achievement of an objective (e.g. the supply of secure food in the EU) with a potential impact and a certain likelihood of occurrence. Some risks can lead to crises. A crisis is an event, or a series of events, that causes a major disturbance. A crisis typically occurs suddenly and poses intense difficulty or danger for the whole business involved in the system. The European Commission (European Commission, 2020a; European Commission, 2005) states that qualifying conditions for an event to be considered as conducive to a crisis in the food system are that it (i) is unforeseen, (ii) exceeds the individual capacity to cope, and (iii) affects a large number of operators.

Vulnerability

The vulnerability of a food supply chain relates to its incapacity to respond to the negative impacts deriving from risks. Vulnerability originates from the concurrent circumstances of exposure to risk(s) with a certain potential impact and likelihood of occurrence, on the one hand, and a certain (in)capacity of a system to address these risk(s), on the other hand. Hence, vulnerability is contingent on the occurrence of a certain risky event. Consequently, vulnerability analysis suggests two main intervention options (FAO, 2008): (i) reduce the degree of exposure to risks and/or (ii) increase the ability to cope with the risk. Resilience and vulnerability are two faces of the same coin. These concepts are opposite and inversely proportional to one another: the higher the vulnerability, the lower the resilience, and vice versa (Matthews, 2021).

Food supply and food security

Food security exists when all people, at all times, have physical and economic access to the sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life (FAO, 2021; World Food Summit, 1996). Three components of food security are: (i) availability (having sufficient quantities of appropriate food), (ii) access (having adequate income or other resources to acquire food), and (iii) utilisation/consumption (having adequate dietary intake and the ability to absorb and use nutrients in the body) (Chijioke et al., 2011).

([1]) The EU's outermost regions – Guadeloupe, French Guiana, Martinique, Mayotte, Réunion and Saint Martin (France); the Azores and Madeira (Portugal); and the Canary Islands (Spain) – are nine EU regions located in the Atlantic and Indian Oceans, in the Caribbean basin and in South America.

([2]) This designation is without prejudice to positions on status, and is in line with UNSCR 1244/1999 and the ICJ Opinion on the Kosovo declaration of independence.

Food supply refers to the production and processing of food products and distribution of those products to consumers through the market (European Commission, 2021a). Food supply chains aim to supply (secure) volumes of food and are therefore central in operationalizing food security. A food supply chain is the network of organisations linked through upstream (input suppliers and primary producers) and downstream (processing and distribution) processes and activities that produce value in the form of food for final consumption. Threats to supply chains mainly affect food security by reducing the availability of food. However, factors that affect access and/or consumption could also affect food security, for instance by affecting affordability and safety.

2 Methodology

2.1 General approach

This study provides a risk assessment of the EU food supply chain and food security in the EU. The approach of the study was built on the relevant recommendations provided by the recent studies of the Joint Research Centre (JRC) and the International Organisation for Standardisation (ISO), including the 'Recommendations for National Risk Assessment' (Poljansek et al., 2021), the 'Contingency Plan for Ensuring Food Supply and Food Security' (Matthews, 2021); the ISO 'Risk Assessment Techniques' (ISO, 2019), and the 'Overview of Disaster Risk in the EU' (De Groeve et al., 2013).

Our general approach to risk assessment consists of two steps: risk identification and risk analysis. To note that our approach does not include risk management, as the scope of this study does not cover it. Risk identification is the process of determining the risks that could potentially prevent a system from achieving its objectives. The purpose of risk identification is to find, describe and categorise risks that a system would like to reduce using existing risk information. This step includes the identification of the factors determining the supply chain's vulnerability to the risks identified.

While the process of risk identification produces a list of risks, risk analysis is a process aimed at the characterisation and prioritisation of the risks identified. Risk analysis is about selecting risks that warrant further attention. It involves examining the main properties of the risks identified, including their potential impact and likelihood of occurrence and the supply chain's vulnerability to them, and prioritizing the risks according to the analysed properties.

The methodology of this study relies on qualitative and quantitative analytical methods using data collected through a systematic literature review, semi-structured interviews, and an online survey. Content and frequency analyses are conducted on the reviewed literature and the interviews. Quantitative analyses, including frequency analysis, perception-based Likert-scale analysis, and econometrics, are conducted on data from the online survey. Based on the survey data, risk indicators were constructed to assess and prioritise risks. Data collection and analysis are explained in the following sections. More details on the methodology are reported in Annex 1.

2.2 Data collection

The risk assessment performed relied on three data collection activities, namely a systematic literature review of scientific and institutional sources, semi-structured interviews, and an online survey consultation. The literature review and semi-structured interviews first served to identify the potential risks and vulnerabilities and to build up a database of risks and vulnerabilities. The analysis then drew upon information from all three data sources.

The aim of the systematic literature review, which resulted in the screening of 101 scientific papers and 38 institutional documents, was to identify a set of risks and vulnerabilities previously identified in research or by policymakers. The list of documents analysed is reported in Annex 2 and the keywords used for the search in Annex 3. The 152 semi-structured interviews conducted aimed at identifying and describing the risks and vulnerabilities perceived by food supply chain stakeholders. The online survey, in which 278 stakeholders participated, aimed to quantify different characteristics of the identified risks and vulnerabilities, including likelihood of occurrence, potential impact, and vulnerabilities. The questionnaire used for the interview is provided in Annex 4, and the questionnaire used for the online survey is provided in Annex 5.

The participants of the semi-structured interviews and the online survey included representatives of private businesses and stakeholders' organisations, representatives of EU agencies and national competent authorities, researchers and academics, and representatives of NGOs and international organisations. The participants belonged to different sectors and stages of the food supply chain and represented all 27 Member States and some associated and neighbouring countries. The composition of the sample of participants is provided in Annex 6.

2.3 Data analysis

The analysis of risks and vulnerabilities relied on quantitative and qualitative methods, based on the information collected from the three data collection activities of the study. Data from different sources, however, have been treated separately. The analysis consisted of four steps.

The definition of the risk types and the factors of vulnerabilities was the first step of the analysis. Risk types were defined based on a three-tiers approach. The literature review and the interviews provided a long list of 1 516 risks (first-tier). This long list of risks was cleaned up to remove duplicates and went through two additional rounds of aggregation: the first producing a list of 108 risks (second-tier), and the second producing a shorter list of 28 risk categories (third-tier). Based on these 28 risk categories, and drawing upon previous relevant categorisations (European Commission, 2023a; Matthews, 2021), six risk types were defined. Factors of vulnerability were also defined. The respondents to the semi-structured interviews were asked to describe the vulnerabilities affecting their sectors. Nine main factors of vulnerability were defined through the inductive analysis of this descriptive information (i.e. as emerging from data without preconceived categories). The factors of vulnerability, therefore, logically group aspects of vulnerability belonging to the same class of issue together.

In the second step, the risks identified were analysed to explore different risk properties. Frequency analyses were applied based on the literature review, the interviews, and the online survey, to assess the frequency of identification, the perceived origin of risks from four categories (domestic, intra-EU, extra-EU, global) and the perceived time horizon of occurrence (within 1, 5, 10 and 20 years). Based on the online survey, the potential impact and the likelihood of occurrence of the risks were measured on a scale from 0 to 10 (with 10 being the highest impact/likelihood); average values were used for the analysis. Risk exposure was derived from the combination of potential impact and likelihood of occurrence values and, hence was measured on a scale from 0 to 100. The risk analysis findings were triangulated with the findings from the content analysis of the literature, in order to substantiate findings.

Third, an analysis of vulnerabilities was performed. Based on the results of the interviews, a frequency analysis was applied to assess the vulnerability to different risks across four levels: low, moderate, high, and extreme. These were compared with the degrees of vulnerability perceived by survey respondents, which were scored on a scale from 0 to 10 (with 10 being the highest degree of vulnerability). Linear regressions were employed to assess the correlation between the factors of vulnerability and the degree of vulnerability to the different risk types.

In the fourth and final step, an analysis was conducted to identify key risks warranting more attention. The analysis builds on the triangulation of the Risk Index, content analysis of the interviews, and review of the literature. The Risk Index, which was used to compare the relevance of different risks, was computed by combining risk exposure and the degree of vulnerability as perceived by survey respondents, and was normalised on a scale from 0 to 100.

2.4 Limitations of the study

The study relied on the collection of qualitative and quantitative data from multiple sources, with different stakeholders participating in the data collection activities. Therefore, the analysis underpinning the study was affected by a number of limitations, which need to be considered when interpreting the results. First, respondents were not drawn at random from a representative sample, thus preventing a statistically representative analysis. However, basic analytical techniques (e.g. frequency and means analysis) remain reliable under such conditions, and specific stakeholder groups (e.g. by country or sector) are referred to throughout the analysis when relevant, in order to account for the potential influence of specific sub-groups. The comparison between the frequency of identification of risks in the literature and in the interviews (see Section 3.2), though, was limited by the differing sources of information used and actors involved, therefore, results should be interpreted with caution.

Although the sectoral and geographical coverage of the sample is heterogenous, with all EU Member States and sectors and stages of the supply chain covered, the extent of coverage varies (see sample composition in Annex 6). This is particularly evident in the case of Spanish respondents to the online survey, who responded to 98 out of the total 278 surveys collected. To address this, country weighting factors were applied for the analysis of average impact, likelihood and exposure presented in Chapter 3 and the analysis of the risk index presented in Sections 4.2.3 and 4.2.4. Weighting factors eliminate the cross-country differences in sample composition (i.e. all countries count the same when computing average values), which avoids deviations of results due to over-represented countries.

Moreover, the perception and understanding of complex concepts such as risk and vulnerability might have differed among respondents. First, perceived risks are not actual, objective risks. Secondly, perceptions are influenced by events and can therefore vary overtime. For instance, recent events linked to the Russian war of aggression against Ukraine or the COVID-19 pandemic are likely to have influenced risk perceptions. Yet, the use of perception-based quantifications is common practice when certain risk properties are difficult to quantify

by other means. All interviewees were given instructions and provided with an explanatory background document prior to their interviews, and questions in the online survey were supported by explanations to align, to the extent possible, respondents' understanding. To increase the robustness of the analysis, quantitative results were also substantiated with qualitative evidence when relevant. However, it is important to remark that this study was not meant to provide quantifications of the actual (potential) damages caused by materializing risks or the potential impact of crises. As such, no indication on (policy) intervention areas can be derived based on the potential impacts.

The analysis of risk correlations was not conducted for two main reasons. First, this is due to the limited sample size. Secondly, because the correlation in terms of frequency of identification or perceived risk impact has limited ability to reflect the actual causality among risks.

Lastly, the study did not assess the risks and vulnerabilities associated with various types of food systems, including, for example, territorial and short supply chain-based systems, or export-oriented and long supply chain-based systems. Differences may exist between these food systems, which are not captured by the study.

3 Maps of risks and vulnerabilities

This chapter first presents an overview of the risk types and factors of vulnerability as defined in this study, which provided a basis for the subsequent analyses. It then presents the risk characteristics, organised by risk type. Lastly, an analysis of vulnerabilities is provided.

3.1 General overview of risks and vulnerabilities identified

3.1.1 Risk types

This section presents the typology of risks used in the report. Risk types and categories were defined through multiple aggregation rounds. An exhaustive and detailed list of risks was built according to the reviewed literature and the semi-structured interviews (interviewees were asked to mention the different risks potentially affecting their sectors). From this exhaustive list, 28 clustered risk categories were identified, which were further grouped into six broad types of risks. Each risk type groups several risk categories, pertaining to the same topics or issues. The six risk types, presented in Figure 1 and Figure 2, are described below.

Biophysical and Environmental: This type refers to risks stemming from the inherent biological and physical characteristics of the natural environment in which food systems operate. This type groups eight categories of risks, including those related to changing climate and weather patterns, natural disasters, extreme weather events, land-related issues, natural resources and biodiversity loss, pollution and nuclear contamination. It should be noted that nuclear contamination risks could be also related to the (Geo)Political risk type; however, these risks were more often referred to in the context of unintended accidents and hence they are included in the Biophysical and Environmental risk type. Natural resources (soil, water, biodiversity, and air) are key for food production, and fishery and especially agricultural production depend on weather patterns; hence, biophysical and environmental drivers leave a major imprint on food systems. Concerns are growing about the effects of climate change in driving adverse weather events and the emergence of pests and diseases, which seem to be occurring with increasing frequency (European Commission, 2023a).

Economic and Market: This type refers to risks caused by disturbances or disruptions in the market, as well as unfavourable (macro)economic and financial circumstances threatening the economic viability of food systems' operators. It comprises six risk categories, including access to and price of inputs, access and cost of labour, financial liquidity, financial and economic crises, market structure issues (contraction, concentration), and market instability. With globalisation and the liberalisation of markets, Economic and Market risks are becoming increasingly relevant, as the exposure of the EU food supply chain to disturbances in the global market increases (e.g. Thorsøe et al., 2020). Moreover, EU food systems still face important domestic economic challenges, such as those related to the scarcity of labour (Schuh et al., 2019), or the accessibility to finance (fi-compass, 2020).

Socio-cultural and Demographic: This type refers to risks arising from changes in the structure, culture and behaviours of the society. This type re-groups five risk categories, including changes in consumer preferences, generational renewal, pandemic and human health, population dynamics, and social unrest. Important demographic dynamics, such as the depopulation or ageing of population in several EU regions ([3]), pose challenges to food systems. Changes in consumers' preferences (e.g. Kimpeler et al., 2022), require food supply chains to adapt or transform what they produce or their production methods. It should be noted that risks related to consumer demand are also related to the Economic and Market risk type. However, in the interviews, they were most often referred to in the context of risks stemming from societal and behavioural changes and hence are included in the Socio-cultural and Demographic risk type.

(Geo)Political and institutional: This type refers to risks stemming from changes in the political framework. This type re-groups three risk categories, including (geo)political instability, conflicts and terrorism; trade barriers and trade flows distortion; and policy changes and regulatory requirements. The EU food supply chain is strongly integrated into the global food supply chain such that disruptions of the trade flows or the (geo)political equilibrium can threaten the functioning of the EU food supply chain. Certain aspects of the EU food supply chain are highly regulated and supported by relevant EU policies (e.g. the Common Agricultural

([3]) See for example Eurostat figures (https://ec.europa.eu/eurostat/web/products-eurostat-news/w/ddn-20230117-2).

Policy or the Common Fisheries Policy). Changes in the policy framework would mean uncertainties for the supply chain operators.

Supply chain performance: This type refers to risks arising from the incorrect functioning of the food supply chain. It includes three risk categories: food contamination and waste; disruptions in transport, infrastructure or logistics; and disruptions in up-stream supply. These issues are relevant given the high degree of interdependencies among the different stages of the supply chain, the high reliance on foreign suppliers, and the high level of specialisation of each operator. The experience of the COVID-19 pandemic, for instance, has revealed the potential damage that can be caused by the disruption of logistic operations.

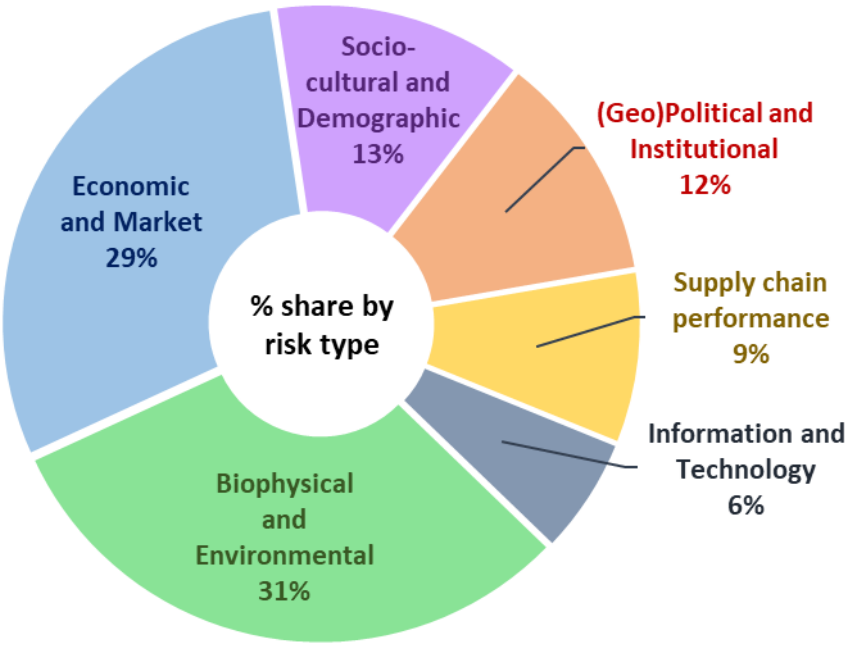
Information and technology: This type refers to risks originating in a lack of information, technical, technological or digital disruptions, and the potential harm caused by innovative technologies. It contains three categories of risk: namely those related to a lack of information, knowledge and innovation; technological risks; cyberattacks and internet blackouts. Information and Technology risks are likely to increase in future as the food supply chain is rapidly becomes more and more digitalised and reliant on technologies.

Respondents to the online survey were asked to select at least 10 main risks affecting their sector(s) from a pre-defined list of 28 risk categories. The pie chart in Figure 1 shows the frequency of identification of risks of each risk type.

Risks of the "Biophysical and Environmental" risk type are the most selected (31% of the cases). This comes as no surprise given the effect that biophysical and environmental conditions have on the primary sector (both farming and fisheries). Indeed, this type includes eight risk categories (more than any of the other five risk types). Selected slightly less are risks of the "Economic and Market" type (29%), which includes six risk categories. Hence, the risk types "Biophysical and Environmental" and "Economic and Market" account for 60% of the risks selected by respondents as most affecting their sectors. The risk types "Socio-cultural and Demographic" and "(Geo)Political and Institutional" are mentioned less frequently together representing 25% of the risks selected. The remaining two risk types ("Supply chain performance" and "Information and Technology") together account for the remaining 15% of responses.

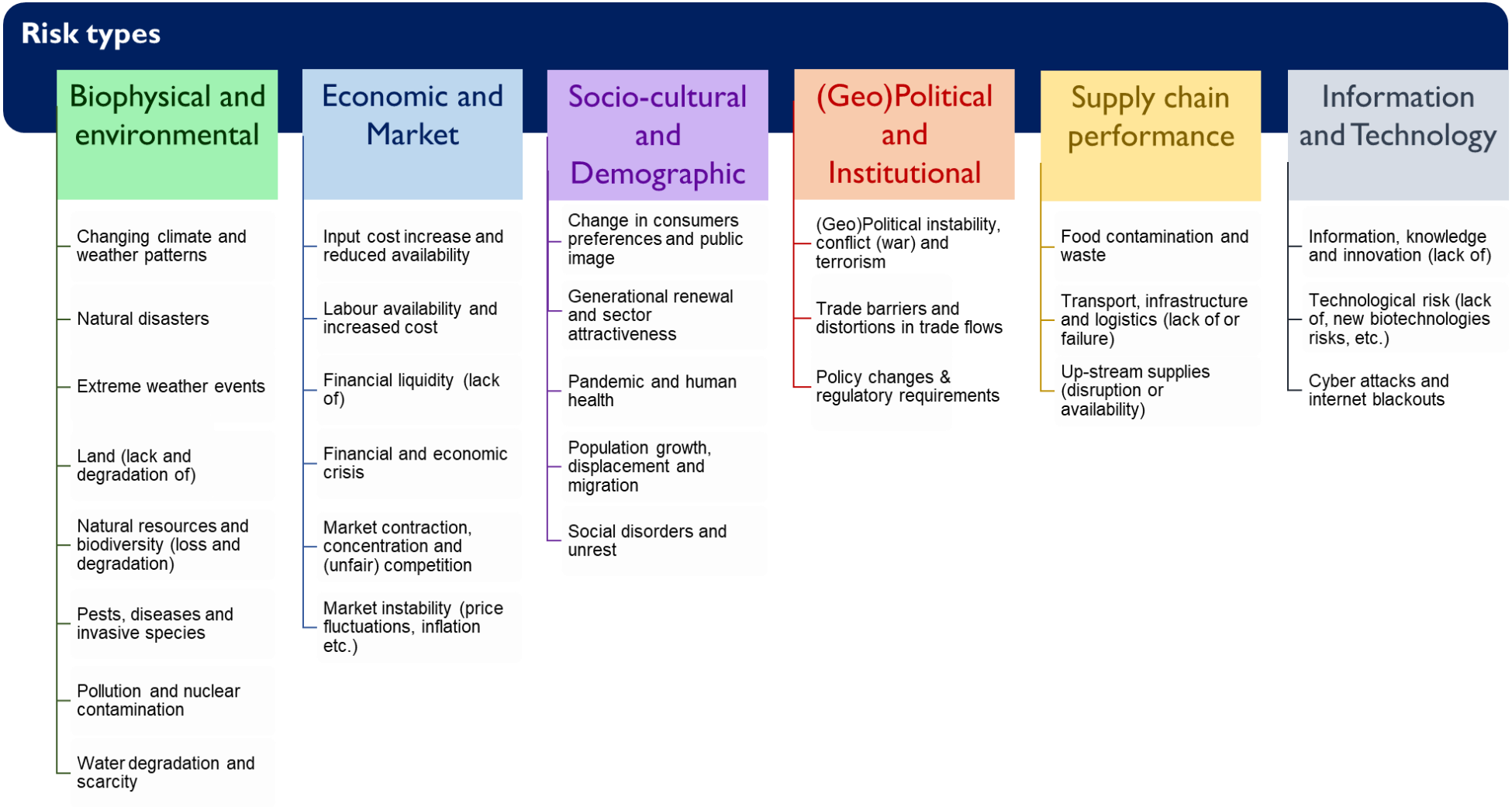
The frequency of identification of a risk type should not be considered as a measure of its importance, because each risk type hides a different level of aggregation (e.g. the "Biophysical and Environmental" risk type includes a longer, more specific list of risk categories than the other risk types). Because of the diverse nature of the risk types identified, and to allow for the detailed profiling and analysis of the different risk categories they include, an analysis by risk types is conducted in Sections 3.2 of frequency of identification, geographical origin, time horizon and likelihood of occurrence, potential impact, and exposure.

Figure 1. Share of risk types mentioned by respondents



Source: Online survey

Figure 2. Categories of risks identified among the six defined risk types



Sources: Semi-structured interviews and literature review.

3.1.2 Structural factors of vulnerability

This section presents the structural factors of vulnerability defined in this study, and the frequencies of identification of such factors in the online survey. Vulnerability refers to the incapacity of the food supply chain to respond to the negative impacts deriving from risks. The vulnerability to each risk might be driven by a series of different factors. First, we aimed to identify the main factors that can determine the vulnerability to a risk. We defined nine main factors of vulnerability through the analysis of information obtained from the semi-structured interviews. These factors of vulnerability logically group aspects of vulnerabilities (as described in the interviews) belonging to the same class of issue together. The factors are described below, ordered from the most frequently identified to the least frequently identified in the online survey (see Figure 3).

Policy and regulatory constraints and risk communication issues: This vulnerability factor refers to situations in which operators perceive that policies and regulations may reduce the room for manoeuvre they need to cope with unexpected negative events. Note that this factor also refers to cases in which rules are perceived as disharmonised, hence leading to the perception that a level playing field is not achieved. Furthermore, vulnerability is also generated whenever information is not correct or not correctly communicated. These vulnerability issues might prevent the food systems and their actors from adjusting or operating as they would want in response to some threats.

Lack of financial resources or limited economic margins: This factor pertains to the pre-existing condition of economic weakness. This can be the case, for example, of food production operators. Farmers and fishers face limited economic margins, and this causes a lack of the financial resources that are needed to buffer the impact of adverse events or to make investments for adaptation. Hence, conditions included in this vulnerability factor prevent the systems from being able to cope with the negative consequences of unforeseen risks and adjust adequately to new conditions.

Low flexibility to change: This factor pertains to specific and structural conditions of food system operators, which, because of the highly specialised nature of some assets (e.g. machinery) or production systems, are not able to be adjusted rapidly enough to respond to unforeseen changes in conditions. Similar considerations apply to cases in which operators strongly rely on a few specific inputs for production.

High dependency on certain import/export markets: This vulnerability factor refers to the case in which operators are strongly linked to specific markets beyond the EU (e.g. a single country) for buying key inputs and/or selling their products. These operators, not having a diversified portfolio of markets to rely on, could be strongly affected by changes in the market conditions. Hence, food systems with such characteristics can be vulnerable to changes in the access to markets.

Lack of (technological) alternatives, research, or infrastructures: This factor of vulnerability pertains to the case in which operators cannot easily rely on alternative technologies or infrastructures to adjust to new conditions stemming, for example, from new regulations or consumers' preferences. Among other things, this factor of vulnerability was discussed in terms of the costs of new technologies; the acceptability of technology (e.g. genetically modified organisms and new genomic techniques, cell meat); the pace of change; and the availability of funding for adopting and deploying the technologies and innovation necessary to comply with increasing sustainability standards and to adapt to climate change.

Lack of human capital: This vulnerability factor refers to a lack of human resources, skills, experience and knowledge in a food system. For example, it refers to cases in which a large share of the labour requirement is met by hired seasonal workers from other Member States or non-EU countries. Under these circumstances, mobility restrictions could drastically affect the possibility of performing key operations (e.g. harvesting) and replacing these workers with alternative labour sources is difficult. A lack of skilled workers can also be a problem especially when operators need to introduce new technologies that require skilled workers.

Weak supply chain organisation, bargaining power and strong interdependences: This factor re-groups all supply chain organisational characteristics that lower the supply chain's resilience. It includes the just-on-time production model, very high concentration in some segments (oligopoly/monopsony), lack of cooperation and unbalanced relationships along the supply chain. These aspects of vulnerability hinders the capacity of the food supply chain to self-organise and react in response to threats.

Lack of natural resources available or accessible: This vulnerability factor refers to cases in which food systems strongly rely on natural resources that are not available in adequate amounts or are not of adequate quality. This can be the case for marine areas and fish stocks or for land and irrigation water for agricultural production. This gives raise to vulnerability issues because the stock of natural resources, which can serve as a

buffer against the impact of adverse events, or used to adapt to new production models, cannot be increased sufficiently in the short term.

Low diversity of inputs suppliers/clients (high concentration): This factor of vulnerability pertains to cases in which operators rely on a very concentrated portfolio of input suppliers and/or clients also within the EU (and hence are not limited to non-EU import/export markets). This generates vulnerability because such operators could be strongly affected by changes in the strategies of those input suppliers or clients. Moreover, while it is possible to adjust purchase and sale strategies including by finding new partners, this takes time and could generate relevant adjustment costs.

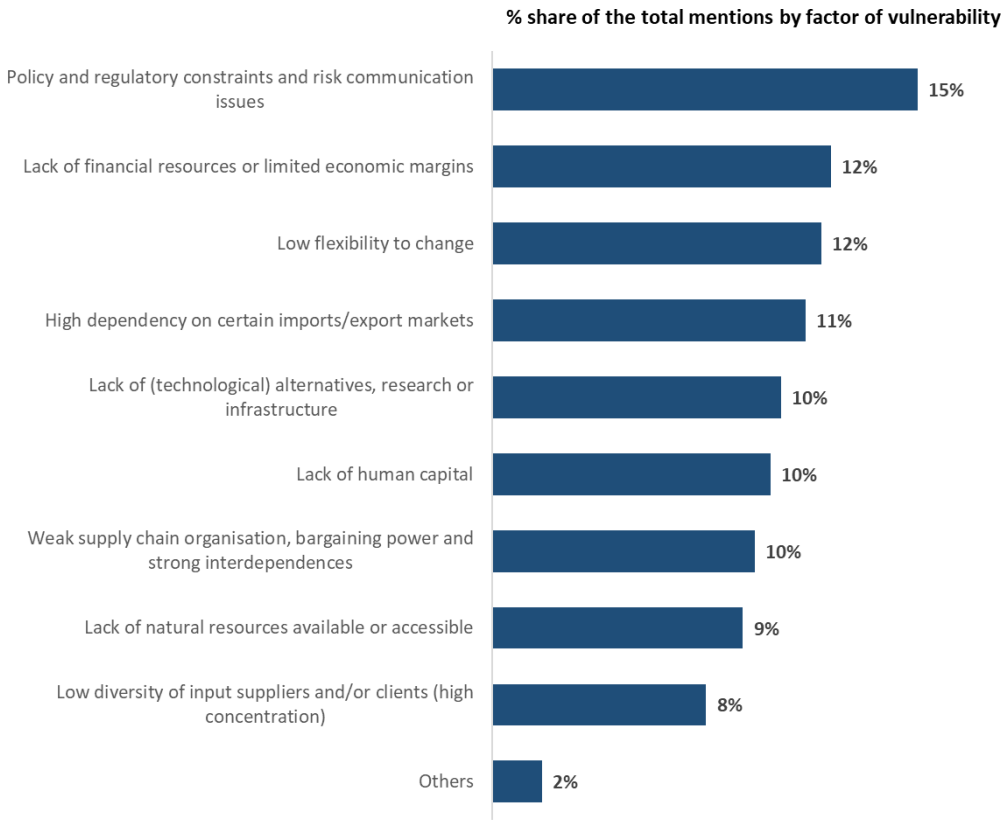
Other factors of vulnerability: Other factors, not belonging to the nine groups described above, were also mentioned in the interviews. These other factors covered different issues, such as the vulnerabilities stemming from operating in a global market, worldwide logistics and monopolistic systems, high national debts, lack of (foreign) investors, declining consumer demand, and media-driven public distrust.

The next step aims to identify how frequently each factor could explain the vulnerability to different risks. In the online survey, respondents were asked to select, for each of the risk types identified (as described in Sections 3.1.1), the main relevant factors of vulnerability. Respondents could select one or more factors from the predefined list of 10 factors described above, including the category "Others". Figure 3 shows the frequency of identification of each factor of vulnerability in the online survey, as perceived by the respondents.

The frequency does not vary significantly among the nine defined factors: it ranges from 15%, for *Policy and regulatory constraints and risk communication issues*, to 8%, for the *Low diversity of input suppliers and/or clients (high concentration)*. This means that there are no factors that are substantially more relevant overall than any others. Furthermore, the residual category *Others* scores only 2%, suggesting that the nine preselected factors cover the vast majority of cases.

However, the relevance of the factors of vulnerability in relation to the different risks was found to vary. Sections 3.3 provides a deeper analysis of vulnerabilities.

Figure 3. Frequencies of identification of factors of vulnerability in the online survey



Source: Online survey.

3.2 Analysis of the risk types

This section presents an analysis by risk type and is organised into sections per risk type accordingly. The risk categories associated with each risk type are analysed. The analysis looks in particular at (i) the frequency of identification of the risks by actors across different sources (namely the literature, the interviews, and the online survey), (ii) the perceived origin and time horizon of the risks based on the interviews, and (iii) the perceived potential impact of, likelihood of occurrence of, and exposure to the risks based on the online survey.

The identification of risks across the literature, the semi-structured interviews, and the online survey, had different objectives. The literature review identifies risks that have drawn most attention from scientists and policymakers in the past 10 years. The interviews identify, based on an open question, risks that stakeholders think may affect their sector(s) from current and future perspectives. In contrast, in the online survey respondents were asked to select the 10 main risk categories (from a list of 28 categories) that can affect their sector(s) the most. Thus, the online survey identifies risks to which respondents attach relatively more importance than they attach to those not selected. The comparison between the literature and the interviews in particular helps to gain an understanding of whether there are significant differences between the focus of the past research and the current perspectives, which might indicate whether certain (emerging or recurrent) risks warrant further attention in future.

The analysis of risk origin relies on information gathered through the semi-structured interviews. Here, stakeholders were asked to categorise each risk identified, based on their perception of that risk, as originating domestically (within the Member State), within the EU, outside the EU (non-EU country/region) or globally. The origin of the risk provides indications about the degree of control over the source of the risk, with stakeholders having relatively less control over risks originating globally or outside the EU and relatively more control over risks originating domestically or within the EU.

Stakeholders were also asked to categorise each risk identified based on its perceived time horizon of occurrence, notably within 1, 5, 10, or 20 years. The time horizon of occurrence for a risk provides indications about the relative urgency to deal with the risk. Identifying a risk as being likely to occur in the long term, however, does not suggest that no action is needed in the short term, given that it may take some time for an action to generate effects.

Potential impact and likelihood of occurrence are two inherent properties of all risks. While the potential impact explains the severity of the negative consequences expected if and when an event occurs, the likelihood defines the probability of the event occurring. The combination of impact and likelihood provides an indication of the exposure to the risk, an indicator used to compare risks and identify those that are potentially most hazardous for a system. In the online surveys, respondents were asked, for each risk identified, to quantify potential impact and likelihood of occurrence on a scale from 0 to 10. A risk exposure indicator was derived by multiplying impact and likelihood scores and is measured on a scale from 0 to 100 (see Sections 2.3 and Annex 1 for further details).

3.2.1 Biophysical and Environmental risks

The Biophysical and Environmental risk type includes those risks that originate from the inherent biological and physical characteristics of the natural environment in which food systems operate. This type of risks has strong and direct implications at the food production level, primarily leading to reduced yields, with its impact being expected to increase in the coming years (European Commission, 2023b). The Biophysical and Environmental type comprises eight risk categories, which are described below.

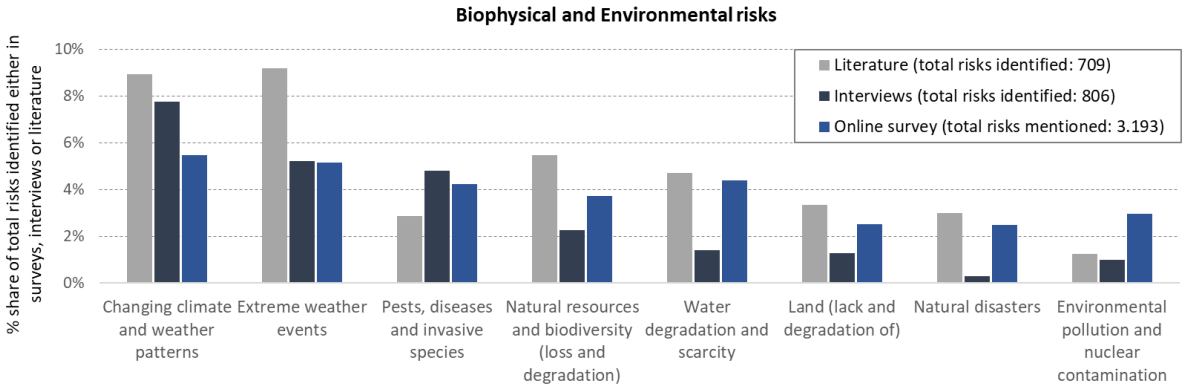
Four categories mainly include risks related to the climate and natural events: *Changing climate and weather patterns*, *Extreme weather events*, *Natural disasters*, and *Pests, diseases, and invasive species*. The category *Changing climate and weather patterns* refers to those climate trends leading to changing climate conditions (including sea conditions), such as increasing CO_2 concentration, changing average temperatures and precipitations, changing sea properties (e.g. acidification, temperature) and declining snowpacks with related consequences for fishery and farm production. The category *Extreme weather events*, on the other hand, refers to sudden and climate-related adverse events, such as droughts, heatwaves, frosts, floods, and (snow, wind) storms, that are linked to climate change. Unlike extreme weather events, the category *Natural disasters* refers to catastrophic events (other than extreme weather events), such as earthquakes, fires or volcanic eruptions, that are highly destructive and cause substantial damage to entire regions and communities. Extreme weather events and natural disasters differ from one another in that the former covers events directly originating in weather conditions and the latter refers to events that are not due to weather (or not necessarily due to weather, as in the case of fires weather conditions can have an influence). The category *Pests, diseases, and invasive*

species refers to risks brought about by emerging harmful organisms or viruses affecting animal and crop production, including also the spread of competing alien species. This category, therefore, includes the impact of natural organisms whose spread is often linked to climate change and globalisation trends.

Other risk categories in this risk type relate to the depletion of natural resources: *Natural resources and biodiversity (loss or degradation of)*, *Environmental pollution and nuclear contamination*, and *Water degradation and scarcity*. The category *Natural resources and biodiversity (loss or degradation of)* refers to the declining quality or availability of the natural resources key to food production, such as biodiversity (e.g. pollinators being affected by the intensive use of pesticide, which is an example mentioned in the interviews) or fish stocks (affected, for instance, by the overexploitation of or reduction in coastal habitats due to anthropic development). The category *Environmental pollution and nuclear contamination* refers to risks originating from the introduction of harmful substances into the environment (including (agro)chemicals and bacteriological contamination), and the consequent depletion of the natural ecosystems in which food systems operate. A special case mentioned in the interviews and in the literature, and included in this category, is nuclear contamination, even although the probable source of nuclear contamination (accident or conflict) is not comparable to the sources of most of the environmental pollution and therefore it could have been included in the (Geo)Political risk type. Yet, as for other types of pollution, nuclear contaminations can have strong negative consequences for the environment and is therefore included in this category. In addition, the category *Water pollution and scarcity* refers to the declining availability of usable water, either because it is not physically available or because of its reduced quality, which strongly constrains its use in irrigation. The category *Land (lack and degradation of)* refers to the lack of soils for food production, caused either by worsening soil health and quality (e.g. biochemical fertility including loss of organic matter), or by inaccessibility due, for example, to natural constraints, alternative uses or land concentration.

Figure 4 compares the frequencies of appearance of these risk categories in the literature, the semi-structured interviews, and the online survey. This frequency analysis reveals that, while risks related to changing climate and extreme weather events are the most frequently identified across the three data sources, other risks related to pests and diseases, loss of natural resources, and water pollution and scarcity are also assigned relatively high importance by online survey respondents.

Figure 4. Frequencies of identification of Biophysical and Environmental risks, and comparison between online survey, interviews and reviewed literature sources



Sources: Online survey, semi-structured interviews and literature review.

Changing climate and weather patterns and *Extreme weather events* are the most frequently identified risk categories across all data sources (Figure 3). These are among the risk categories most frequently identified in the online survey, signalling that more stakeholders are concerned about these risks than about other risks. Moreover, these risks are the most frequently mentioned (also compared to other risk types) in the reviewed literature, which indicates the large degree of attention that has already been paid by scientists and policymakers to these risks.

Relatively less mentioned in the literature, interviews, and surveys, are the risks related to the categories *Pests, diseases, and invasive species*, *Natural resources and biodiversity (loss or degradation of)*, and *Water degradation and scarcity*. Yet, the frequencies of identification of these risks in the online survey remain high

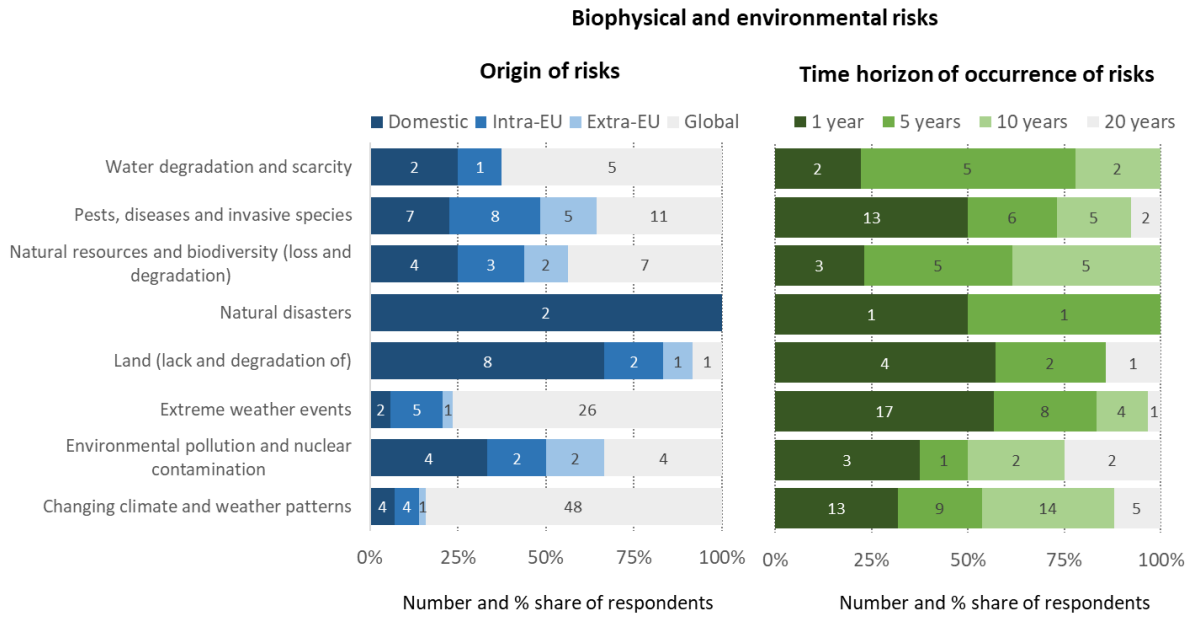
compared with other risk types, which points to the relatively high importance attached to these risks by stakeholders.

The least frequently identified risk categories (considering the literature, interviews, and surveys) within the Biophysical and Environmental risk type are the *Land (lack and degradation of)*, *Natural disasters* and *Environmental pollution and nuclear contamination*. These categories are also generally less frequently identified compared to other risk types (see Annex 7), indicating that fewer stakeholders are concerned about these risks compared to the other risk categories. It should be noted that the frequency of identification of risks in the category *Natural disasters* in the interviews was very low, which suggests that, when asked to think openly about possible risks, stakeholders rarely consider this risk category. This might be because of the perceived sporadicity or regionality of these risks.

Unlike the other risk types assessed in the following sections, Biophysical and Environmental risks are generally identified more often in the literature than in the interviews. This indicates that while high attention has been paid to these risks by scientists and policymakers in the past decade, stakeholders pay less attention to these risks, from current and future perspectives, than the other risk types. *Pests, diseases and invasive species* is the only risk category that is identified more frequently in the interviews than in the literature. This might indicate that, in the stakeholders' perception, this risk draws higher attention compared to other risks, and may require additional attention in future. For instance, the increasing pressure caused by emerging diseases on the livestock sector (e.g. avian flu being an example that was mentioned often in the interviews) or invasive species on the fishery sector might lead stakeholders becoming more concerned about these risks than in the past. Accordingly, it is recognised that the risk of the emergence of pests and pathogens has increased as a consequence of major global drivers such as climate change and increased trade among countries (Richardson et al., 2016).

Figure 5 shows the perceived origins and time horizons of occurrence for Biophysical and Environmental type of risks. An overview of perceptions for all risk types is provided in Annexes 7 (origins) and 8 (time horizons). The analysis shows that most of the Biophysical and Environmental risks are expected to occur in the short term (within 1 to 5 years). Yet, their perceived origins differ, with risks related to the changing climate and extreme weather being perceived as global and extra-EU risks, while risks linked to natural disasters and a lack of land being considered mainly domestic or intra-EU risks. The origin of risks related to environmental pollution, and pests and diseases can vary depending on the specific event.

Figure 5. Origins and time horizons of occurrence for Biophysical and Environmental risks as perceived by respondents



NB: Full comparisons of all risk types and categories are provided in Annexes 7 and 8.

Source: Semi-structured interviews.

According to the interviews, most Biophysical and Environmental risks are generally perceived to have originated globally. In particular, the risk categories *changing climate and weather patterns* and *extreme weather events*

(which are also among the most-mentioned risks) are very often considered to have a global origin (75% of responses or more). This is linked to the role that climate change, a developing global driver, plays in generating most of these risks. The global origin of climate change makes it difficult to deal with these risks by intervening at the source, as the complexity in achieving multilateral climate agreements demonstrates. Mitigating climate change and the related risks only locally (e.g. at the national level) is rather difficult, at least in the short term, as climate adaptation strategies take time.

The risk categories *Pests, diseases and invasive species*, *Water degradation and scarcity*, *Natural resources and biodiversity*, and *Environmental pollution and nuclear contamination* show more balanced results, with about half of respondents perceiving either a prominent domestic or intra-EU origin, and the other half perceiving a mainly extra-EU or global origin. This might reflect the diverse nature of these risks, which might include for example punctual or diffused environmental pollution, pandemic or endemic pests.

In contrast, the categories *Lack or degradation of land* and *Natural disasters* are perceived to have a mainly domestic origin (between 70% and 100% of responses). The identification of a domestic origin for risks related to land is consistent, as the quality of soils and the availability of lands are likely to be dependent on local situations. This risk is also strongly related with the problem of land use competition. Specific examples are mentioned in the interviews, such as land concentration (e.g. in Romania), high land costs, alternative land uses like renewable energy (e.g. in the Netherlands and Sweden), or the intensive use of synthetic fertilisers (mainly in regions relying on intensive agriculture).

Regarding *Natural disasters*, exposure is generally linked to specific regions; for example, southern regions of the EU are regularly affected by fires, and some Member States are geologically prone to earthquakes (e.g. Italy). When specific regions are historically affected by certain catastrophic risks, then local strategies can be of use for dealing with them. However, the frequency of some natural disaster events (e.g. fires) and the number of regions involved seem to be increasing (at least to some extent) as a result of climate change, calling into play global dynamics as determinants of natural disasters (Lavell et al., 2012).

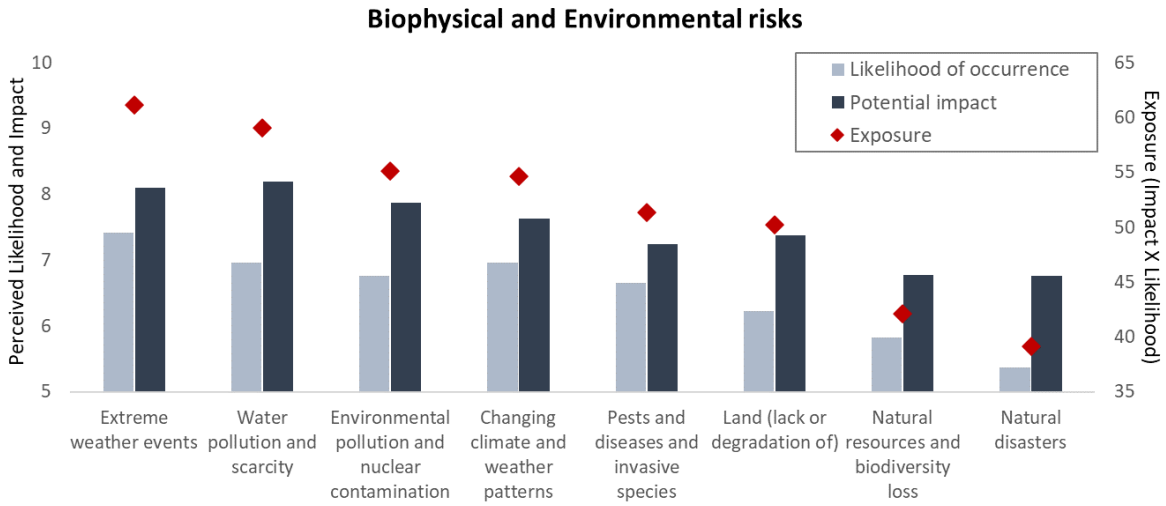
According to the interviews, most of the risks are expected to materialise in the short term, especially within the next 1 to 5 years. In particular, risks in the categories *Natural disasters*, *Lack or degradation of land*, *Pests, diseases and invasive species*, and *Extreme weather events* are expected to materialise within 1 year in around 50% or more of the reported cases. This suggests that these three risk categories are already putting the systems under pressure, highlighting the need for strategies not only to anticipate but also to cope with their impacts. It is not a case, in fact, that (some) natural disasters (e.g. fires) and extreme weather events appear to be occurring with growing frequency, mostly as a consequence of climate change (European Commission, 2023a). In addition, a relevant number of pests and diseases are emerging because of global changes in the way food is produced, moved and consumed (Richardson et al., 2016). Experiencing such events with growing frequency might lead stakeholders to expect further occurrence over the next few years. Moreover, the quality of soils and the availability of land are already pressing issues in the EU ([4]), and stakeholders expect these issues to have adverse consequences on the sector in the short term.

For only a few risks, the time horizon of occurrence falls within 10 and 20 years in a significant share of responses. This is the case of *Changing climate and weather patterns*, and *Environmental pollution and nuclear contamination* with around half of responses suggesting that these risks are expected to materialise in the long term. While challenges related to climate change and environmental pollution are already affecting food systems (which is also the case in relation to some risks discussed above), they are likely to be perceived as long term trends or, in the case of nuclear contamination, as occurring rarely.

Figure 6 shows the perceived likelihood of occurrence of (within the next 3 years), potential impact of, and exposure to each of the eight identified Biophysical and Environmental risk categories. The analysis of exposure shows that risks in the categories *Extreme weather events* and *Water pollution/scarcity* are perceived to be the most hazardous risks because of their potential significant impact on various sectors, particularly primary production. Other notable risks with high exposure values include those in the categories *Environmental pollution*, *Changing climate*, *Land degradation*, and *Pest and diseases*. Exposure to pests and diseases risks can be expected to increase as a result of climate change trends. Risks in the *Natural disasters* category have the lowest exposure values, mostly because of their perceived sporadic occurrence, even though they might still cause significant impacts on food supply.

([4]) See for example the EU Soil Observatory Soil Health Dashboard (https://esdac.jrc.ec.europa.eu/esdacviewer/euso-dashboard/), indicating that, at present, at least 60% of EU soils are unhealthy.

Figure 6. Perceived likelihoods of occurrence of (within the next 3 years), potential impacts of, and exposure to Biophysical and Environmental risks



Source: Online survey.

Extreme weather events and *Water pollution and scarcity* are the two categories with the highest exposure values within this risk type, each with an exposure indicator value of around 60. Moreover, these risk categories are also among those with the highest exposure values across all risk types. These two risk categories, therefore, are perceived to be much more hazardous than other risk categories. This could be due, on the one hand, to the implications of a large set of possible extreme weather events, which could potentially significantly affect all sectors, especially at the level of primary production. On the other hand, water is key in many food production and processing steps. Water is key not only in agricultural productions like fruit and vegetables, livestock and cereal production, but also for other processes, for instance, the production of yeasts and food processing.

While the *Extreme weather events* category is frequently identified across all data sources (see Figure 4), *Water pollution and scarcity* is much less frequently identified, especially in the interviews. This fact could indicate that fewer stakeholders are concerned about *Water pollution and scarcity* than are concerned about *Extreme weather events*, but that those stakeholders who do identify *Water pollution and scarcity* as a risk, perceive it to be very hazardous.

The risk categories *Environmental pollution and nuclear contamination*, *Changing climate and weather patterns*, *Lack or degradation of land*, and *Pests, diseases and invasive species* also have a high level of exposure values, ranging between 50 and 55 points. These values are also relatively high compared with the exposure values of risk categories in the other risk types. This is not surprising, as these risks strongly affect several sectors. For example, several stakeholders are already experiencing changing weather patterns, which can affect directly both agricultural production (e.g. through changing temperature and rainfall patterns) and fishery and aquaculture production (through changing sea temperature or composition). The impact of the changing climate is even expected to increase by 2050 (Hristov et al., 2020). Similarly, pests and diseases are affecting several sectors with growing frequency, such as the livestock (e.g. African swine fever, and avian influenza), crop (e.g. the marmorated stink bug affecting pears production, and the chestnut wasp, Dryocosmus kuriphilus, or wireworms, Coleoptera elateridae, affecting potato production), and fishery and aquaculture (e.g. viral diseases causing heavy losses in salmonids) sectors. In addition to their impact, stakeholders perceive that the likelihood of these risks may be increased by climate change trends.

The risk categories *Natural disasters,* and *Natural resources and biodiversity loss* have the lowest exposure values within the Biophysical and Environmental risk type, varying between 39 and 42. This is due in particular to these risk categories being perceived to have a significantly lower likelihood than the other risk categories. This is particularly evident for *Natural disasters* such as earthquakes which are, by nature, relatively more sporadic than other Biophysical and Environmental adverse events, for example those linked to extreme weather or water scarcity. Risks in the categories *Natural disasters,* and *Natural resources and biodiversity loss* might still have relevant impacts on food supply (e.g. the loss of a large shares of fishing stocks in the sea, or the

destruction caused by fires in dry seasons), but, because these risks are perceived to be rarer or more localised, stakeholders might see themselves as being less exposed to them.

3.2.2 Economic and Market risks

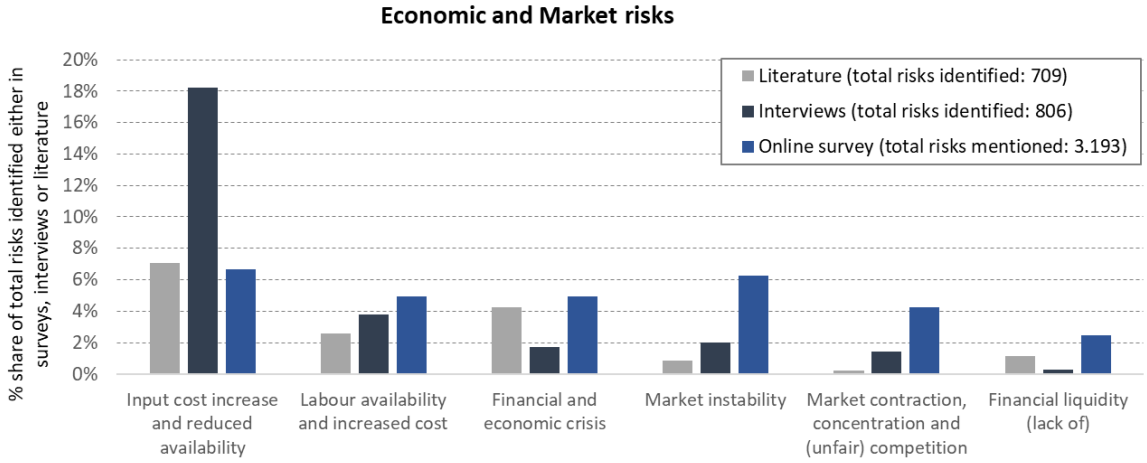
The Economic and Market risk type refers to risks caused by disturbances or disruptions in the market, as well as unfavourable (macro)economic and financial circumstances threatening the economic viability of food systems' operators. The Economic and Market type includes six risk categories, which are described below.

The first group of categories relates to risks arising from macro economy and market dynamics, including *Input cost increase and reduced availability*, *Financial and economic crisis*, *Market instability*, and *Market contraction, concentration and (unfair) competition*. The category *Input cost increase and reduced availability* refers to the reduced accessibility to input of production either because of increasing costs of purchase, or because of the limited availability in the market. Notable examples of inputs are energy, feed for livestock or aquaculture, fertilisers and pesticides, and other raw materials. The category *Financial and economic crisis* refers to risks arising from the impacts of sudden downturns and crises on the economy, including a decline in economic activity, dropping output and rising unemployment, recession and its effect on demand and trade, and uncertainty in exchange rates. An example of risk arising from a financial crisis is the consequences of the 2008 crisis for food insecurity in the EU (Davis and Baumberg Geiger, 2016). The category *Market instability* refers to risks linked to situations where market conditions (e.g. price levels) strongly deviate from its normal level causing problems to the operators. Market instability can lead to wrong production decisions, less investments, spending, and growth, and higher unemployment. Most often, interviewees specifically referred to the disruption of the EU market as a cause of market instability. The category *Market contraction, concentration and (unfair) competition* refers to risks arising from significant imbalances or misconduct in the market. This includes, for instance, the fragmentation of a sector into small and medium-sized enterprises and the monopoly of suppliers. It also pertains to maintaining a level playing field including with non-EU countries, and unfair competition due to fraudulent, deceptive, dishonest, or coercive trade practices.

A second group of categories relates to the cost and availability of two key assets of production: labour and capital. It comprises the categories *Labour availability and increased costs, and Lack of financial liquidity*. The former refers to the limited accessibility to hired workers, either because not enough workers are available, or because hiring costs have becomes very high, and the limited economic margin of businesses that do not allow for hiring. The latter category refers to risks originating in the unavailability of capital, including lack of access to credit. This in turn can cause, for instance, the difficulties in paying suppliers, difficulties in making new investments needed to maintain business competitiveness or meet sustainability standards, and, ultimately, potential bankruptcy.

Figure 7 shows and compares the frequencies of appearance of these risk categories in the literature, the semi-structured interviews, and the online survey. This frequency analysis shows that risks related to input cost increases are the most identified by far, especially in interviews, indicating a notable shift from past research. Recent developments (the energy price shock and its repercussion on fertilisers prices in 2021/2022) have certainly contributed to this focus. Other risks in this category, like labour shortages, are also highlighted, reflecting a growing issue across the EU. Risks related to market instability, contraction, and unfair competition are mentioned less in literature, but stakeholders express increased concern in interviews.

Figure 7. Frequencies of identification of Economic and Market risks, and comparison between online survey, interviews and reviewed literature sources



Sources: Online survey, semi-structured interviews and literature review.

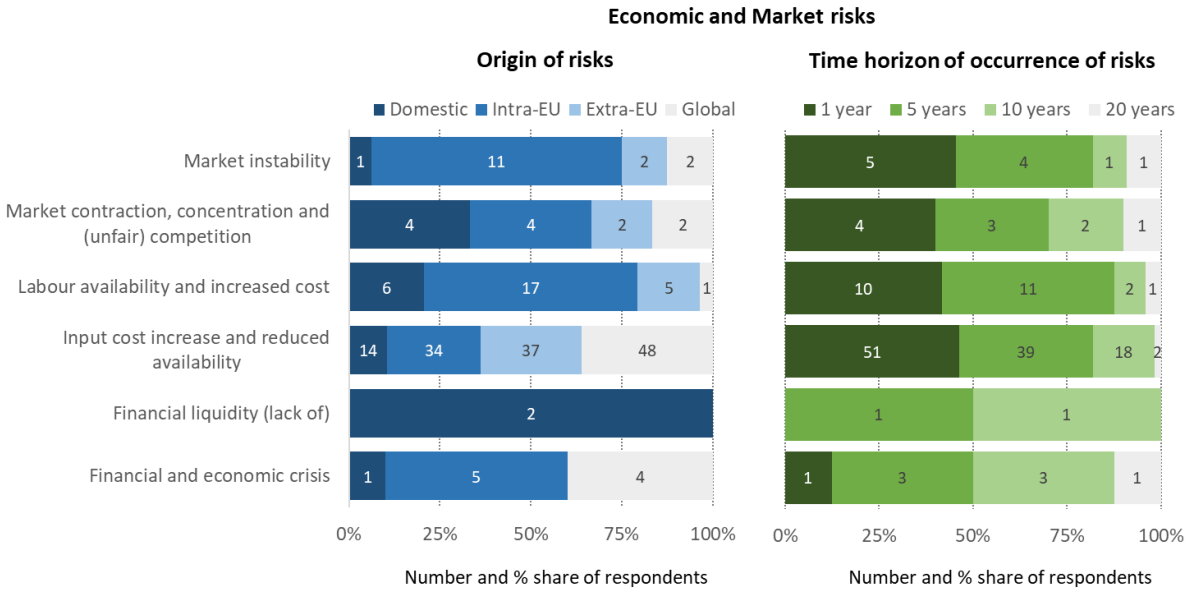
Risks related to *Input cost increase and reduced availability* constitute, by far, the most frequently identified category within the Economic and Market risk type, especially in terms of risks identified in the semi-structured interviews where they account for 18% of all the risks mentioned. When compared with other risk types, this risk category is the most frequently identified in both the interviews and the online survey. This indicates clearly that concerns about risks in this category are widespread among stakeholders, and that stakeholders attach great importance to them. In contrast, this risk category was relatively less mentioned in the past literature. To a large extent, this result is due to the recent events related to Russia's unprovoked invasion of Ukraine and, before that, the COVID-19 pandemic. While the negative impact of the war seems to be reducing over time, these events have most likely led to stakeholders paying greater attention to the strategic issue of inputs' availability (European Commission, 2023b).

Risks in the other categories belonging to the Economic and Market risk type are mentioned less frequently. It is interesting to note that many interviewees, from different sectors, have clearly highlighted paying attention to the risk of a shortage of labour. This relates particularly to seasonal workers and labour coming from both within and outside the EU. This challenge has become more evident in recent years and seems to be widespread across the EU (Schuh et al., 2019).

Note also that risks in the categories *market instability and volatility* as well as *market contraction, concentration and (unfair) competition* are not frequently identified in the literature review. In contrast, stakeholders interviewed are concerned about these risks more frequently than past studies (although these risks remain less frequently mention than many other types of risk by stakeholders). This seems to suggest that these risks, and in particular the possible disruption and fragmentation of the EU single market (as suggested by the interviews), are perceived to be more relevant now than in the past. These concerns have been (partly) triggered by certain events, such as the Brexit and the Russian war of aggression against Ukraine and national actions taken to cope with the negative consequences of the COVID-19 pandemic, and the impacts of these events and actions, for instance the impacts of on favouring national suppliers during the pandemic and the Russian war of aggression against Ukraine on the cereal and oilseed markets. Concerns were also expressed in relation to the lack of harmonised rules, possible unfair competition with non-EU countries and the growing geographical concentration of food chain operators.

Figure 8 shows the perceived origins and time horizons of occurrence for the Economic and market type of risk type. The analysis indicates that increased input costs risks are perceived to be mostly of global or extra-EU origins, whereas risks such as market instability, unfair competition, market contraction, and labour availability are often seen as originating within the EU. Financial liquidity risks are considered to have a domestic origin, tied to the financial structures and economic performance of food systems. Most risks are expected to occur in the short term, except for risks related to financial crises, which are expected to occur in the mid or long term because of their infrequent occurrence.

Figure 8. Origins and time horizons of occurrence for Economic and Market risks as perceived by respondents



NB: Full comparisons between all risk types and categories are provided in Annexes 7 and 8.

Source: Semi-structured interviews.

Increasing input cost is seen as having a global or extra-EU origin by around 65% of respondents. This seems to be in line with the high level of integration of the EU markets with the global markets. According to many of the stakeholders interviewed, the main issue in this regard is the rise in energy prices that happened after Russia's unprovoked invasion of Ukraine, which in turn led to increases in the prices of other raw materials' including fertilisers. Being of mainly global and extra-EU origins, it might be challenging to address this risk.

However, risks such as *market instability*, *market contraction, concentration and (unfair) competition*, and *labour availability* are often perceived as originating within the EU boundaries (respectively by 75%, 60%, and 80% of respondents). Concerning *market contraction, concentration and (unfair) competition*, for example, in the aquaculture sector, stakeholders mentioned that aquaculture products that are being imported from outside the EU have lower standards and are much cheaper, which is perceived to be unfair. However, some sectors are export-oriented and do not present this risk (e.g. dairy). Similarly for a lack of labour availability, the stakeholders flagged that they are already suffering from this locally. This could be the result of new technologies, the ageing of the workforce and harsh conditions of work and employment in the farm sector (Weber et al., 2021).

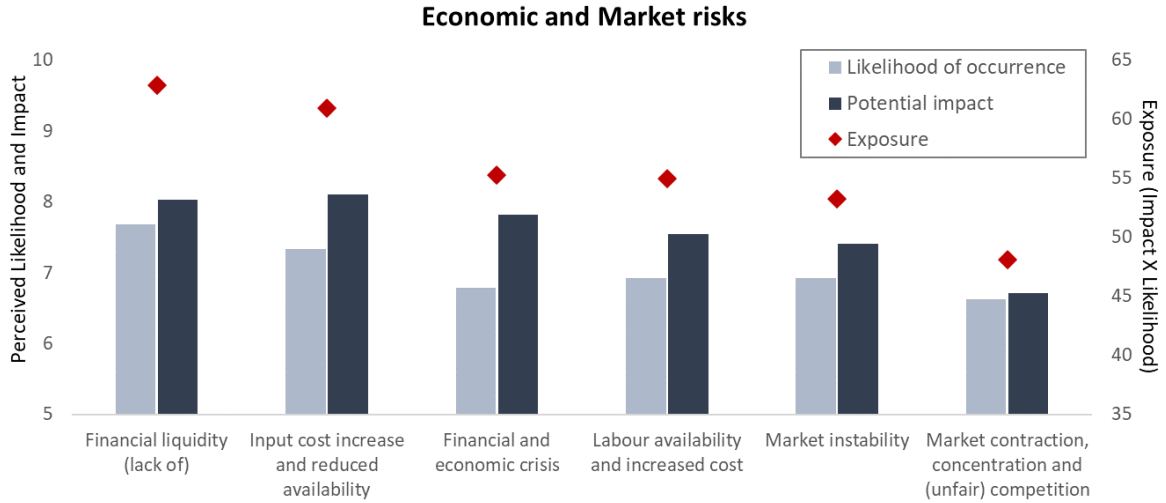
The only two interviewees who described the risk category *Lack of financial liquidity*, perceived this to have a domestic origin. This is consistent with the fact that a lack of financial liquidity is mainly linked to the financial structure and economic performance of food sectors, and the existence of financing gap (fi-compass, 2020).

Four of the six risk categories (all but *lack of financial liquidity* and *financial and economic crisis*) are expected to occur in the short term, mostly within 1 year according to around 50% of the responses for each of the four risk categories. For these risk categories, only between 12% and 30% of the respondents suggest that the risks would materialise in a time horizon of more than 5 years. Hence, the overall picture is that these risks are often perceived to be likely going to occur in the short term. This could be explained by the fact that many stakeholders stated that they are already suffering from these risks and their consequences, especially *input cost increase* and *labour availability and increased cost.* However, it also suggests that stakeholders expect these risks to continue occurring in the short term.

In contrast, risks in the category *financial and economic crisis* is expected to occur in a time horizon of 5 or more years by about half of respondents. The reason behind this answer could be linked to the relative infrequency and sporadic nature of such crises, like the one that took place in 2008, which could have led stakeholders to think that such risks are not likely to occur again soon.

Figure 9 shows the perceived likelihood of occurrence of (within the next 3 years), potential impact of, and exposure to each of the six identified Economic and Market risk categories. The analysis shows that Economic and Market risks are generally associated with higher levels of exposure than other risk types. The risk categories with the highest exposure values are *Lack of financial liquidity* and *Input cost increase*. While the former is less frequently identified by stakeholders than the other categories, this risk category is perceived to be highly hazardous by those stakeholder who did identify it. The categories *Financial and economic crisis*, *Labour availability and increased costs*, and *Market instability* have medium exposure levels. *Market contraction, concentration and unfair competition* risks have lower exposure values than other risks in this risk type, but the exposure values are still significant compared with those of other risk types.

Figure 9. Perceived likelihoods of occurrence of (within the next 3 years), potential impacts of, and exposure to Economic and Market risks



Source: Online survey.

The Economic and Market risk categories have higher exposure values than those of the other risk types assessed, which to some extent might be explained by the prevalence of business-oriented respondents in the sample (e.g. private businesses and stakeholder organisations). According to the survey results, the exposure values for Economic and Market type of risks range between 48 and 63 points, and this can be segmented into three groups.

The risk categories with the highest exposure values are *Lack of financial liquidity* and *Input cost increase and reduced availability*. Stakeholders assigned to these two risk categories the highest likelihood of occurrence as well as a high potential impact within this category. This resulted in an exposure index values of around 60 for *Input cost increase and reduced availability* risk and 63 for the *Lack of financial liquidity*. This latter is perceived to be the most hazardous risk category, not only of the economic and market risk categories but also of all the other risk categories identified. This is probably because this risk could potentially affect the majority of sectors and stages of the food supply chain. Financial liquidity can threaten the stability of the food supply chain, especially in uncertain contexts, whereby the lack of finance can imply impossibility to invest and conduct business-as-usual operations and, ultimately, leading to business closure. A lack of finance can be also attributed to the lack of collateral to get loans.

It should be noted that, while *Input cost increase and reduced availability* risk is the most frequently identified risk category in the online survey (see Figure 7), *lack of financial liquidity* is the least frequently identified. Hence, this suggests that fewer stakeholders are concerned about a *lack of financial liquidity* than are concerned about *Input cost increase and reduced availability* but that those who are concerned perceive the former risk category to be highly hazardous. A broad range of stakeholders identify risks related to *Input cost increase and reduced availability*, and perceive them to be significantly hazardous. The high perceived levels of exposure to these risks is, at least in part, linked to the experiences of the COVID-19 pandemic (which, for example, affected the availability of inputs) and Russia's unprovoked invasion of Ukraine (and the consequent increases in energy

and input prices). Several segments of the food supply chain were affected by these events, and the perception of risks stemming from further instabilities in the inputs' markets has been growing.

The risk categories *Financial and economic crisis*, *Labour availability and increased costs*, and *Market instability*, have medium exposure index values. These range between 53 and 55 points, which is still relatively high compared with categories in the other risk types. Several stakeholders have already experienced *Financial and economic crisis* and *market instability*, with a reduction in profitability, loss of competitiveness and price fluctuations. The same is true for the *labour availability and increased costs*, with many stakeholders expecting to experience a shortage of workers, leading to challenges in harvesting and other key labour-intensive operations. A reduction in the availability and an increase in the cost of labour can decrease the capacity to develop further or re-adapt the businesses, especially when skills and know-how are required. This can have a ripple effect along the supply chain, resulting in reduced product availability and higher prices.

The category *Market contraction, concentration and (unfair) competition* has lower potential impact and likelihood values than the other categories within this risk type, which resulted in a lower exposure value, of around 48 points. However, these values are not among the lowest compared with other risk types, suggesting that exposure of the food supply chain to this risk category is still relevant. According to the interviews, growing attention is being paid to the risk of the single market fragmentation in particular.

3.2.3 Socio-cultural and Demographic risks

The Socio-cultural and Demographic risk type refers to risks arising from changes in the demographic structure, culture and attitudinal values, and stability of the society. It includes five risk categories, which are described below.

The category *Change in consumers' preferences and public image* refers to risks such as sudden changes in consumer preferences and consumption patterns, reputational risk and reduction in the purchasing power of consumers. Reputational risk is mentioned often because it can affect the demand by decreasing the public's acceptance of some goods. A reduction in the purchasing power negatively affects the demand. All these phenomena disrupt the equilibrium of the systems and require a quick adaptation response, which may not always be possible or cost-effective.

The category *Pandemic and human health* refers, in most cases, to pandemics affecting the human population. These phenomena can pose a serious threat to human health and could lead to the introduction of containment measures, affecting among other things the health and mobility of people, the market demand and the supply of workers along the different stages of the food supply chain, potentially reducing food supply. This category also includes risks for human health within the food systems, for example contamination linked to the use of chemicals on the farms or generated during food processing.

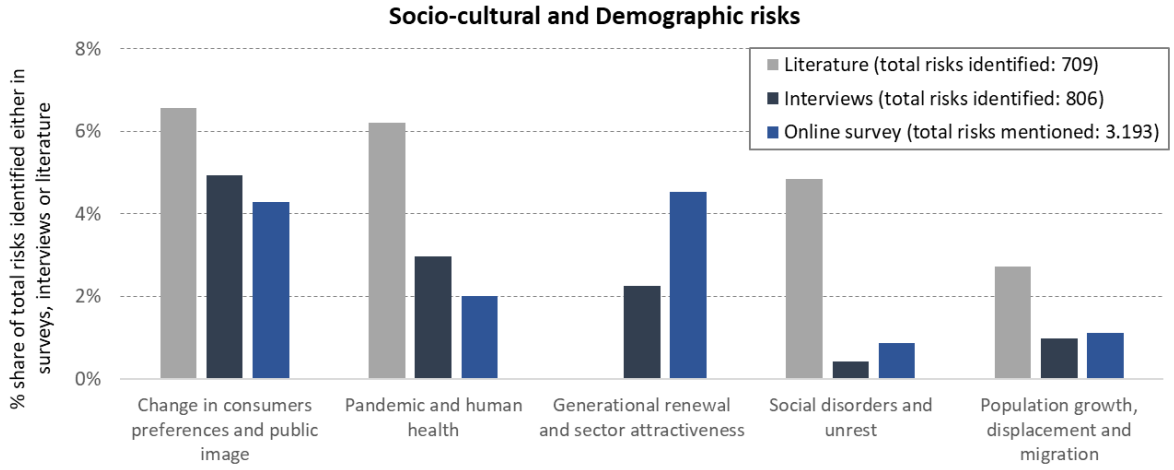
The category *Social disorders and unrest* refers to risks stemming from social instabilities, such as strikes and manifestations, which can lead to supply chain disruptions, for instance in the transport and logistics stages of the supply chain. While infrastructures can be damaged by social disorder events, labour shortages might also occur because of social unrest. This category also includes risks caused by weakened social solidarity.

The category *Population growth, displacement and migration* refers to risks related to changes in the demographic structure of the population. This includes the high rate of global population growth, urbanisation and the aging of populations and depopulation trends in many EU regions. The pressures caused by migration and the failure in the inclusion of migrants are also mentioned within this risk type.

The category *Generational renewal and sector attractiveness* refers to the declining economic attractiveness of working in the food systems for the younger generations. This is one cause of the lack of generational renewal and, consequently, of the aging of the people working in food systems, especially in the agriculture and fishery sectors.

Figure 10 shows and compares the frequencies of appearance of these risk categories in the literature, the semi-structured interviews, and the online survey. This frequency analysis shows that risks related to *Change in consumers' preferences and public image*, and *Pandemic and human health*, are mentioned most. Recent experiences with the COVID-19 pandemic and the need to meet evolving consumer demands most likely drive this. The categories *Social disorders and unrest*, and *Population growth displacement and migration* risks, are mentioned less frequently by stakeholders, but are highlighted in the literature, suggesting that despite the immediate level of concern being low, these issues still merit attention. A high level of importance is assigned to risks related to *Generational renewal* by stakeholders in the online survey.

Figure 10. Frequencies of identification of Socio-cultural and Demographic risks, and comparison between online survey, interviews and reviewed literature sources



Sources: Online survey, semi-structured interviews and literature review.

Overall, the risk categories mentioned most within the Socio-cultural and Demographic type are *Change in consumers' preferences and public image*, and *Pandemic and human health*. While the stakeholders' perceptions about risks related to *pandemic and human health* are most likely to have been driven by recent experiences with the COVID-19 pandemic, risks related to *change in consumers' preferences and public image* are a key issue for all sectors, as the food supply chain faces the constant challenge of properly meeting consumers' needs, demands, and expectations. This results in the identification of these risk categories by a wide range of stakeholders. However, because of the nature of the survey, it did not capture the positive impacts of dietary changes and these should not be forgotten.

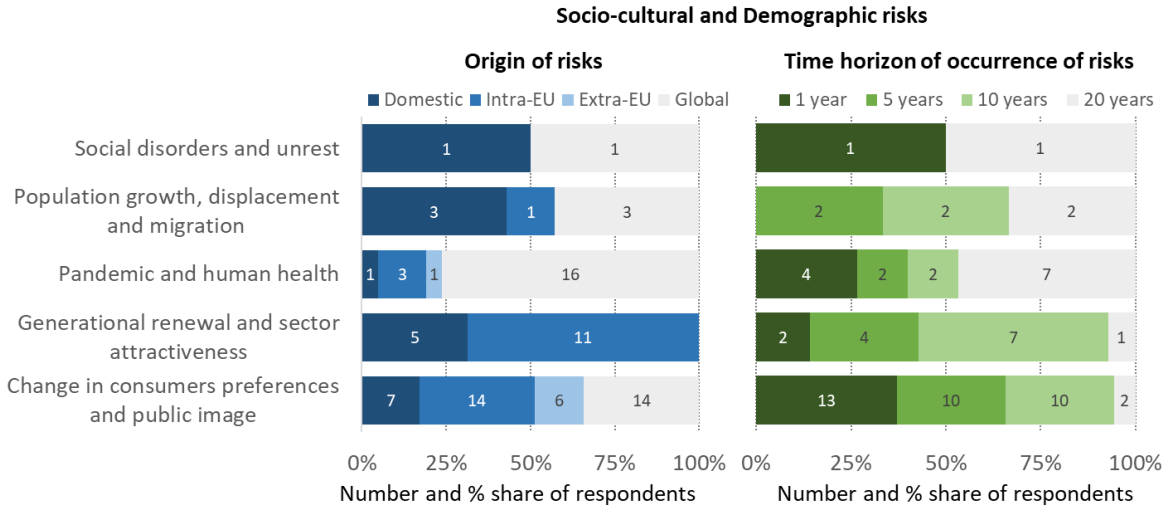
The risk categories *Social disorders and unrest* and *Population growth displacement and migration* are mentioned less frequently. These risks are mentioned mostly in the literature review, and less by interviewees and surveys' respondents. This means that relatively few stakeholders identify these risks as possible threats to their sectors or attach less importance to them than to other risk types. Yet, recent research pays great attention to these risks. The Global Risk Report (World Economic Forum, 2023), for instance, identifies trends of social polarisation and related risky factors that can lead to social instability, such as raising unemployment and cost-of-living, or disinformation.

The category *Generational renewal and sector attractiveness* is the most frequently mentioned Socio-cultural and Demographic risk category in the online survey, but it does not appear in the literature reviewed specifically related to risks and vulnerabilities of the EU food supply chain. This does not mean that literature on the topic does not exist; the topic is addressed especially in agricultural literature (see for example Coopmans et al., 2021), but not from the perspective of analysing vulnerabilities of the food chain. A wide range of stakeholders, belonging not only to the agricultural production sector, but also to other sectors and stage of the supply chain, perceive generational renewal to be a possible threat and attach great importance to it. It is also worth considering that generational renewal and population growth are interrelated, and thus the identification of one could, to some extent, mirror the identification of the other.

Figure 11 shows the perceived origins and time horizons of occurrence of Socio-cultural and demographic type of risks. An overview of all risk types is provided in Annexes 7 (origins) and 8 (time horizons). The analysis highlights that the *Pandemic and human health* risk category is largely considered global, primarily because of the recent experiences of the COVID-19 pandemic. Risks related to changes in consumer preferences and public image are perceived to have a mixed origin, possibly because of the influence of global trends, whereas the perceived origins of the *Population growth, displacement and migration* risk category is split between domestic/intra-EU and global origins, reflecting local population trends and global migration issues. *Generational renewal* risk origins are mostly perceived to be domestic or within the EU, linked to issues such as the ageing of certain sectors, urbanisation, and low remuneration. The perceived time horizons of occurrence of these risks varies, with risks related to *Changes in consumers' preferences* being expected to occur in the short

term, whereas risks related to *Population growth, displacement and migration*, *Pandemic and human health*, and *Generational renewal* being mostly expected to occur in the long term risks.

Figure 11. Origins and time horizons of occurrence of Socio-cultural and Demographic risks as perceived by respondents



NB: Full comparisons between all risk types and categories are provided in Annexes 7 and 8.

Source: Semi-structured interviews.

The *Pandemic and human health* risk category is considered to have originated mostly at the global level (around 75% of responses). This comes as no surprise given the origin of the COVID-19 pandemic and other similar pandemics. In addition, the *Change in consumers' preferences and public image* risk category is perceived to have originated globally or outside the EU according to 50% of the responses. This can be explained by global trends and events that can influence consumer behaviour in Europe. One such trend is the growing concern for the environment and sustainability, which has led to an increase in demand for eco-friendly products and services. Another example is the rise of digital technology and the increasing use of social media, which have allowed consumers to share information quickly and easily on a global scale (European Environment Agency, 2023).

The *Population growth, displacement and migration* risk category is perceived to have multiple origins, with around half of respondents considering this risk category to have a domestic origin or to have originated within the EU, and the other half considering it to have originated globally. Respondents who considered this risk category to have a domestic or EU origin had in mind local population trends and rural depopulation, often linked to socioeconomic or infrastructural factors. On the other hand, respondents who considered this risk category to have a global origin had in mind the global migration into the EU from non-EU countries happening because of climate change, wars, harsh economic conditions or political instabilities.

In contrast, the *Generational renewal and sector attractiveness* risk category is perceived to have originated mostly domestically (30% of responses) or within the EU (about 70% of responses). Two sectors mentioned here are the agricultural and fishery production sectors, where both stakeholders stressed the importance of tackling both the ageing of the workforce in these sectors and the unattractiveness of these sectors for younger generations. Tackling these issues is mainly hindered by their low remuneration compared with other sectors of the economy. The lack of generational renewal is, to a large extent, linked to structural and intrinsic problems of food systems (e.g. low remuneration or quality of life for workers) and major societal trends across EU Member States (e.g. rural depopulation), which are mostly independent from external factors.

Results suggest that the time horizon of occurrence of the risks considered may differ. Around 65% of respondents indicated that risks related to *Changes in consumers' preferences and public image* might occur in the short term, within 1 to 5 years. As for other topics, perceptions in this area depend on the stakeholder consulted. For example, livestock stakeholders mentioned that risks in this category are being driven by the shift to more sustainable diets, by substituting meat for non-meat products, which is already happening. In addition, other stakeholders mentioned that there could be a consumers' shift to cheaper products of lower quality because of the recent food inflation caused by the COVID-19 pandemic and the Russian war of

aggression against Ukraine. Accordingly, signs of changes in consumers' behaviour have been observed since the COVID-19 pandemic, and these changes seem to have been driven by factors such as financial losses, risk of unemployment, and risk aversion to health risks (Kimpeler et al., 2022).

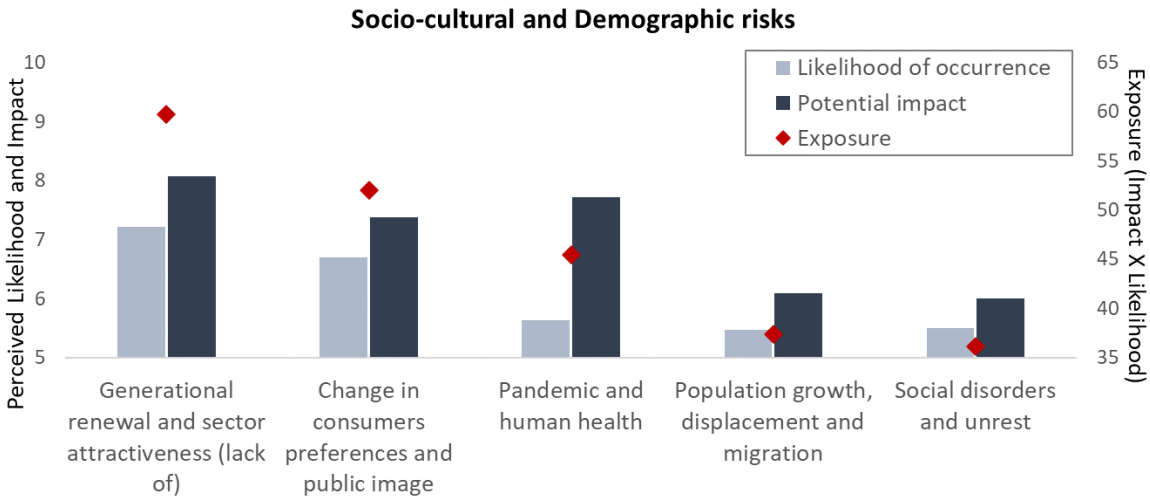
On the other hand, for the three risk categories related to *Population growth, displacement and migration*, *Pandemic and human health,* and *Generational renewal and sector attractiveness*, more than 60% of the cases respondents perceived a long-term time horizons of occurrence (10-20 years). However, it is important to note that for the final two of these risk categories, around 40% of respondents also chose the short-term option (within 1 to 5 years). This is because, as mentioned before, some sectors (e.g. the fishery and agricultural production sectors) are already suffering from this risk, while stakeholders from other sectors (e.g. retailers and processors) expect this risk to occur on the long term.

For the *Pandemic and human health* risk category, the duality in responses can be explained by the fact that, naturally, pandemics are relatively rare and are separated by long intervals. However, scientific research suggests that many disease-causing organisms are strongly influenced by ongoing climate change (Thomas, 2020), which shrinks the time horizon for this risk category. On the other hand, risks related to population growth, displacement and migration were considered by around 70% of respondents to have long-term time horizons (occurring within 10 to 20 years period).

Only two respondents described risks related to *Social disorders and unrest*, and they provided opposing opinions on the origins and time horizons of occurrence of these risks. While social unrest can have a very specific origins (e.g. domestic in the case of strikes), stakeholders may also refer to risks stemming from the global trends of growing inequality, poverty and populist threats (European Strategy and Policy Analysis System, 2019).

Figure 12 shows the perceived likelihood of occurrence of (within the next 3 years), potential impact of and exposure to each of the five identified Socio-cultural and Demographic risk categories. The analysis of exposure shows that the food supply chain is perceived to be more exposed to risks related to *Generational renewal* and *Change in consumers preferences* than to other sociocultural and demographic risks. The risk categories *Pandemic and human health*, *Population growth, displacement and migration*, and *Social disorders and unrest* have the lowest exposure values, with the last two being perceived to be the least hazardous among all risk categories. Despite the high potential impact of pandemic-related risks, their sporadic nature results in a lower perceived exposure value.

Figure 12. Perceived likelihoods of occurrence of (within the next 3 years), potential impacts of, and exposure to Socio-cultural and Demographic risks



Source: Online survey.

Within this risk type, the categories *Generational renewal and sector attractiveness* and *Change in consumers preferences and public image* stand out. These two categories have higher perceived exposure values than the other sociocultural and demographic risks identified, at 60 and 52 points, respectively. As discussed above, these risks are also those to which stakeholders attach greatest importance. Furthermore, it should be noted

that the category *Generational renewal and sector attractiveness* has one of the highest exposures values of all risk categories across all risk types, suggesting the relatively high hazardousness of this risk. A lack of generational renewal, in fact, is a matter of great concern especially in agricultural production (European Commission, 2021b). However, according to the stakeholders, this risk is also a concern for the fishery and aquaculture sectors and for other stages of the supply chain, such as food processing and logistics. Fishery stakeholders, for example, mention that the low quality of the work environment and low quality of life in the fishing vessels make the attractiveness of this sector low for new, younger fishers. The lack of new generations taking over the businesses represents a remarkable threat to food sectors, as it could irremediably lead to business closure and, eventually, to the decline of the sector.

Risks related to *Change in consumers preferences and public image* risks are also a widespread threat across the food supply chain. Such changes not only can lead to a decline in consumer demand (hence affecting profitability) but can also require major adaptations of the food supply chain. Similarly, reputational risks related to a worsening public image can lead to a sudden and unexpected drop in demand. For instance, stakeholders in the livestock sector often mentioned risks related to worsening public image being driven by the opinions of vegetarian, vegan or animal welfare activists.

The risks categories *Pandemic and human health*, *Population growth, displacement and migration*, and *Social disorders and unrest* have the lowest exposure values within this risk type, ranging between 36 and 46 points. It should be noted, in fact, that the exposure values for *Population growth, displacement and migration*, and *Social disorders and unrest* are the lowest among all 28 risk categories, meaning that stakeholders perceived them to be the least hazardous. The *Pandemic and human health* category stands out as being perceived to have a particularly high potential impact, although the food systems appeared to be able to cope with the pandemic's consequences (European Parliamentary Research Service, 2022a). However, this is coupled with a perception of a very low likelihood of occurrence, given the relatively sporadic nature of pandemics. Because of this, stakeholders assess the exposure to this risk as relatively low.

3.2.4 (Geo)Political and Institutional risks

The (Geo)political and Institutional risk type refers to risks stemming from changes in the policy framework or in the existing trade arrangements, and from (geo)political instabilities. It includes three risk categories, which are described below.

The category *(Geo)Political instability, conflict (war) and terrorism* refers to risks stemming from disturbances or disruptions of the political (either domestic or international) stability and trade relationships. This category includes issues pertaining to conflicts such as wars, geopolitical crisis, political and socio-economic instability, terrorism, and corruption. These risks can disrupt food supply chains, affect food security, and escalate costs, thereby affecting the sector's profitability and sustainability. While the food supply chain can be indirectly affected by the consequences of conflicts and terrorism, it can also be a target (e.g. CBRN incidents) ([5]). The uncertainty and unpredictability associated with these risks can also discourage investments in the agri-food sector, hindering the sector's growth and development.

The category *Policy changes and regulatory requirements* refers to the uncertainties arising from possible changes in standing policy and regulatory frameworks, aspects over which supply chain operators have limited control (Komarek et al., 2020). Tax laws, regulations for chemical use and the level of income support are examples of policy decisions that can have a major impact on the food supply chain ([6]). Policy changes are democratically adopted and pursue relevant policy and societal objectives. While policy changes are generally aimed at reducing risks and vulnerabilities in food systems (see, for example, the Green Deal strategies), they can come with a cost for supply chain operators in the short term. Policy and regulatory changes at the national or EU level can disrupt established production practices, require significant adjustments and impose additional compliance burdens. These changes, although oriented to improve the resilience of food systems, can be perceived as risks by single supply chain operators, as adapting to new rules can imply significant technological, organisational and/or financial effort.

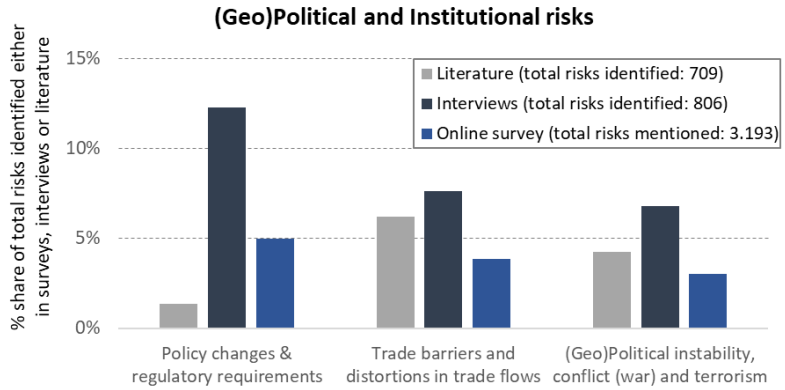
([5]) For example, it can be a target of the malicious use of chemical, biological, radiological and nuclear materials or weapons with the intention of causing significant harm or disruption.

([6]) In the agricultural context, these risks are generally referred to as institutional risks. See for example the US Department of Agriculture's classification of risks (https://www.ers.usda.gov/topics/farm-practices-management/risk-management/risk-in-agriculture/).

The category *Trade barriers and distortions in trade flows* refers to risks originating in the disruption or interruption of existing trade flows. This group includes issues stemming from trade shocks or uncertainties, protectionism (trade restrictions or disputes), the closure of borders or increased border controls, legislation not being harmonised and a decreased ability to import. These risks can distort trade flows and limit market access for EU food products in non-EU-country export markets or for the import of key raw material and inputs, and they can negatively impact on the sector's export competitiveness. Similarly, abrupt changes in trade policies or trade disputes can create uncertainties, disrupt established trade relationships and result in losses for exporting sectors.

Figure 13 shows and compares the frequencies of appearance of these risk categories in the literature, the semi-structured interviews, and the online survey. This frequency analysis highlights that (Geo)Political and Institutional risks are among the most frequently identified when compared with the other types of risk. These risks are identified by a wide range of stakeholders in the interviews, while mentions in the literature reviewed are relatively low. Risks in the category *Policy changes and regulatory requirements*, in particular, are the most frequently identified risks in the interviews and online surveys. It should be noted, however, that the sample composition of interviewees, who represented several stakeholder organisations, might explain (at least in part) the frequent identification of this risk type in the interviews, as these stakeholders are largely engaged in policy discussion.

Figure 13. Frequencies of identification of (Geo)Political and Institutional risks, and comparison between online survey, interviews and reviewed literature sources

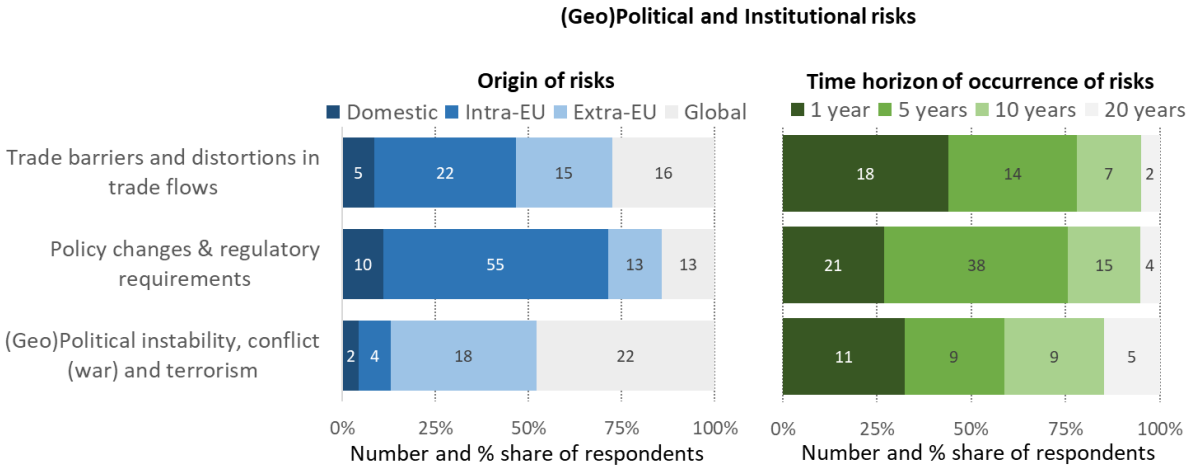


Sources: Online survey, semi-structured interviews and literature review.

All the three risk categories are among the most frequently identified (compared with other risk types) in the interviews, suggesting that a wide range of stakeholders think that they are potential risks to their respective sectors. In particular, risks related to *Policy changes and regulatory requirements* are the most frequently identified in the interviews and online survey within this risk type. This suggests that stakeholders tend to attach a relatively high degree of importance to this risk category. This is not surprising, since EU food systems operate under stringent regulations (e.g. environmental, sanitary, animal welfare) and are supported by relevant policies (e.g. the common agricultural policy and the common fisheries policy). Changes in current policy frameworks, therefore, could create uncertainties at multiple stages of the food supply chain. Likewise, many stages of the EU food supply chain are integrated into the global food supply chain and rely on international trade (either for import or export). Hence, disturbances to trade can pose a risk for many food system stakeholders. It should be noted, however, that risks related to *Policy changes and regulatory requirements* are rarely mentioned in the literature and are emphasised much more by stakeholders.

Figure 14 shows the perceived origins and time horizons of occurrence of the Geopolitical and institutional risks. An overview of all risk types is provided in Annexes 7 (origins) and 8 (time horizons). The analysis shows that interviewees typically identify geopolitical instability, conflict, and terrorism risks as originating outside the EU. Most respondents perceive *Policy changes and regulatory requirements* as primarily stemming from intra-EU or domestic sources, indicating that EU policy shifts can pose significant uncertainty. Opinions were divided on the origins of trade risks. All these risks are seen as likely to materialise in the short term by a large proportion of respondents, although many respondents also perceive geopolitical risks to have a notably long-term outlook.

Figure 14. Origins and time horizons of occurrence of (Geo)Political and Institutional risks as perceived by respondents



NB: Full comparisons between all risk types and categories are provided in Annexes 7 and 8.

Source: Semi-structured interviews.

(Geo)political instability, conflict (war) and terrorism risks were generally perceived by interviewees to be of global or extra-EU origin (about 90% of mentions). This was expected as the (Geo)Political situation in the EU is stable compared with other parts of the world.

The intra-EU and domestic sources were perceived to be the main origins of risks related to *Policy changes and regulatory requirements*, according to around 75% of all respondents, with around 70% of all respondents pointing to intra-EU sources. This might indicate that EU-level, rather than domestic, policy changes are perceived to be the main source of uncertainty. To some extent, this might be because of the EU-level nature of the survey and interviews carried out for this study, which might have led participants to pay greater attention to EU-level policy. Moreover, most relevant policies to support food systems and key regulations related to, for example, environmental protection, food hygiene and human health originate at the EU level. Yet, to some extent, policy shifts might originate globally, for example when driven by the sustainable development goals or multilateral trade negotiations.

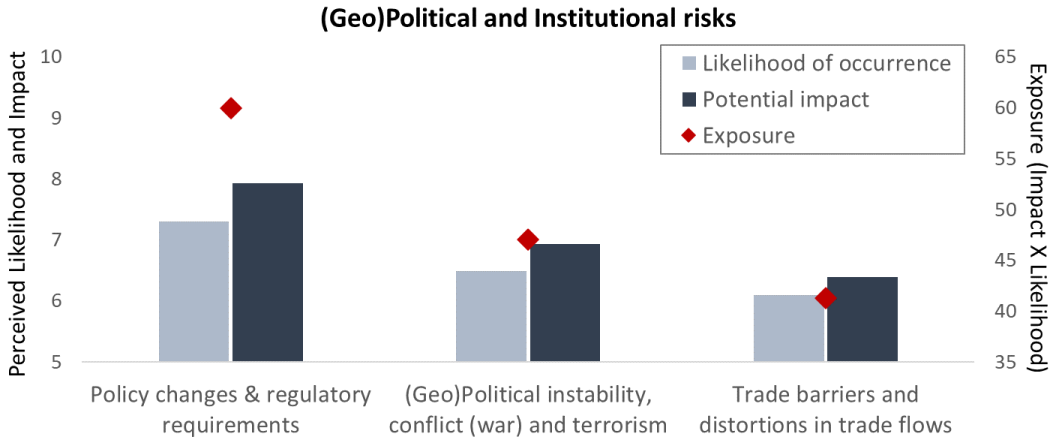
Answers about origin were mixed for the *Trade barriers, distortions in trade flows* risk category. Slightly more than 50% of respondents perceived extra-EU or global origins to be the sources of these risks, giving examples of international trade disruption such as the 2021 Suez Canal obstruction; increased trade tariffs or export bans by non-EU countries (e.g. in response to harvest failures); and changes in the trade policies of some extra-EU countries such as the United States. However, the largest category of reported origins for this risk is the intra-EU, accounting for about 40% on its own. This in turn was explained by disturbances to intra-EU trade flows caused by, for example, farmers, truck drivers, and air traffic control strikes and blockades, or obstacles to the single market by unilateral national measures. It is also likely that limitations caused by the recent pandemic influenced stakeholders' perceptions of the origins of risks in this category.

All three Geopolitical and institutional risks were perceived to have a short-term time horizon (1 to 5 years) by more than 50% of respondents, and, more specifically, by around 75% of respondents for the risk categories *Trade barriers, distortions in trade flows*, and *Policy changes and regulatory requirements*. As mentioned before, the ongoing Russian war of aggression against Ukraine has led to major instabilities worldwide and might cause stakeholders to perceive related risks to be imminent. For instance, the combination of the price hikes caused by the ongoing conflict and the increased frequency of extreme weather events leading to harvest failures (European Commission, 2023) could make stakeholders perceive these risks to be very likely in the coming (few) year(s). It is important to mention that, for the *(Geo)political instability, conflict (war)* risk category, the answers varied, as this category was perceived to have a long-term time horizon (within 10 to 20 years) by around 40% of respondents.

Figure 15 shows the perceived likelihood of occurrence of (within the next 3 years), potential impact of, and exposure to each of the three identified (Geo)Political and Institutional risk categories. The analysis indicates that the level of exposure is perceived to be higher for the *Policy changes and regulatory requirements* risk category than for the other Geo)Political and Institutional risk categories; this is mostly driven by the high

perceived likelihood associated with this category. The perceived exposure value for the category *(Geo)political instability, conflict, and terrorism* is lower than that for the Policy changes and regulatory requirements risk category. The category of *Trade barriers and distortions in trade flows* has the lowest perceived impact and likelihood values within this risk type.

Figure 15. Perceived likelihoods of occurrence of (within the next 3 years), potential impacts of, and exposure to (Geo)Political and Institutional risks



Source: Online survey.

According to the survey results, exposure values for (Geo)political and Institutional risks range between 41 and 59 points. The category 'policy changes and regulatory requirements' has the highest exposure value within this risks type, equal to 59 points, which is also notably high compared with the other risk types identified. Therefore, despite the opportunities they can create, changes in policies and regulatory requirements are perceived by the survey respondents to be among the risks most likely to occur, across not only the (Geo)Political and Institutional risk type but also the other risk types. The high exposure value for this risk category is mainly driven by its high likelihood value.

The high perceived likelihood value is largely influenced by the already advanced level of development of certain draft regulations identified by the industry stakeholders during the interviews. Some examples mentioned by interviewees include the proposal for changes to the packaging and waste regulation, and the proposed restriction of per- and polyfluoroalkyl substances; the establishment of new marine protected areas; the possible prohibition of diesel engines in fishing vessels; and the green transition in general. Policy and regulatory changes generate uncertainties about the actions that must be taken to comply with rules. Similar reasoning applies to modifications of existing aid schemes. All of these factors might represent risks in terms of increasing production costs or administrative burden, or requirements for the adaptations and investments necessary for transitioning towards more sustainable and resilient food systems.

Political instability can also hinder international trade. The *(Geo)Political instability, conflict (war) and terrorism* category has a lower exposure value than the 'policy changes and regulatory requirements' category, equal to 48 points, and it is also the least frequently mentioned category within this risk type during the survey and interviews. Risks in this category are expected to have a lower impact and be a little less likely to occur than risks in the other categories. Generally, the level of exposure of the sector to political instability is expected to be low unless the instability endangers supply chains with critically concentrated input sources (e.g. soybean or potassic fertilisers). EU exporters might be affected by such risks (e.g. the sudden loss of a key outlet), but this would cause less of a risk for food security in the EU. However, the potential consequences of conflicts might have been underestimated, especially in the long term, as these events are hard to envisage.

Finally, the *Trade barriers and distortions in trade flows* category has the lowest potential impact and likelihood values within this risk type, resulting in an exposure value of around 41 points, one of the lowest values across all risk types. This might be explained, at least in part, by existing dependencies on imported inputs or export markets being specific to only certain sectors of the supply chain, or by existing trade flows being sufficiently diverse to ensure the provision of key inputs or export flows even in the event of major instabilities. Standing

international trade rules and EU trade policy might have contributed to the perceived risk of trade disruption being relatively low. Note that many risks related to international trade, such as input availability, market instability and competition, are also categorised under the economic and market risk type, discussed in Section 3.2.2.

3.2.5 Supply chain performance risks

The Supply chain performance risk type refers to risks arising from issues affecting food management, logistics operations and input provision in the food supply chain. It includes three risk categories, which are described below.

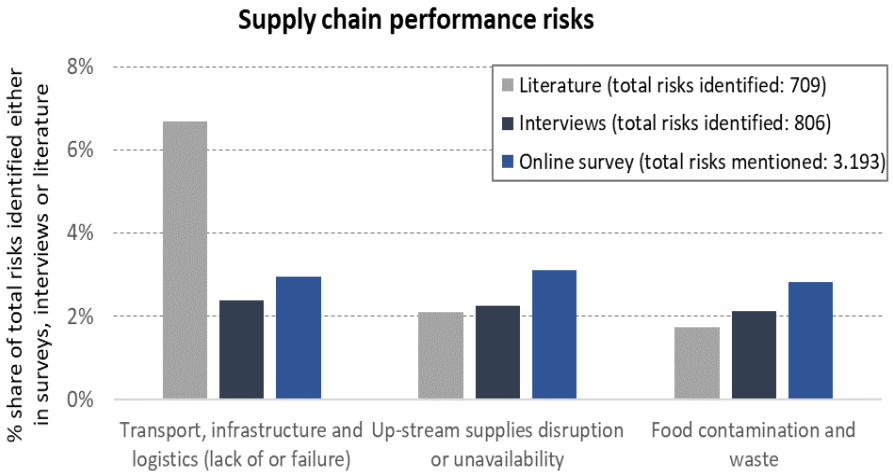
The category *Food contamination and waste* refers to risks originating in the management of food and intermediary products. These pertain to issues such as food chain pollution deriving from industrial accidents (microbiological, radiation, viruses, toxins, etc.), recycling related contamination, unreliable laboratory methods used in contaminant monitoring and fraud. These risks are tightly related to the effectiveness of control and monitoring of contaminants that allow for timely detection.

The category *Transport, infrastructure and logistics (lack of or failure)* refers to risks arising from the network of interconnections between different actors of the food supply chain, notably linked to the movement and storage of food and other intermediary products. It includes threats affecting logistics and facilities (scarcity/disruption), transport (inefficiency, lack of, increased costs), ports (inefficiency of / closure of), machinery (malfunctioning / lack of) and travel restrictions. Examples include the recent COVID-19 pandemic restrictions, Brexit-related logistics challenges, unavailability of storage space and the sudden scarcity of critical and highly specialised machinery components.

The category *Up-stream supplies disruptions or unavailability* refers to risks stemming from the interruption of supplies of key inputs. It includes threats to the availability of critical inputs from the primary sector, some of which are often imported from extra-EU sources. The EU is highly reliant on several key imports such as primary ingredients, packaging raw material and feed. Disruptions in intra-EU packaging production activities, for example, could have a severe impact on the sector, leading to interruption of marketing and food waste.

Figure 16 illustrates and compares the frequencies of appearance of these risk categories in the literature, the semi-structured interviews, and the online survey. This frequency analysis shows that none of the three risk categories stands out within this risk type. Moreover, these risks are among the least frequently identified of all risk types in the interviews and the online survey. Therefore, fewer stakeholders perceive these risks as very frequent in their sectors supporting the idea that they are not concerned about them. Risks related to *Transport, infrastructure and logistics (lack of or failure)*, however, are frequently identified in the literature (about 6% of total risks identified), in comparison with the other supply chain performance risk categories and also with categories of the other risk types. Consequently, this risk category includes recurrent adversities in the supply chain logistics, but it is also partly due to the disruptions caused by COVID-19 restrictions, which received special attention in the literature.

Figure 16. Frequencies of identification of Supply chain performance risks, and comparison between online survey, interviews and reviewed literature sources

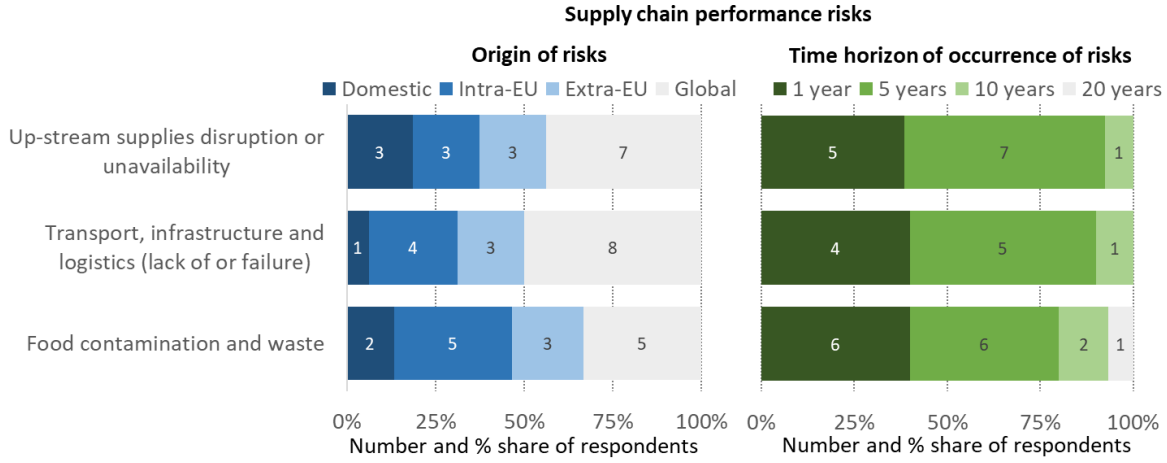


NB: A full comparison between all risk types and categories is provided in Annex 7.

Sources: Online survey, semi-structured interviews and literature review.

Figure 17 shows the perceived origins and time horizons of occurrence of Supply chain performance type of risks. An overview of all risk types is provided in Annexes 7 (origins) and 8 (time horizons). The analysis highlights that the categories *Up-stream supply disruptions* and *Transport or logistics failures* are mainly perceived to have global or extra-EU origins, reflecting the EU food supply chain's global integration. However, perceptions of the origins of the category *Food contamination and waste* risk origins are evenly split between domestic/intra-EU and extra-EU/global origins, suggesting the potential for both imported and local food contamination. All three risks are considered likely to occur in the short term, possibly influenced by recent events such as the COVID-19 pandemic, geopolitical instabilities, and Brexit.

Figure 17. Origins and time horizons of occurrence of Supply chain performance risks as perceived by respondents



NB: Full comparisons between all risk types and categories are provided in Annexes 7 and 8.

Source: Semi-structured interviews.

All three supply chain performance risk categories were perceived to have a global or extra-EU origin by at least 55% of respondents. In the case of both the *Up-stream supplies disruptions or unavailability* and *Lack of or failure of transport, infrastructure and logistics* categories, around 70% of respondents perceived a global or extra-EU origin. These results reflect the degree of integration of the EU food supply chain into the global supply chain, and the many risks associated with each logistical step. Alternatives could be found in local and regional

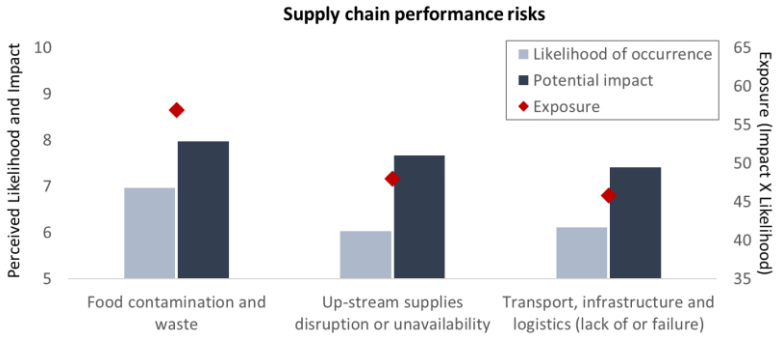
food supply chains, where the interdependencies with external sources are reduced, and the vulnerable points along the supply chain logistics are limited.

However, responses for the *Food contamination and waste* risk category were diverse and balanced, with around half of respondents selecting domestic and mainly intra-EU origins and the other half selecting extra-EU and global origins. This most likely reflects the possibility that imported food can be contaminated, in addition to the fact that contamination can also occur within the EU.

All three supply chain performance risk categories were perceived to have short-term time horizons (within 1 to 5 years) by more than 75% of respondents. This result reflects stakeholder perceptions of the need to address these risks with relative urgency. This perception could have been influenced by recent events, such as the COVID-19 pandemic, current geopolitical instabilities and challenges brought about by Brexit, all of which have revealed several vulnerabilities and threats to the functioning of the EU food supply chain.

Figure 18 shows the perceived likelihood of occurrence of (within the next 3 years), potential impact of, and exposure to each of the three identified Supply chain performance risk categories. The analysis of exposure shows that the *Food contamination and waste* risks has the highest exposure value. The *Transport, infrastructure, and logistics* and *Up-stream supplies disruptions or unavailability* risk categories have lower exposure values, mainly because of their lower likelihood values, but their impacts can be significant because of the complex nature of the food supply chain.

Figure 18. Perceived likelihoods of occurrence of (within the next 3 years), potential impacts of, and exposure to Supply chain performance risks



Source: Online survey.

The *Food contamination and waste* category has the highest exposure value within this risk type, equal to 57 points, which is also notably high compared with the other risk types identified. This risk category is perceived to have a higher likelihood of occurrence than other supply chain performance risks. In fact, according to recent studies (EFSA, 2023), certain contaminants are increasingly present in EU food. This category of risk has the potential to impact on every sector and every stage of the supply chain. Food can be contaminated at the production level, such as by pesticides on farms or by microplastics in the oceans, and at other stages. Examples include microbiological and chemical contamination at the processing level or during storage. Initial contamination can compromise product availability along the supply chain, creating a cascading effect. This may subsequently affect prices, and demand could halt, as consumers might choose to avoid the product because of safety concerns or concerns about potential health repercussions from consumption.

The other two risk categories, *Transport, infrastructure, and logistics*, and *Up-stream supplies disruptions or unavailability*, have the lowest exposure index values within this risk type, of between 41 and 47. Specifically, the exposure index value for *Transport, infrastructure, and logistics* risks is significantly lower than the exposure index values for the other risk types identified. It is also worth noting that these risks have a low likelihood value but a significant impact value. This could be attributed to the complex arrangement of the food supply chain, developing along several steps and involving multiple intermediaries.

3.2.6 Information and Technology risks

The Information and Technology risk type refers to risks originating in a lack of information; technical, technological or digital disruptions; and the potential harm caused by innovative technologies. These risks hold

significant importance for EU food systems, as their productivity and sustainability largely depend on the successful application of knowledge, innovation and technology. The information and technology risk type includes three risk categories, which are described below.

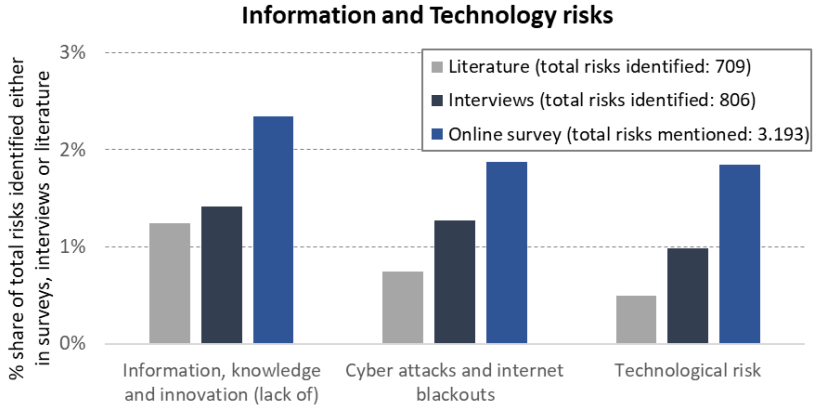
The category *Lack of information, knowledge and innovation* covers issues related to insufficient research and training; inadequate information and transparency (including fake news) and declining trust in official information; limited innovation and investments; inaccurate or unavailable forecasts; agricultural transition; and loss of cultural heritage or traditional knowledge.

The category *Technological risks* includes concerns such as technical disruption, technology fatigue, the application of biotechnologies (e.g. genetically modified organisms and clustered regularly interspaced short palindromic repeat (CRISPR) technology), late or no adoption of innovative technologies (possibly linked to low acceptability) and the technological divide. Technological risks, such as the malfunctioning of advanced agricultural machinery or fishing vessels, interconnected precision-farming tools, automated processing lines or software systems, could result in operational inefficiencies, reduced productivity, financial losses and lower outputs.

The category *Cyberattacks and internet blackouts* refers to risks that can paralyse digital operations, halt real-time data collection and analysis, and disrupt communication channels, thereby hindering decision-making processes and causing significant operational delays. This risk category includes threats such as large-scale internet blackouts (due to war or conflict, as well as large-scale cyberattacks), more localised failures of the internet, cybersecurity risks, disinformation campaigns and IT system failure. While the increasing digitalisation of food systems brings clear positive effects, it also makes systems more vulnerable to cyberattacks. These can compromise sensitive data, disrupt operations and erode trust among stakeholders.

Figure 19 shows and compares the frequencies of appearance of these risk categories in the literature, the semi-structured interviews, and the online survey. This frequency analysis reveals that Information and Technology risks are mentioned less frequently than the other risk types; yet, growing trends in cyberattacks warrant paying further attention to this risk in future.

Figure 19. Frequencies of identification of Information and Technological risks, and comparison between online survey, interviews and reviewed literature sources



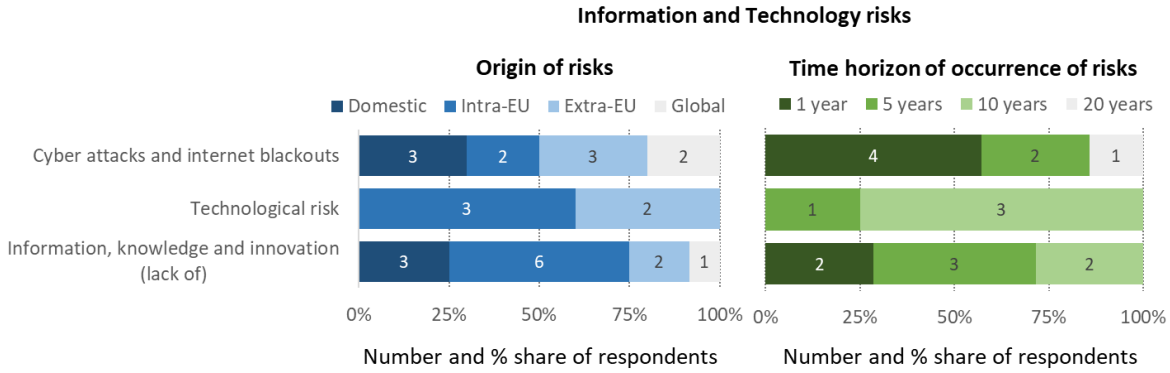
Sources: Online survey, semi-structured interviews and literature review.

The three information and technology risk categories are generally mentioned less frequently than the other risk type categories; thus, this suggests that relatively few stakeholders perceive them to be possible risks or attach importance to them. However, as suggested by some interviewees, it is interesting to consider that the low frequencies of identification of these risks could also be interpreted as indicating a general low level of awareness among stakeholders about risks related to cybersecurity and cyberattacks. Past literature also paid a relatively little attention to these risks, possibly because the digitalisation of the food systems is a relatively recent phenomenon, however, the growing rate of adoption of digital technologies is likely to come with increasing risks (OECD, 2022). The recent increase in cyberattacks in the EU, linked in part to the Russian war of aggression against Ukraine, might also have contributed to increasing concerns about the security of data

and digital infrastructures ([7]). This underscores the importance of further research and analysis in this area, given the growing adoption of digital technologies in the food systems.

Figure 20 shows the perceived origins and time horizons of occurrence of Research and technology type of risks. An overview of all risk types is provided in Annexes 7 (origins) and 8 (time horizons). Note that the results for this risk type should be considered with caution, as they are derived from a relatively small number of responses. The analysis highlights that risks related to *Cyberattacks and internet blackouts* are perceived to have both domestic and global origins, reflecting the widespread nature of these threats. *Technological risks* and risks related to a *Lacking information, knowledge, and innovation* are mostly perceived to have originated within the EU, often in relation to local technological and knowledge gaps within sectors. Risks related to a lack of *Information, knowledge and innovation*, as well as risks related to *Cyberattacks*, are seen as being likely to occur in the short term, with cyberattack risks heightened by the current political climate and the pace of innovation being seen as posing challenges. *Technological risks*, in contrast, are mostly seen as long term issues, linked to uncertainties about future technologies.

Figure 20. Origins and time horizons of occurrence of Information and Technological risks as perceived by respondents



NB: Full comparisons between all risk types and categories are provided in Annexes 7 and 8.

Source: Semi-structured interviews.

Responses for the *Cyberattacks and internet blackouts* risk category were diversified and balanced, with 50% of respondents referring to a domestic or intra-EU origin and the other 50% to an extra-EU or global origin. This was expected, as it reflects the natural ambiguity of cyberattacks, which can originate from anywhere in the world, with the exact origin often being difficult to determine. When mentioning extra-EU and global cyberattacks, stakeholders referred to those that occurred after (and often because of) Russia's unprovoked invasion of Ukraine.

On the other hand, the *Technological risk* and the lack of *Information, knowledge and innovation* categories were perceived to have domestic and intra-EU origins by 60% and 75% of respondents, respectively. The know-how and technologies adopted in the EU food supply chain are mostly independent from extra-EU influences. An example is the risk associated with the introduction of new biotechnologies. Hence, risks stemming from technologies are mainly intrinsic to the food supply chain. Some interviewees explained this by stressing the fact that, in some cases, there are local technological gaps between different stakeholders in the same sector, mainly due to financial or educational reasons.

The *Cyberattacks and internet blackouts* and the lack of *Information, knowledge and innovation* risk categories were perceived to have short-term time horizons (within 1 to 5 years) by 80% and 75% of respondents, respectively. For the *Cyberattacks and internet blackouts* risk category, this could be explained by the current political situation in Europe that is, following Russia's unprovoked invasion of Ukraine, which has made stakeholders more prudent and cautious. For the lack of *Information, knowledge and innovation* risk category, the perception of a short-term time horizon is likely to be explained by the fact that, as mentioned above, the need for innovations in the EU food system is increasing rapidly (e.g. because of increasing sustainability

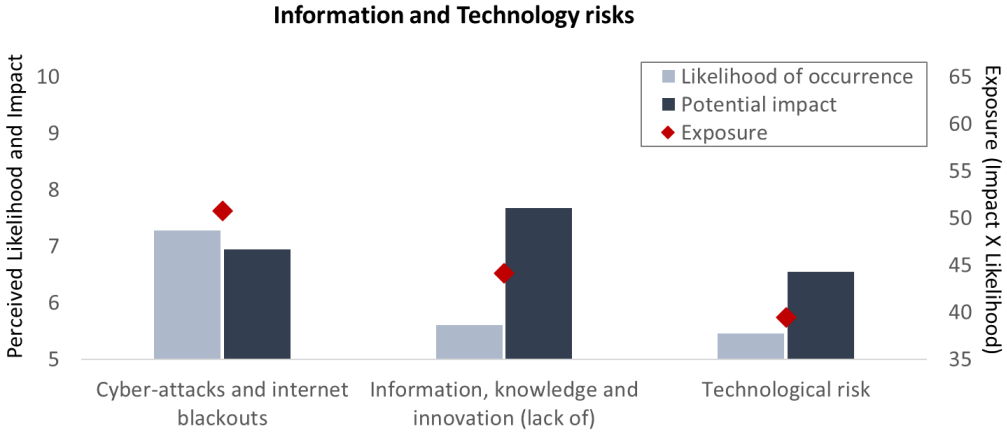
([7]) See for example the debate at the European Parliament on recent cyberattacks and the EU cybersecurity strategy (https://www.europarl.europa.eu/RegData/etudes/ATAG/2021/690639/EPRS_ATA%282021%29690639_EN.pdf).

requirements and climate adaptation needs). This puts stakeholders at risk of not being able to keep up with the pace of innovations in the coming years.

In contrast to the abovementioned categories, three out of four respondents chose the long-term option (within 10 years) for the *Technological* risks category. These risks might be perceived to be linked to uncertainties around the development of technologies, the implications of which are still mostly unknown (artificial intelligence being an example).

Figure 21 shows the perceived likelihood of occurrence of (within the next 3 years), potential impact of, and exposure to each of the three identified Information and Technology risk categories. The analysis of exposure shows that the *Cyberattacks and internet blackouts* risk category has the highest exposure value, also because of the increasingly digitalised food supply chain. The risk categories *Information, knowledge, and innovation*, and *Technological risks* have a lower exposure values, mainly driven by their very low perceived likelihood values.

Figure 21. Perceived likelihoods of occurrence of (within the next 3 years), potential impacts of, and exposure to Information and Technology risks



Source: Online survey.

The *Cyberattacks and internet blackouts* category has the highest exposure index value within this risk type, equal to 51 points. This exposure level suggests that this risk category is considered as important as categories from the other risk types assessed above, even though it is less well known and, in general, was less frequently mentioned during the interviews and in the online survey. It is worth noting that they have a relatively high likelihood of occurrence, apart from a significant potential impact. Since food supply chain processes are being increasingly digitalised, cyberattacks were reported by some stakeholders to seriously affect the food supply chain at several steps.

The Information, knowledge and innovation category has a relatively low exposure index value, equal to 44 points, and was the risk most frequently identified within this risk type, both during the interviews and in the online surveys. It is interesting to note that the likelihood of this risk occurring was perceived to be low, but that the level of potential impact was perceived to be relatively high. Know-how is key to adopting the new technologies and innovative solutions needed to meet growing sustainability goals and requirements, and information is key to making market choices and monitoring risks. A lack of information leads to lower competitiveness and lower capacity to anticipate adversities. Furthermore, as emphasised during the interviews, the lack of investment in innovations aimed at shifting production towards sustainability models can lead to reduced competitiveness, greater dependency on imports, limited product availability and reliance on obsolete technologies with related risks. Consider, for example, the case of the EU's fleet of fishing vessels, which, on average, is quite aged. This poses a potential risk to the fishery industry, since the sector might struggle to comply with new sustainability regulations. Moreover, it may face challenges in maintaining high-quality work among crews, making it difficult to attract new workers. Consequently, the ageing fleet could ultimately result in a substantial decline in the overall size of the fleet.

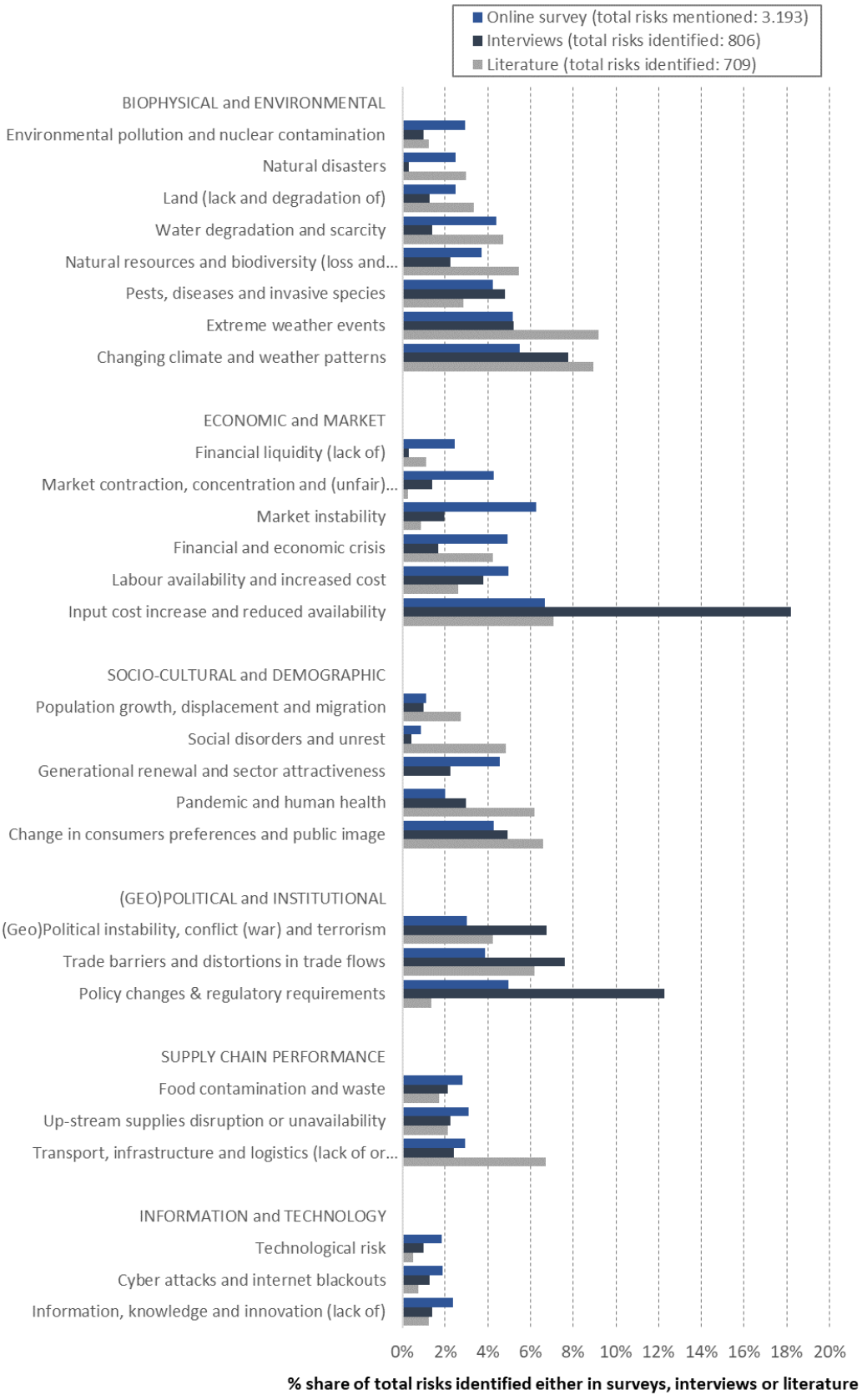
Finally, the category *Technological risks* has the lowest exposure value of this risk type, equal to 39, which is also one of the lowest among all risk types. Although interviewees mentioned risks such as technical disruption, technology fatigue, the technological divide and those inherent to the application of biotechnologies, both the likelihood and impact values for this risk category are perceived to be relatively low.

3.2.7 Synthesis of the analysis of risk types

The aim of this section is to define which risk types and categories are most frequently identified by stakeholders or characterised by the highest exposure values overall. This is done by synthesising the takeaways of the previous sections (Sections 3.2.1–3.2.6) and by comparing the findings across risk types. Figure 22 shows the frequencies of identification of all risk types and categories across the literature, the interviews and the online survey.

Overall, the Biophysical and Environmental, Economic and Market, and Socio-cultural and Demographic risk types are the most frequently identified across all sources. However, some differences among sources can be underlined, especially when it comes to the identification of categories.

Figure 22. Frequencies of identification of all risk types and categories in the literature review, interviews and online survey



Sources: Literature review, semi-structured interviews, and online survey.

Biophysical and Environmental and Socio-cultural and Demographic risks are generally the most frequently identified in the literature. Hence, this suggests that these have drawn a higher degree of attention from scientists and policymakers in the past 10 years than the other risk types. Specifically, the risk categories most frequently identified in the literature are *Extreme weather events, Changing climate and weather patterns, Lack of transport, infrastructure and logistics, Change in consumers preferences and public image,* and *Pandemic and Human Health*.

On the other hand, the interviews reflect stakeholder perceptions regarding the array of risks that may affect the sector from current and future perspectives. (Geo)Political and Institutional risks are generally the most frequently identified in the interviews, followed by some Biophysical and Environmental, and Economic and Market risks. In particular, the risk categories that are most frequently identified by stakeholders in the interviews are *Input cost increase and reduced availability* (by far the most frequently identified), *Policy changes and regulatory requirements*, *Changing climate and weather patterns*, *Trade barriers and distortions in trade flows*, *(Geo)Political* instability*, conflict (war), and terrorism*, *Extreme weather events* and *Pests, diseases, and invasive species*. Risks related to input costs are frequently identified in the interviews (much more than in the literature) probably because this phenomenon is ongoing or has been recently experienced by stakeholders.

The risk categories *Water degradation and scarcity, Social disorders and unrest*, *Loss of natural resources and biodiversity*, and *Disruption of transport, infrastructure and logistics* are often highlighted in the literature. However, despite the emphasis previously placed on these risks by scientists and policymakers, they draw less attention from stakeholders from current and future perspectives. Yet, these risks merit further attention, as stakeholder perceptions can be driven by current events. On the other hand, risks that are more frequently identified by stakeholders but less frequently identified in the literature, such as risks in the categories *Pests, diseases and invasive species*, *Market contraction and concentration* (especially threats to single market) and *Cyberattacks and internet blackout*, warrant further attention, as their frequent identification by stakeholders might indicate (perceived) threats that are likely to increase in the future.

While the interviews identify a range of possible risks perceived by stakeholders, the online survey identifies risks to which respondents attach more importance to than others. In the online survey, the Economic and Market, Biophysical and Environmental, and (Geo)Political and Institutional risk types are the most frequently selected. In contrast, the Supply chain performance and Information and Technology risk types are the least frequently selected. Specifically, the risk categories to which stakeholders attach greatest importance in the survey are *Input cost increase and reduced availability*, *Market instability*, *Changing climate and weather patterns*, *Extreme weather events*, *Policy changes and regulatory requirements*, *Labour availability*, *Lack of generational renewal*, *Pest, diseases and invasive species* and *Financial and economic crises*.

Figure 23 shows the risk exposure values for all risk types and related risk categories. These risk exposure values measure the potential hazardousness of the risks, as perceived by stakeholders. The Biophysical and Environmental, and Economic and Market risk types have the highest exposure levels. Nonetheless, some other risk categories, belonging to different risk types, also have very high exposure levels.

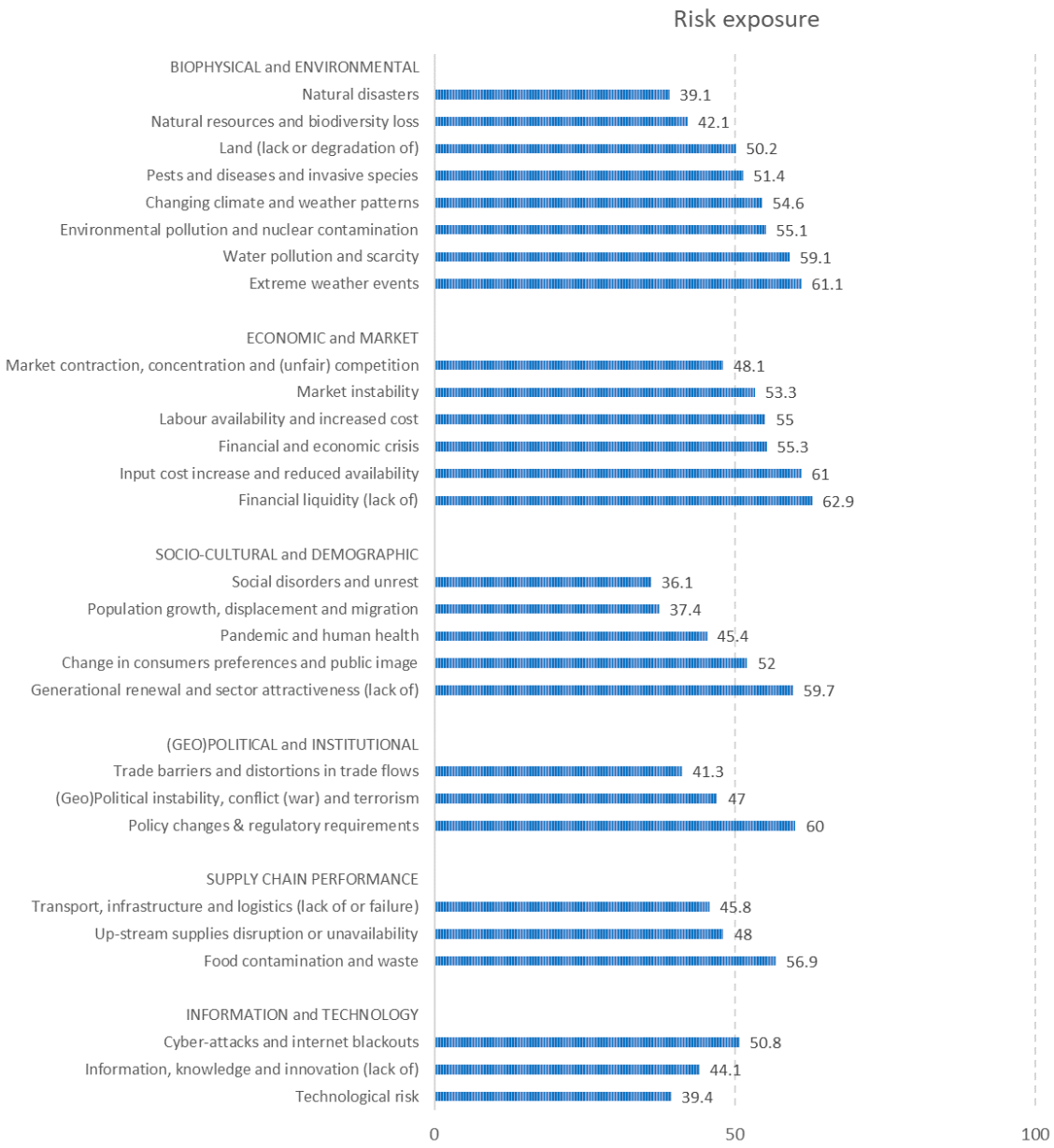
The risk categories with the highest exposure values are *Lack of financial liquidity*, *Extreme weather events*, *Input cost increase or reduced availability*, *Policy change and regulatory requirements*, *Lack of generational renewal*, *Water degradation and scarcity*, *Food contamination and waste*, and *Environmental pollution and nuclear contamination*. It is interesting to note that several risk categories that were identified less frequently by stakeholders were perceived to be very hazardous. This is the case, for example, for *Water degradation and scarcity*, *Lack of financial liquidity*, *Lack of generational renewal*, and *Cyberattacks and internet blackout*. This is likely to be because a narrower range of stakeholders perceive these to be risks, but, when they do, they perceive them to be very hazardous.

Risks of the (Geo)political and Institutional type and in the category *Input cost increase and reduced availability*, are frequently identified across all sources and perceived to be highly hazardous. However, when assessing these results, it is important to consider that stakeholder perceptions regarding these risks might have been influenced by the effects of Russia's recent unprovoked invasion of Ukraine and related international instability, which has affected markets for raw materials, including energy and fertilisers, and general international trade patterns. This is supported by the fact that the frequencies of identification of these risks are higher in the interviews and survey than in the literature.

In conclusion, while Biophysical and Environmental, Economic and Market, and Socio-cultural and Demographic risks are consistently mentioned across the literature, interviews, and online surveys, the emphasis placed on specific risks varies among these sources. Some risks, extensively covered in the literature, attract less attention from stakeholders, whereas other risks, less prominent in the literature, emerge as potential future threats

based on stakeholder responses. The influence of recent geopolitical events, such as the Russian war of aggression against Ukraine, on stakeholder perceptions underscores the evolving nature of risk assessment. This highlights the importance of regularly updating our understanding of risks in response to changing global events.

Figure 23. Risk exposure: comparison of all risk types and categories



NB: A full comparison of the potential impact and likelihood of occurrence of all risk types and categories is provided in Annex 9.

Source: Online survey.

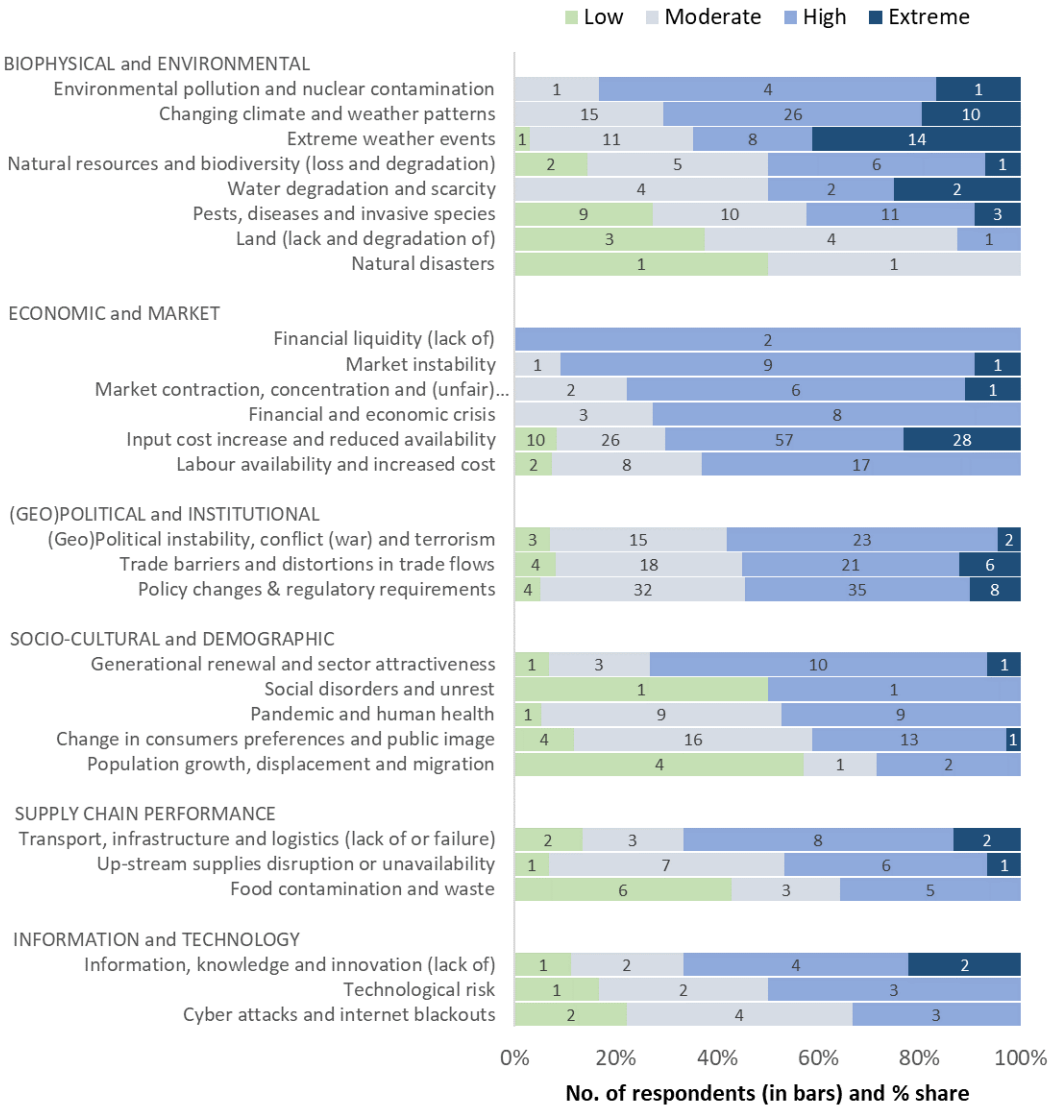
3.3 Analysis of the structural factors of vulnerability

An important piece of information to complement the analysis of risks relates to the capacity of the food supply chain to cope with or adapt to risks. This aspect is captured through the analysis of vulnerabilities. This section first explores the degree to which the supply chain would be vulnerable to the risks identified and then describes the factors driving this vulnerability.

3.3.1 Degree of vulnerability to different risks

This section presents the analysis of the degree to which the supply chain would be vulnerable to the risks identified. Figure 24 shows the degrees of vulnerability for each of the 28 risk categories, as perceived by the interviewees, according to four classes: low, medium, high and extreme vulnerability. It indicates the extent to which the supply chain is capable of dealing with each risk category: the higher the degree of vulnerability, the lower the ability to cope. Moreover, this figure is compared with the degrees of vulnerability perceived by respondents to the online survey (which is scored on a scale from 0 to 10, with 10 indicating the highest degree of vulnerability). Because the results of the interviews and the online survey are very consistent, the analysis of perceived vulnerability can be considered highly robust. The results from the interviews and the survey are analysed together below, while the survey results are reported in Annex 13.

Figure 24. Perceived degree of vulnerability by risk category



Source: Semi-structured interviews.

The analysis reveals that the highest level of vulnerability of the EU food supply chain is perceived for the "Biophysical and Environmental" and "Economic and Market" risk types. The highest degrees of vulnerability is recorded in relation to the risk categories *Extreme weather events*, *Input cost increase and reduced availability*, and *Changing climate and weather patterns*. However, vulnerability is also perceived to be high for other risk categories, such as *Generational renewal and sector attractiveness (lack of)*, *Transport, infrastructure and logistic failure*, and *Information, Knowledge and Innovation (lack of)*.

Biophysical and Environmental risks are the type of risks with the highest proportion of extreme levels of vulnerabilities in the interviews and, accordingly, it shows the highest average perceived vulnerability in the online survey. According to both the interviews and the online survey, *Environmental pollution and nuclear contamination*, *Changing climate and weather patterns* and *Extreme weather events* are the categories associated with the greatest levels of vulnerabilities. The *Water pollution and scarcity* category also stands out in the online survey, while a lower share of respondents assigned this category high or extreme levels of vulnerability in the interviews. This might be because fewer respondents in the interviews described this risk category.

Risks related to the *Changing climate and weather patterns* and *Extreme weather events* can be induced by climate change, which is a global trend over which stakeholders have little control (at least in the short term). This can partly explain such a high perception. As a further argument, interviewees often mention that alternatives and technological solutions for adapting to new (extreme) weather patterns are lacking, which could also have contributed to respondents perceiving the degree of vulnerability to these risks to be high or extreme. Yet, the degrees of vulnerability to *Natural disasters* and *Land (lack or degradation of)* are perceived to vary between low and moderate in the interviews and, likewise, have the lowest perceived vulnerability scores in the survey. As discussed in the analysis in previous sections (see Section 3.2.1), these risk categories are mainly perceived to be localised (i.e. limited to regional boundaries, or specific to certain regions) or rare (especially for natural disasters, which are most likely to occur over long time frames), which could explain why stakeholders perceive the degree of vulnerability to these risks to be low or moderate.

The EU food supply chain is perceived to be either highly or extremely vulnerable to Economic and Market risks by at least 70% of interviewees and this risk type has the second highest average perceived vulnerability score in the survey. *Input cost increase and reduced availability* is the risk category that is assigned the highest share of extreme values in the interviews and it also scores highly in the survey. However, survey respondents perceive equal degree of vulnerability for *Lack of financial liquidity* and *Financial and economic crises*. This difference with the interviews is probably due to the low number of interviewees describing these risks (only two in the case of financial liquidity). Recent experiences with input cost spikes triggered by Russia's unprovoked invasion of Ukraine, and also with difficulties in getting input supplies during the pandemic, have made evident the critical role of input provision for the food supply chain. Interviewees often refer to the lack of alternatives to current inputs for production and to the unavailability of inputs within the EU as critical issues for the food supply chain.

The degrees of vulnerability reported for the (Geo)Political and Institutional risk type are generally on a par with or slightly below the levels reported for the economic and market type, based on both interview and online survey responses. For the former risk type, around half of the interviewees perceived either high or extreme degrees of vulnerability. The three risk categories belonging to this risk type were assigned similar shares of high and extreme values in the interviews. However, survey respondents perceived a higher degree of vulnerability for the *Policy changes and regulatory requirements* category than for the other (Geo)Political and institutional risk categories. While policy changes often aim to reduce risks and vulnerabilities in food systems, they can come with costs for supply chain operators in the short term. Policy changes might require supply chain operators to adapt to new rules and support levels. It is likely that stakeholders perceive the evolution of policies to be an overarching dynamic over which they have no control (Komarek et al., 2020), and consequently they are likely to perceive themselves as vulnerable to the possible (sometimes uncertain) implications of policy changes.

Some Social-cultural and Demographic risk categories are assigned relatively low levels of vulnerability. It should be noted, however, that the degree of vulnerability to the risk category *Generational renewal and sector attractiveness (lack of)* is perceived to be high or extreme in about 70% of the cases in the interviews, and this category has one of the highest perceived vulnerability scores in the online survey of all risk types. This can be explained by the indispensable need for new people to take over businesses, on the one hand, and a generalised lack of (young) people willing to enter the sector, on the other, issues over which stakeholders do not have much control. The decline in generational renewal not only is a matter of economic attractiveness (as often mentioned

by the interviewees), but is also rooted in major cultural and demographic dynamics affecting the whole of the EU (Schuh et al., 2019), which are difficult to counter in the short term or by single stakeholders.

The Supply chain performance risk type comprises categories of risks to which the sector is considered less vulnerable, with a greater share of low and moderate vulnerability levels being assigned in the interviews to these risks than to the other risk types. This is possibly due to better mitigation possibilities and lower or more localised impacts. However, the degree of vulnerability to risks related to *Transport, infrastructure and logistic (lack of)* is perceived to be high or extreme in almost 70% of the cases in the interviews, which is also reflected by the fact that this risk category is assigned the highest score for this risk type in the online survey. According to the interviewees, this can be explained mainly by the broad interconnectedness of the food supply chain within the EU and the dependency on non-EU countries, which in turn lead to dependency on transport infrastructures.

Degrees of vulnerability assigned to Information and Technology risks are mixed, with the degree of vulnerability to *Cyberattack and internet blackout* being perceived to be relatively low, but greater shares of high and extreme vulnerability levels being assigned to *Information, knowledge and innovation* risks. This is reflected in both the interviews and the online survey. It was a shared opinion among interviewees that there is generally a low degree of awareness about risks stemming from cyberattacks, which could lead to a misinterpretation of the actual capacity to deal with this type of risk. Given the relatively recent emergence of this risk category, the perceived vulnerability to this risk might be not adequately pondered.

3.3.2 Factors determining the vulnerability to different risk types

This section presents the analysis of factors determining the degree of vulnerability to the different risk types. According to the frequencies of identification previously presented in Section 3.1.2, there are no significant differences between the frequencies of identification of the different factors. It is likely that the factors determining vulnerability are specific to the type of risk, meaning that the factors most frequently mentioned overall are not necessarily the most relevant for all risk types.

Based on the online survey, Table 1 shows which factors of vulnerability have a significant positive correlation with the degree of vulnerability for each of the six risk types, where degrees of vulnerability were assigned by survey respondents on a scale from 0 to 10 (with 10 being the maximum degree of vulnerability). The table is based on the results of linear regression analyses, the estimates from which are shown in Annex 14. By observing significant correlations, this analysis helps to identify which factors are likely to determine vulnerability to different risk types.

The analysis shows that the factors determining the degree of vulnerability can differ depending on the risk type. In particular, the *Low flexibility to change* can determine the degree of vulnerability to risks of the Socio-cultural and Demographic type and Economic and Market type, and a *Lack of (technological) alternatives* can increase the degree of vulnerability to Supply chain performance risks and Socio-cultural and Demographic risks. *Weak supply chain organisation* can determine the degree of vulnerability to Supply chain performance risks as well, whereas a *Lack of human capital* is relevant for Socio-cultural and Demographic risks and Information and Technology risks. A *Lack of financial resources* and a *Lack of natural resources* can increase the degree of vulnerability to multiple risk types, including Biophysical and Environmental risks, Economic and Market risks, (Geo)Political and Institutional risks and Socio-cultural and Demographic risks.

Table 1. Identification of the factors of vulnerability that significantly correlate with the degree of vulnerability to different risk types

Factors of vulnerability	Risk types					
	Biophysical and Environmental	Economic and Market	(Geo)Political and Institutional	Socio-cultural and Demographic	Supply chain performance	Information and Technology
Low diversity of input suppliers and/or clients						
High dependency on import/export						
Low flexibility to change		▲		▲		▲
Lack of financial resources or limited economic margins	▲	▲		▲		▲
Lack of natural resources available/accessible	▲	▲	▲			
Lack of human capital				▲		▲
Lack of (technological) alternatives, research or infrastructure	▲				▲	
Weak supply chain organization	▲				▲	
Policy and regulatory constraints and risk communication			▲		▲	

▲ Significant correlation among the factor of vulnerability and the vulnerability to the risk type

NB: Correlations were measured through a linear regression, and cluster-robust standard errors were computed (by Member State). Significance set at 90% confidence level. Estimates are reported in Annex 14.

Source: Online survey.

The degree of vulnerability to Biophysical and Environmental risks seems to be mostly affected by a *Lack of Natural Resources* (correlation coefficient 0.72), *Weak supply chain organisation* (0.45), a *Lack of (technological) alternatives* (0.39) and a *Lack of financial resources or limited margins* (0.28). The effect of lacking natural resources on the degree of vulnerability to Biophysical and Environmental risks is most likely linked to the availability of water for irrigation. Interviewees mentioned, for example, that European river systems depend on a limited number of mountains and that the use of water is often affected by (administrative) conflicts among river basins. Other examples mentioned were the lack of enough land to produce sufficient feed (especially important in dry years when yields are lower) or the limited availability of other natural resources within the EU, such as gas sources. On the other hand, the effect of *Weak supply chain organisation* on the degree of vulnerability to Biophysical and Environmental risks can be related to difficulties for producers in transferring increasing production costs downstream in the supply chain. Most climate-related risks, in fact, affect the production level, but the consequent (economic) losses are not evenly distributed along the supply chain. Lastly, as pointed out by some interviewees, the role of the factor *Lack of (technological) alternatives, research or infrastructure to cope with the risk* in affecting vulnerability to Biophysical and Environmental risks could be explained by the fact that adaptation to climate change and compliance with increasing environmental targets require the adoption of new techniques or technologies, but that these can be costly and are not always available or promptly available. The same could also apply to a *Lack of financial resources or limited margins*, which might lead to reduced capacity to invest in new strategies or simply to buffer economic losses caused by climate and environmental risks (e.g. droughts, pests).

The degree of vulnerability to Economic and Market risks mainly seems to be driven by a *Low Flexibility to Change* (correlation coefficient 0.34), a *Lack of Natural Resources* (0.32) and a *Lack of financial resources or limited margins* (0.18). According to the interviewees, this could be linked to those sectors that are highly dependent on specific inputs for which there are no alternatives (and also the natural resources available), which constrains the ability of the sector to make changes. Examples mentioned by the interviewees were the lack of accessibility to new land for agricultural production, the intrinsic dependence of food production on weather (e.g. seasonality) and the lack of alternatives to current inputs for production (e.g. feed, energy), but also the lack of financial resources to invest in new alternatives. At the production level (including agricultural, fishery and aquaculture production), interviewees mentioned limited economic margins as a driver of vulnerability to market risks (e.g. price volatility). The combination of these factors constrains the capacity of the food supply chain to react to Economic and Market risks.

The degree of vulnerability to (Geo)Political and Institutional risks seems to be mainly explained by *Policy and regulatory constraints and risk communication* issues (correlation coefficient 0.79) and a *Lack of natural resources* (0.63). As one could expect, factors related to *Policy and regulatory constraints* are strongly linked to risks related to policy changes (one of the risk categories under the (Geo)Political risk type). According to interview findings, stakeholders perceive that future policy changes may come with burdens in addition to existing rules. Hence, the current regulatory framework (which is already perceived to be demanding) makes stakeholders more vulnerable to further policy changes. *Policy and regulatory constraints* can also increase the vulnerability to risks stemming from international competition. According to interviewees, the differences between rules and standards of production applied in the EU and in non-EU countries for the production and supply of food (where either rules are different or compliance is not easily tracked) could contribute to making EU food systems more vulnerable in the global market. The correlation found between a *Lack of natural resources* and the degree of vulnerability to (Geo)Political and Institutional risks can be explained by the fact that disruptions of supplies of key inputs caused by conflicts or disturbances in trade are more difficult to compensate for when there is a lack of key resources within the EU. This is the case, for instance, for energy and fertilisers, whose import has been threatened by Russia's recent unprovoked invasion of Ukraine. Moreover, another interesting example emerging from the interviews is related to animal medicines and sanitary products, which are to a large extent supplied by Asian countries. The limited production of these products within the EU could represent a vulnerability of the food supply chain to an eventual interruption of supplies.

The degree of vulnerability to Socio-cultural and Demographic risks seems to be mainly determined by a *Lack of Human Capital* (correlation coefficient 0.93), a *Lack of financial resources or limited margins* (0.82) and a *Low flexibility to change* (0.65). A lack of human capital is particularly relevant for labour-intensive sectors (generally dependent on seasonal and migrant workers), where not only the lack of workers is challenging, but also the lack of know-how and skills is hindering the capacity of the sector to adapt. Regarding the effects of a *Lack of financial resources or limited margins*, interviewees explained, for instance, that the combination of businesses' cost structures (in particular labour costs) and inflation reduces their margins and therefore their ability to cope with risks related to, for example, *Changing consumer preferences*. Furthermore, a lack of economic perspective (reflected in low remuneration) can reduce the attractiveness of sectors (hence explaining the vulnerability to generational renewal), and financial resources for investments that would increase the quality of work are often lacking (frequently mentioned for the fishery industry).

The degree of vulnerability to Supply chain performance risks seems to be mainly driven by a *Lack of Technological Alternatives* (correlation coefficient 0.56), *Weak supply chain organisation* (0.48), and *Policy and regulatory constraints and risk communication* issues (0.38). Technologies are key to improving the functioning of the transport and logistics infrastructures underpinning the food supply chain. As an example, interviewees referred to the lack of new technological solutions or infrastructure to reinforce the logistics of the supply chain (e.g. the limited freezing capacity and the lack of technologies to remove microbiological contamination along the chain). In addition, interviewees mentioned how organisation along the supply chain can affect its performance, especially in relation to transport and logistics infrastructures. For example, fragmentation along the chain can hinder cooperative efforts to set up the necessary infrastructure. The relatively low degree of organisation at the production level (where several, often relatively small, actors are involved in food systems) can also weaken producers' ability to cope with risks related to the disruption of upstream input supplies.

The degree of vulnerability to Information and Technology risks seems to be related to the factors *Lack of Financial Resources or Limited Economic Margin* (correlation coefficient 0.61), *Low flexibility to change* (0.59) and *Lack of Human Capital* (0.50). A common thread across the interviews, in fact, was the mention of the high costs of investing in new technologies. This holds true for a wide range of technologies, including irrigation and other on-farm technologies, information and data technologies, and technologies for modernising fishing vessels. While the lack of financial capital represents a barrier to investments in new technologies, the low profitability of businesses can hinder access to credit or make investment economically unfeasible. The findings in relation to the effect of a *Lack of Human Capital* are not surprising, as the adoption of innovation and new technologies requires (sometimes very advanced) know-how and skills, which are not always available. In this regard, it is also interesting to mention that, according to some interviewees, the generally low level of awareness and knowledge about cyber risks and cybersecurity across businesses and administrations leads to insufficient investment in cybersecurity solutions.

Factors related to *Low diversity of input suppliers or clients* and *High dependency on import/export* are not correlated to the vulnerability to any specific risk type, despite being identified as important factors of vulnerability (see figure 3). In part, this could be due the fact that these are crosscutting vulnerabilities that do not particularly explain any of the risks. Moreover, the correlations were estimated at aggregated level and,

thus, may hide some relationships potentially present at sectoral or supply chain stage levels. Due to limited sample size, analysis of correlations at sectoral or stage level were not conducted.

4 Key risks to food supply and security

This chapter presents the risks identified as outstanding, that is, those that appear to threaten the EU food supply chain the most. The identification of these risks is based on the analysis of Risk Index values, the frequencies of identification in the online survey and the content analysis of the interviews and literature. The Risk Index values are used to assess and compare the relevance of each risk category, with risks with high Risk Index values being considered to warrant major attention. The Risk Index takes into account both risk exposure and vulnerability to risk (see Section 2.3 and Annex 1 for further details on the Risk Index).

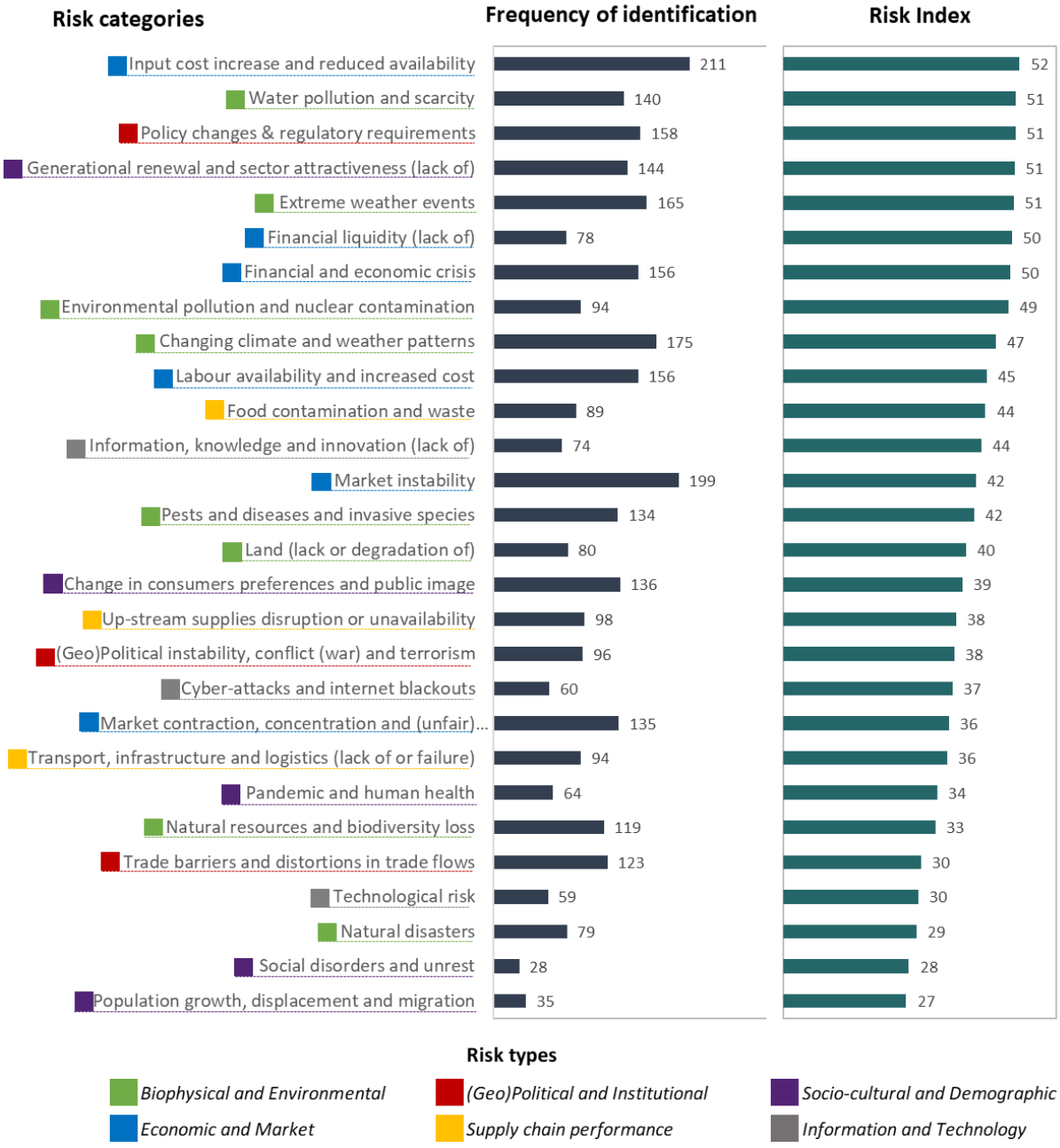
In the first place, outstanding risk categories are highlighted by comparing the overall Risk Index, and their frequency of identification in the online survey. Secondly, the Risk Index is computed by risk type and compared between the 27 EU Member States, to assess the heterogeneity of risks across countries. A focus is put on the outermost regions, where information from the literature and the interviews is brought together to outline the particular risks affecting these regions. The Risk Index of the 28 risk categories and the content analysis of the interviews and the literature are used to assess the main risks affecting sectors and stages of the supply chain. Lastly, an analysis of the differing risk perceptions among stakeholders is provided. The analysis compares the frequency of identification and the perceived Risk Index for the six risk types between different business size categories, and between different types of stakeholders.

4.1 Outstanding risks

This section presents the most outstanding risk categories, that is, those that are perceived to threaten the food supply chain the most, based on the assessment of the Risk Index values, and the frequency of identification in the online survey. The findings suggest that, overall, the most threatening risks for the EU food supply chain appear to be mainly Biophysical and Environmental type, as well as Economic and Market type of risks. There are, however, other types of risks that can threaten the supply chain, such as *Generational renewal and sector attractiveness*, and *Food contamination and waste*.

Figure 25 shows the frequency of identification in the online survey and Risk Index for the 28 risk categories. The frequency of identification allows for assessing the relative importance that stakeholders attach to different risks, which reflects how wide the range is of stakeholders identifying the risk as important. On the other hand, the Risk Index reflects the extent to which a risk represents a threat.

Figure 25. Frequency of identification and Risk Index value by risk category



NB: Risk categories are ordered from the highest to the lowest Risk Index.

Source: Online survey.

Observing the frequency of identification, most importance seems to be attached to Economic and Market type, and Biophysical and Environmental type of risks. For instance, *input cost increase* (211), *market instability* (199), *changing climate and weather patterns* (175), and *extreme weather events* (165) are the most frequently selected risks. Yet, other types of risks are also frequently identified. This is the case of *policy changes and regulatory requirements* (158), *generational renewal and sector attractiveness (lack of)* (144), and *change in consumer preferences and public image* (136).

On the other hand, Socio-cultural and Demographic type and Information and Technology type of risks are generally selected less frequently. In particular, the frequency of identification of *social disorders and unrest*, *population growth, displacement and migration*, *technological risk*, *cyberattacks and internet blackout*, and *pandemic and human health*, varies between 28 and 64. Thus, fewer stakeholders attach importance to these risks.

Overall, the most frequently identified risk categories are also those with higher Risk Index. Reasonably, the risks to which stakeholders attach more importance are also those that could represent a major threat. Among these, *Input cost increase and reduced availability*, *Water pollution and scarcity*, *Policy changes and regulatory requirements*, *Generational renewal and sector attractiveness*, and *Extreme weather events*, stand out from the list of risks.

There are, however, other risks among the less frequently identified ones, that show high Risk Index. Specifically, *Environmental pollution and nuclear contamination*, and *Lack of financial liquidity*, are relatively less identified (respectively by 94 and 78 respondents) but stand out with a high Risk Index. It is also worth noting the relatively high Index for *Food contamination and waste*, *Pests, diseases and invasive species*, *Information, knowledge and innovation* (lack of), and *Land (lack or degradation of)*. Hence, a smaller range of stakeholders attach the most importance to these risks, but when they do, these risks represent a major threat. These risks might not be widespread but may pose a serious threat to specific segments of the supply chain.

On the other hand, risks related to *Social disorders and unrest*, *Population growth, displacement and migration*, *Technological risk* and *Natural disasters* are at the same time the less frequently identified, and the ones with lowest Risk Index. In the stakeholders' perception, therefore, these risk categories represent the smallest threat to their sectors. The findings, however, appear surprising for *Natural disasters*, which are catastrophic events often causing devastation of large portions of the territory. As previously discussed (see section 3.2.1 and 3.3), the result seems to be mainly driven by a low perception of likelihood and vulnerability. This could be explained by, on the one hand, the relative low frequency of such events and their often regional-specific origin that might lead only few stakeholders to identify this risk, and to perceive it as likely. On the other hand, natural disasters are traditionally followed by extraordinary policy measures providing significant public funds for recovery, which might partly explain the perceived low vulnerability.

Assessing the overall frequency of identification and Risk Index helps understand which risks are generally threatening the most the EU food supply chain, based on stakeholders' perceptions. However, it is likely that the importance of different risks differs across countries, sectors, and stages of the food supply chain. Risks, in fact, are inherent to the specificities of the context. The following section provides an analysis of the heterogeneity of risks across EU Member States, sectors, stages of the supply chain, and businesses.

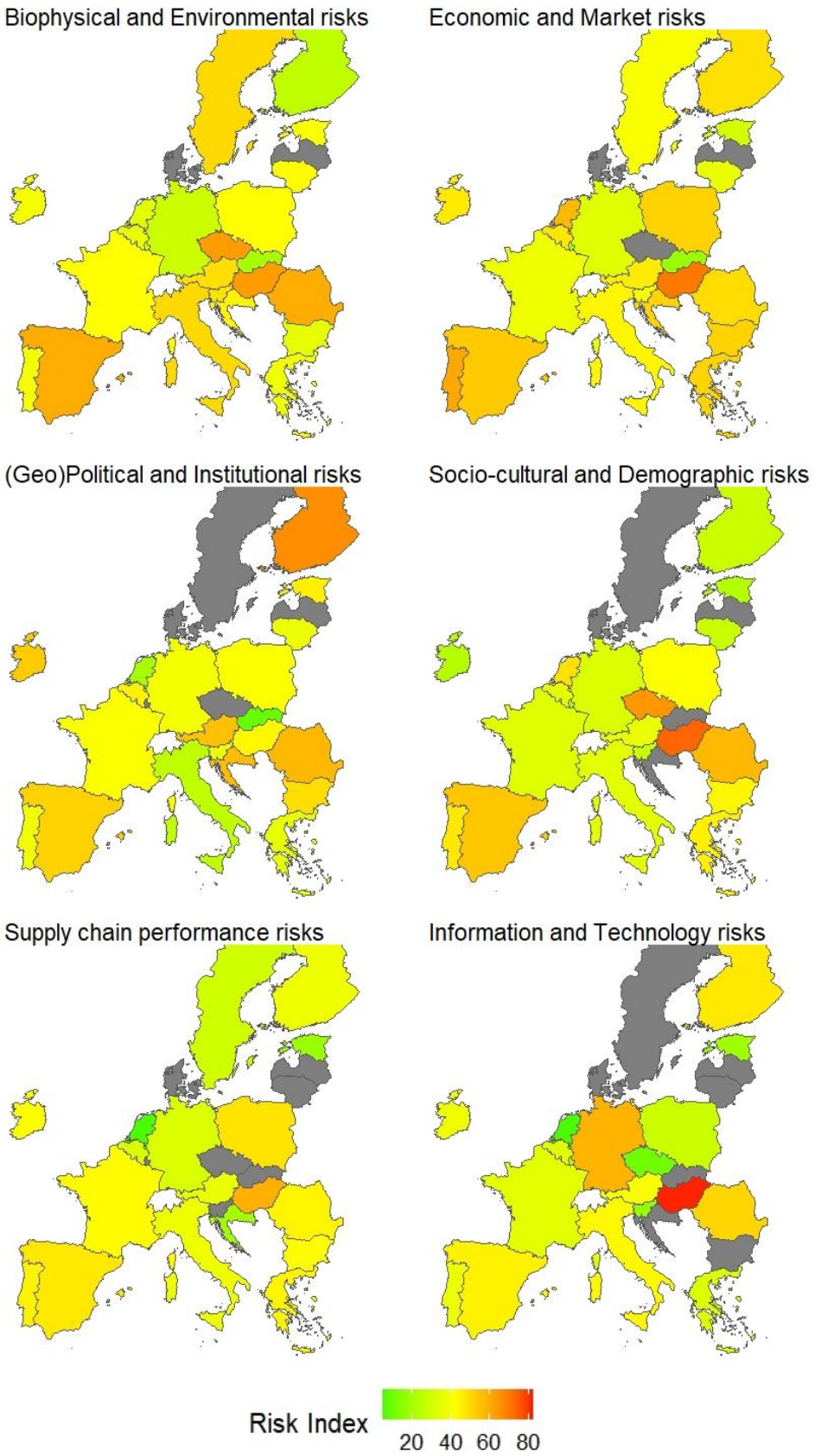
4.2 The heterogeneity of risks across the EU food supply chain

4.2.1 Risks across Member States

This section presents the analysis of risks across Member States, where Member States are identified according to the location of the respondent's organisation's headquarters. The Risk Index values are used to identify the main risks in each Member State, and where the Risk Index is perceived higher or lower overall.

Figure 26 shows the Risk Index by risk type across Member States, according to the surveyed stakeholders (a table with Risk Index values is reported in Annex 10). The Risk Index for all risk types is the generally evenly distributed across Member States, exception made for Information and Technology risks, which show the highest variation across Member States. This suggests that Information and Technology risks are possibly related to differing technological and infrastructural characteristics across the EU, whereas the exposure to cyber risks could be higher for regions closer to the Russian war of aggression against Ukraine.

Figure 26. Risk Index by Member State based on stakeholders' perceptions



NB: When no risk is identified for a specific risk type in a Member State, that Member State is depicted in grey. Note that the Risk Index is not weighted, as the figure shows the within-country averages. The coloured scale is set on the sample Risk Index mean.

Source: Online survey.

Based on stakeholders' perceptions, the Risk Index of Biophysical and Environmental is higher in Malta, Hungary, Czechia, Spain, Italy and Romania. On the other hand, Slovak Republic, Finland and Germany have the lowest Risk Indexes within this type. Climate-related risks, in particular, are perceived higher in southern EU. This is consistent with recent studies and projections, which indicate that Member States like Portugal, Spain, Italy, Greece and regions of southern France are generally the most affected by droughts, heat waves, forest fires, coastal flooding ([8])([9]). Here, the impact of climate change on farmers' income is the highest.

For Economic and Market risks, the Index is higher in Hungary, Portugal, the Netherlands, and Spain. On the contrary, Slovak Republic, Luxembourg, Estonia, and Germany have the lowest Risk Index. According to recent studies (Alessi et al., 2018; Pontarollo and Serpieri, 2018), regions of southern and eastern EU have a lower economic territorial resilience, and lower resilience to financial and economic crises. This is partly reflected in the stakeholders' perception, which points to higher Risk Index in countries like Spain, Portugal, Greece, Hungary, Poland, Bulgaria and Croatia. In the case of the Netherlands, stakeholders mainly identified risks related to *market instability*, and *lack of financial liquidity*.

Regarding (Geo)Political and Institutional risks, the highest Index is reported in Finland, followed by Romania, Croatia, Austria, Ireland, and Spain. Slovak Republic, the Netherlands, and Italy show the lowest Risk Indexes within this category. While the Russian war of aggression against Ukraine has led to a generally increased concern over trade disruptions and geopolitical stability, this is particularly strong in the case of Finland and Romania.

When it comes to Socio-cultural and Demographic risks, the highest Index is reported in Hungary, which is followed by Czechia, Cyprus, Malta, and Romania. On the other hand, Estonia, Ireland, and Lithuania have the lowest Risk Index within this risk type. Research shows that demographic challenges related to demographic decline, depopulation, lower fertility rates, and higher migration pressures are stronger in the southern and eastern EU Member States (European Parliamentary Research Service, 2022b; ESPON, 2020). This can partly explain the higher risk perceptions recorded in Malta, Romania, Cyprus, Bulgaria, Spain and Hungary. Likewise, Member States such as Bulgaria, Romania, Spain and Greece are those with higher risk of poverty or social exclusion ([10]), which could lead to higher concerns about risks of social disorders and unrest.

The highest Supply chain performance Risk Index is reported in Malta, Hungary, and Poland. The lowest Risk Index is perceived in Netherlands, Estonia, and Croatia. Because of its relative remoteness, insularity, and small extension, Malta is particularly exposed to risks related to transportation and logistics costs and availability, as well as disruption of up-stream supply. Cyprus and Ireland share similar issues and, in fact, have relatively high Risk Index. Regional challenges related to logistic and transportation can explain the higher Risk Index in eastern EU Member States, such as Hungary, Poland, Romania and Bulgaria. The Logistic Performance Index developed by the World Bank ([11]), shows that eastern EU Member States (notably Romania, Poland, Bulgaria, Hungary, Czechia, Latvia and Lithuania) rely on less developed trade and transport infrastructures; hence, these Member States might be more exposed to related risks.

Finally, for the Information and Technology risk, the highest Index is reported in Hungary, Malta, Germany, Finland, Sweden and Romania. The Netherlands, Czechia, and Slovenia have the lowest indexes within this category. The high Risk Index perceived in Germany, Finland, and Romania can be linked to, at least to some extent, the rapidly growing trends in cyberattacks, which have been aggravated by the Russian war of aggression against Ukraine. The European Union Agency for Cyber Security (2022) reports, for instance, that the supply chain incidents in 2021 accounted for 17% of cyber intrusions, against the 1% of 2020.

Overall, Member States with the highest Risk Index are Malta, Hungary, Spain, Romania, Czechia, Croatia, Portugal, Bulgaria, and Poland. In most risk types, Malta, Hungary, Romania, and Spain have one of the highest Risk Indexes. On the other hand, the Member States with the lowest Risk Index are Slovakia, Luxembourg, Estonia, Germany, Lithuania, France, Slovenia, and the Netherlands. It is noticeable that Estonia, the Netherlands, and Slovak Republic are the countries with one of the lowest Risk Index in most of risk types. The

([8]) See for instance the bulletin of the European Environment Agency (https://experience.arcgis.com/experience/5f6596de6c4445a58aec956532b9813d/).

([9]) See for instance Copernicus data (https://climate.copernicus.eu/copernicus-european-state-climate-2022-unprecedented-extreme-heat-and-widespread-drought-mark).

([10]) See for instance Eurostat figures (https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Living_conditions_in_Europe_-_poverty_and_social_exclusion&oldid=584082).

([11]) The Logistics Performance Index measures the quality of trade- and transport-related infrastructures (https://data.worldbank.org/indicator/LP.LPI.INFR.XQ?locations=EU).

remaining Member States ([12]) have a medium Risk Index. Yet, some of them show very high Risk Index for certain risk types. For example, Ireland, Finland, and Austria have high Risk Index for (Geo)Political and Institutional risks.

4.2.2 Risks in the outermost regions

While risks can be heterogeneous across Member States, certain regions might be particularly vulnerable because of their geographic location. This is the case for the outermost regions of the EU ([13]). The outermost regions are part of the EU territory but are geographically very distant from the European continent. Consequently, these regions suffer from specific challenges, such as remoteness, insularity, small size, difficult topography and climate, and economic dependence on only a few products ([14]).

This section presents the results of the analysis, based on the content analysis of the interviews and the literature, of the main risks affecting outermost regions. The results suggest that the characteristic remoteness and isolation of the outermost regions make them potentially more exposed to all risk types, whereby certain risks that are less relevant on the European mainland (e.g. Socio-cultural and demographic, and Supply chain performance risks) become key risks in outermost regions. Likewise, the dependence on imports and the lack of natural resources appear to be key determinants of vulnerability in outermost regions. Because of their remoteness, different risk profiles, and isolation from the EU food supply chain, ad hoc strategic approaches are needed to anticipate and manage risks and crises in outermost regions.

The remoteness and insularity of these regions can limit access to markets, transport infrastructure, trade and resources, making it more difficult to develop and sustain food production. The high dependency on certain import/export markets is the main source of vulnerability in these regions. Because local production, the availability of resources and logistics infrastructures are limited, the outermost regions are highly dependent on imports, which makes them particularly vulnerable to instability or disruptions in trade flows and the market overall. Moreover, these regions are highly dependent on transport links, but their transport costs are significantly higher than those of continental Europe because of the considerable distances involved and the sometimes limited transport options. This can lead to higher prices for imported goods and can also make exports less competitive, but it can also lead to the isolation and fragmentation of local food supply chains, which are not closely interlinked with the wider EU food supply chain. For example, fishery stakeholders from the Canary Islands mentioned difficulties in finding operators to process and export fish after it is caught. The outermost regions primarily rely on maritime and air transport. While these modes are essential, they can sometimes be infrequent and are more susceptible to disruptions due to weather or other factors than other modes. The lack of alternative transport modes can increase exposure to logistics risks. In addition, the outermost regions can be limited in terms of port and airport capacities, and upgrading or expanding these facilities can be challenging. Consequently, the outermost regions are particularly exposed to supply chain performance risks, such as risks related to *Up-stream supply disruption or unavailability* and *Failure of transport, infrastructure or logistics*.

In addition, some outermost regions have fragile economies and high rates of unemployment (European Commission, 2022b). This can impact the viability and competitiveness of the food system, as well as the ability of local populations to access affordable and nutritious food. They also face social challenges such as poverty, inequality, migration, and demographic change, which have been worsened by the coronavirus pandemic (European Parliamentary Research Service, 2021). The proximity to less prosperous third countries entails stronger migratory pressure. These factors make the outermost regions particularly exposed to risks related to *Population growth, displacement and migration*, and *Social disorders and unrest*. While these risks seem less relevant in the European continent (see results in section 4.1 and 4.2.1), they can represent major threats in the outermost regions.

The conditions for carrying out activities in agriculture or fisheries are more challenging compared to other EU regions, mainly due to the small size of business holdings and the limited market. Moreover, food system operators suffer from a generalised low innovation, digitalisation, diversification and competitiveness, which

([12]) Belgium, Ireland, Greece, Italy, Cyprus, Austria, Finland and Sweden.

([13]) The EU outermost regions – Guadeloupe, French Guiana, Martinique, Mayotte, Réunion and Saint Martin (France), the Azores and Madeira (Portugal) and the Canary Islands (Spain) – are nine EU regions located in the Atlantic and Indian Oceans, in the Caribbean basin and in South America.

([14]) See for example Interreg Europe's project on EU entrepreneurship development and capacity-building policies for business creation and growth in the outermost regions (https://projects2014-2020.interregeurope.eu/growrup/).

poses challenges in a context of globalisation, market liberalisation and increasing sustainability targets (European Parliamentary Research Service, 2021). While *Cyberattacks* and *Technological risks* can be less concerning compared to other EU regions given the relatively low technological and digital component in the food systems, the low competitiveness of food businesses in outermost regions can make them particularly exposed to *Market instability*, *Input costs increase and reduced availability*, and *Lack of financial liquidity*. The combination between poor economic perspectives, and limited business competitiveness can pose relevant risks in terms of *Generational renewal*, even more serious compared to other EU regions.

When it comes to natural resources, some outermost regions may have limited access to arable land, water resources, and fertile soil. This can pose challenges for agricultural production ([15]), which is more exposed to risks related to *Land (degradation or lack of)*, *Water pollution and scarcity*, and *Loss of natural resources and biodiversity*. Similarly, due to limited local production capacity, outermost regions often rely heavily on imports for their food supply. This dependency can make them more susceptible to disruptions in global food markets, such as price fluctuations and supply chain disruptions (European Parliament, 2023). For example, livestock and fisheries stakeholders from Madeira mentioned suffering from scarcity in oilseeds, soy, and cereals (used as animal feed) after the global market crisis that followed Russia's unprovoked invasion of Ukraine.

The outermost regions are particularly vulnerable to the impacts of climate change, including adverse weather events, rising temperatures and sea level, and changing rainfall patterns. These changes can affect crop yields, water availability, and overall agricultural productivity. A possible consequence of climate change is that outermost regions may face unique challenges related to the spread of pests and diseases. These regions may be more susceptible to invasive species and have limited resources for pest control and disease management (European Parliament, 2023). Stakeholders from Martinique mentioned that their aquaculture sector is suffering from climate change, especially from long periods of heat and drought, which in extreme cases can lead to water rationing. Adding to that, dairy stakeholders from Martinique mentioned the risk of pathogens and animal diseases of high mortality due to the increase in temperature, which could potentially limit animal production.

4.2.3 Risks by sector

This section presents the results of the analysis of the key risks faced by each sector. This analysis is carried out through a comparison of the Risk Index obtained through the online survey, and a triangulation with evidence from the interviews and the literature. It is important to consider that stakeholders often operate in multiple sectors. Stakeholders' perceptions of risk, in fact, were elicited in relation to their businesses or organisations, thus they refer to the multiple sectors in which the business/organisation operates. This poses a limitation, as an exact distinction of risk perceptions between sectors through the Risk Index is not possible. The Risk Index of a risk in a certain sector might be influenced by the perceptions of the same risk in a connected sector where same stakeholders often operate ([16]). However, the Risk Index helps assess the extent to which different risk categories could threaten a sector, whereas the content analysis of the interviews and the literature serves to substantiate the identification of main risks within the sector. The values of the Risk Index by sector are reported in Annex 11.

The analysis of the Risk Index shows that the Fishery and Aquaculture sector is, on average, the most concerned by risks, followed by the sector of Beverage and Alcoholic drinks. These two sectors show critical values of the Risk Index for several risk categories. The dairy sector shows the lowest Risk Index on average. The remaining sectors show lower average Risk Index values, equal among them, and fewer risk categories with critical values of the Risk Index. However, there are risk categories that appear threatening most of the sectors. This is the case of *Environmental pollution*, *Extreme weather events*, *Financial and economic crises*, *Generational renewal*, and *Lack of Information, knowledge, and innovation*.

Below, the analysis of the specific risks faced by each sector is presented.

Fishery and Aquaculture sector

According to the Risk Index, the most relevant risks for fishery and aquaculture are those of the Economic and Market type, particularly: *Financial and economic crises*, *Financial liquidity (lack of)* and *Input cost increases and*

([15]) See for example Interreg Europe's project on EU entrepreneurship development and capacity-building policies for business creation and growth in the outermost regions (https://projects2014-2020.interregeurope.eu/growrup/).

([16]) Take for example the case of a stakeholder operating in the livestock sector and hence potentially simultaneously involved in both meat and dairy production.

reduced availability. The up and downstream segments of the sector are sensitive to energy markets (e.g. diesel for fishing vessels, or refrigeration equipment). Aquaculture is also dependent on input markets (such as feed) which might often be exposed to extra-EU dynamics. Yet, stakeholders' perception about input costs and availability might be influenced by the recent rise in energy costs. To a large extent, the fishery industry relies on small-scale coastal fleet (European Commission, Joint Research Centre, 2022), whereas the aquaculture sector mainly consists of micro enterprises and small businesses ([17]). The small size of businesses and the relative fragmentation of the sector increase the vulnerability to market risks, above all in a context of market liberalisation. Moreover, the financial capacity of these businesses is limited, which has been worsening in the recent few years due to a general decrease of business profitability (European Commission, Joint Research Centre, 2022).

The sector, according to the Risk Index, is also affected by Biophysical and Environmental risks, especially *Extreme weather events*, *Changing climate and weather patterns*, and *Environmental pollution*. Fishing activities depend on weather conditions, whereby extreme weather like storms can impede the regular activities. Moreover, because the fishery industry relies on the availability of fishing stocks, it is intrinsically exposed to Biophysical and Environmental risks. The effects of climate change and adverse weather events are well documented in the literature. *Extreme weather events*, such as extreme heats, can cause the warming of ocean surface temperatures and changes in ocean currents, which can affect the migration patterns of fish, alter species distributions, and contribute to harmful algal blooms (Wells et al., 2015; Pörtner et al., 2014; Hoegh-Guldberg and Bruno, 2010). By impacting on sea temperature, climate change also favours the occurrence of diseases outbreaks and the arrival of invasive species. Increased CO_2 in the atmosphere leads to more CO_2 being absorbed by oceans, making them more acidic. This can harm shellfish and other marine species. Some interviewees mention that, due to climate change, production of certain species started moving to northern areas.

Environmental pollution can threaten the fishery and aquaculture sector, as shown by the high Risk Index. This is broadly recognised in the literature, which explains that pollutants like heavy metals (e.g. mercury) and persistent organic pollutants (e.g. PCBs), can accumulate in the fishes (Dietz et al., 2013; Hites et al., 2004). These toxins can harm fish health and reproduction, potentially leading to population declines. They can also pose health risks to humans. Some interviewees, for example, were concerned about the possible reduction of consumption triggered by increased environmental (and consequently food) contamination, although the EU has a high dependency on imported fisheries as well.

Two additional risk categories belonging to other risk types are also relevant for the sector: *Information, knowledge, and Innovation (lack of)*, and *Generational renewal and sector attractiveness*. The former risk refers mainly to the increasing need for technological innovation required by sustainability goals and adaptation to climate change. As explained by several interviewees belonging to the fishery sector, currently it is difficult to apply alternative energy systems in the EU fleets, especially for long-distance activities in the high seas. There is also a risk, mentioned by some interviewees, that research funds might not be sufficient to generate the necessary technological advance. Moreover, many interviewees mentioned the growing risk brought by a lack of generational renewal in the sector. The two main determinant factors identified by the interviewees were the low remuneration and the low quality of work conditions on the vessels.

Beverage and alcohol sector

The risk index for the beverage and alcoholic drinks sector shows higher values on average. *Policy changes and regulatory requirements* appear to be an important concern for the sector. EU and national regulations on food standards and labelling are stringent, and they also cover beverages and alcoholic drinks. However, alcohol beverages industry in particular is generally more regulated, often taxed differently, and generally suffer from higher trade barriers (Smith, 2014). Therefore, the sector is highly exposed to uncertainties stemming from policy and regulatory changes. This aspect must be weighed against the fact that alcoholic beverages production has a limited role in ensuring food security.

The sector is also reported as being strongly affected by risks derived by *Financial and economic crises* and threats to its *inputs* supply, according to the Risk Index. It is one of the key exporting sectors of the EU, which is therefore highly exposed to economic developments across global markets. According to the interviews, some

([17]) See an overview on aquaculture by the European Commission (https://oceans-and-fisheries.ec.europa.eu/ocean/blue-economy/aquaculture/overview-eu-aquaculture-fish-farming_en#:~:text=EU%20aquaculture%20accounts%20for%20about,directly%20employs%20about%2070%2C000%20persons).

adverse events that can threaten the output of the sector include breakdown in trade flows (intra or extra EU), due to logistics or policy issues, and large spikes in input costs, including energy costs. The sector relies on the supply of a wide range of inputs, including for example, ingredients from the fruit and vegetable sector, sugar, yeasts, as well as energy and other raw materials. Instability of input costs, which can also originate in increasing energy prices, threaten the sector. The concerns also come in the area of Biophysical and environmental risks because *Changing climate* and *Extreme weather events* related categories score very high on the index. Global climate-related adverse events can reduce the availability and prices of agricultural products, which can lead to reduced availability or higher costs of key ingredients.

According to the Risk Index, the sector seems to be the most affected by risks related to *Change in consumer preferences and public image*. This, to a large extent, seems to be linked to alcoholic beverages in particular. The consumption of alcoholic beverages has been decreasing over the past decades in many EU countries, especially in southern EU Member States (Rabinovich et al., 2009). While, on the one hand, the affordability of alcohol beverages has been increasing over the past decades, on the other hand alcohol consumption can generate harms for individuals. New and more healthy dietary trends are likely to influence changes in consumption patterns (Kearney, 2010), with a risk for worsening public image of the sector.

Meat sector

According to the Risk Index, the meat sector is mostly affected by *Changing climate and weather patterns* and *Extreme weather events*, and by Economic and Market issues. Animals' health can be severely impacted by heat waves, and most of their feed supply is highly dependent on weather developments (Renaudeau et al., 2012; Rotter and Van de Geijn, 1999). Stable and cost-efficient input supply is one of the main drivers of the performance of the sector. Hence, according to the interviews, market disruptions or weather-related challenges impacting animal feed can be highly disruptive.

The sector is exposed to important changes in consumption patterns. The consumption of certain meat products has decreased significantly, and vegetarian and vegan trends and increasing health-related concerns are making consumers more and more willing to reduce their meat consumption. Moreover, new technological products that can displace meat products are entering the market (Peyraud and MacLeud, 2020).

Pests and diseases risks are relevant for the sector and are often mentioned by stakeholders. Interviewees mentioned several examples of animal diseases that are threatening the livestock sector, such as Avian Influenza (flu), H1N1 swine flu, and African swine fever. Due to the increasing effects of climate change, as well as market liberalisation, there was widespread perception among the interviewed stakeholders that pressure from pests and diseases may increase in future, either because existing pests might spread globally, or because new (unknown) pests may emerge. In this regard, the lack of forecasting capability was mentioned as an important vulnerability.

Other risks are important to the meat sector according to the Risk Index, including *Food contamination and waste, lack of Information, knowledge and innovation*, and *lack of Generational renewal and sector attractiveness*. Meat production is exposed to biological (e.g. Salmonella, E.coli) and chemical contamination (antibiotics, hormones etc.). Contaminated meat can cause foodborne illnesses when consumed. Some emerging infectious diseases in humans are of livestock origin and are classified as zoonosis (Cutler et al., 2010), whereas the rapid expansion and worldwide spread of new antibiotic resistance genes is become an urgent issue (Peyraud and MacLeud, 2020). This poses a significant public health concern, while strict regulations are in place in the EU to ensure sanitary standards.

Risks related to generational renewal are relevant for livestock production, where quality of life is perceived particularly low (Bertolozzi-Caredio et al., 2020). The decline in the number of livestock farms in the EU has been stronger compared to crop and mixed farms ([18]).

Fruit and Vegetable sector

As shown by the Risk Index, the fruit and vegetable sector is affected by *Policy changes and regulatory requirements*, *Environmental pollution and nuclear contamination* and *Extreme weather events*, which score

([18]) See Eurostat figures (https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Farms_and_farmland_in_the_European_Union_-_statistics#:~:text=There%20were%20about%20400%20000,of%204.4%20%25%20of%20all%20farms).

relatively high. Not less important are *Water pollution and scarcity*, *Generational renewal (lack of)*, and *Food contamination and waste*, which also have high Risk Index values for this sector.

Fruit and vegetable production is often undertaken through intensive agricultural systems, which remain particularly exposed to the degradation of environmental resources, such as soil, also due to the high use of chemicals (e.g. pesticides and fertilisers). Likewise, the growing EU legislation to increase sustainable production (e.g. on pesticides use), comes with short term uncertainties as regards the methods of production which, in a context of growing environmental pressures (e.g. increasing pests), can be perceived as a risk by stakeholders.

In line with the literature, the fruit and vegetable production is found to be one of the sectors more exposed to extreme weather events (Lesk et al., 2016; Lobell and Field, 2007). The sector is especially affected by late spring frost, extreme heat and droughts (Devot et al., 2023). The (on average) small size of many businesses operating in the sector is also an obstacle to the diffusion of digital and precision farming techniques that are essential to cope with climate change (Wolfert et al., 2017; Fountas et al., 2015).

The sector is highly reliant on irrigation water. Previous research suggests that the risk of water scarcity, hence the need for adaptation, is bigger in southern Europe because of increased production vulnerability, reduced water supply and increased demands for irrigation, all of which is aggravated by increasing drought risks (Falloon and Betts, 2010). An interesting case is reported in the Netherlands, where interviewees explain that water scarcity can also affect river-based transportation infrastructures.

The Risk Index for *Market contraction, concentration and (unfair) competition* is generally low across sectors, but shows its higher value for the fruit and vegetable sector compared to other sectors. According to the interviews, the sector remains very fragmented in many European countries, with production distributed among small and medium-sized producers with little organisation among them. Such fragmentation and small sizes imply reduced bargaining power along the supply chain, but also limited competitiveness in the global market. The small size is also an obstacle to the diffusion of digital and precision farming techniques that are essential to cope with climate change.

As in other sectors, the decline in generational renewal represents a risk for the Fruit and Vegetable sector. This is particularly evident at the level of production. Fruit and vegetable farms build on expensive assets, including land, orchards and machinery. Setting up a business can be very costly, whereby challenges like difficult access to finance and land hinder generational renewal (Coopmans et al., 2021).

Cereals, legumes, and oilseeds sector

The cereals, legumes and oilseeds sector seem strongly affected by Biophysical and Environmental type of risk, according to the Risk Index. With primary production being an essential stage of this sector, risks related to *Extreme weather events*, *Water pollution and scarcity*, and *Changing climate and weather patterns* play an important role. It is the second most sensitive sector to *Extreme weather events* (after the meat sector). This is much aligned with the literature, which abundantly reports on the risks related to water scarcity (Iglesias et al., 2011), extreme weather (Porter et al., 2014) and, more in general, climate change (Challinor et al., 2014). Aside from droughts, floods and other weather anomalies, examples of adverse events reported by the interviewees include loss of plant protection options, trade bans, and abrupt input price hike.

The sector shows a higher Risk Index for *Market instability* risks compared to other sectors. The sector produces and processes among the most traded agricultural commodities worldwide. The EU is also a great importer of such commodities, wheat, soy and oilseeds being examples ([19]). As such, the sector is exposed to risks stemming from price variability and availability of commodities (Galtier et al., 2014; Swinnen and Squicciarini, 2012). As explained in the interviews, these risks can be triggered or aggravated by geopolitical instability, such as Russia's recent unprovoked invasion of Ukraine, or worldwide extreme weather events causing major harvest failures. In turn, this can lead to trade bans by third countries for certain products.

The Risk Index for *Information, knowledge and innovation* (lack of) risks is relatively high for the sector. While the production of extensive crops requires increasing adaptations to the effects of climate change, the EU has set ambitious environmental and climate targets. This poses a challenge for extensive agriculture, which needs to adopt novel technologies and practices. As reported in the literature (Barnes et al., 2019; Rose et al., 2016, Tey and Brindal, 2012), and confirmed in the interviews, the adoption of new technologies, such as precision

([19]) See Eurostat figures (https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Extra-EU_trade_in_agricultural_goods#Agricultural_products:_four_groups).

agriculture, agri-tech solutions, and new genetic techniques, can be hindered by high upfront costs, a lack of necessary digital skills among farmers, and uncertainty about the return on investment. In addition, the risk of not meeting the necessary technological advances is particularly stronger for smaller producers, which have lower investment capacity.

Sugar and miscellaneous sector

Finally, the sugar and miscellaneous sector, to a large extent, relies on imported commodities like cocoa, coffee and tea, which are not produced in the EU. This exposes the sector to the availability and variability of prices of key ingredients, which is why the Risk Index for *Input cost increase and reduced availability* is very high for the sector. However, the production of sugar beet in the EU remains an important segment of the sector, although it suffers from growing competition with sugar produced from other sources outside the EU (Burrell, 2010).

Information, knowledge and innovation (lack of) risks show the highest Risk Index for this sector. Likely, this is linked to the increasing technological advances and know-how required at processing stage. Interviewees mentioned, for example, the inherent risks of technological obsolescence, and the lack of market info. Processing agricultural commodities like sugar, cocoa, and coffee involves a number of stages, from initial cleaning and sorting through to final packaging. Quality control, for instance, is a major challenge (Ribeiro et al., 2016). Advanced sensors and AI-powered algorithms can help monitor and control quality (Makino et al., 2016; Sun, 2014), but they require significant investment and technical expertise. Consumers and regulators are increasingly demanding sustainable and waste-reducing practices. Related innovations may be costly to implement and operate.

The Risk Indexes for *Change in consumer preferences and public image*, and *Food contamination* also scores relatively high. Consumer preferences are often influenced by a variety of factors, including health trends and ethical considerations. For example, research shows that there is an increasing consumer attitude towards fair-trade products, environmental-friendly production, and sugar-free products (Burgin and Wilken, 2022; Tandon et al., 2020). In addition, risks of food contamination increase as the supply chain of these commodities is global. These commodities typically have global supply chains, with key ingredients sourced extra-EU, which makes tracking and managing safety, quality, sustainability, and ethical labour practices difficult.

Dairy sector

The dairy sector is affected by risks somehow similar to those reported for the meat sector even if the Risk Index for the categories *Food contamination and waste* and *Pest and disease* risks score higher in the case of dairy. Major contamination events can endanger the production of large dairy processing facilities, and diseases can shutter milk production while the sector attempts to reduce antibiotic use (Mollenkopf et al., 2020; Ruegg, 2017). Some interviewees mentioned the risk coming from biological contaminants and also physical contaminants such as unsafe components in packaging. Due to limited investment capacity, data and methods to assess certain contaminants are lacking.

Similarly, Biophysical and Environmental risks such as *Extreme weather events*, and *Changing climate patterns*, are highly relevant to the sector, as they affect animal health and food supply. Dairy livestock, for instance, is more frequently exposed to heat stress (Renaudeau et al., 2012). Changes in temperature and humidity can directly impact livestock health and productivity, potentially leading to decreased milk production, reduced fertility, and increased susceptibility to diseases.

Interviewees mentioned the high level of fixed costs of production in the dairy sector, which make these businesses particularly vulnerable to market instabilities and competition. Worsening social perceptions about dairy production, mainly driven by growing animal welfare concerns, might lead to increasing competition with plant-based milk products in the EU.

The sector seems severely concerned by *Policy changes and regulatory requirements* type of risks. Dairy producers are important beneficiaries of the Common Agricultural Policy, which makes them exposed to any change in the policy framework. The EU has high animal welfare standards. Changes in these regulations could affect dairy and other animal productions. More stringent welfare regulations can improve the quality of dairy products but could also increase costs for farmers. Any changes in food safety standards can also impact the dairy production process, from the way cows are milked, to how the milk is processed, stored, and transported.

Concluding remarks

The analysis of both interviews and literature underscores that different sectors possess distinct risk profiles. The dairy and meat sectors deal with unique risks from animal diseases, inherent food contamination, and

climate-induced impacts on animal health and productivity. Notably, the meat sector confronts threats from shifting consumption trends. Both the fruit and vegetable sector and the cereals and legumes sector are acutely susceptible to the adverse effects of extreme weather events and water scarcity. Further, the cereals and legumes sector is especially vulnerable to global market disruptions, also linked due to geopolitical instabilities. The sugar and miscellaneous sector faces risks primarily from escalating costs and potential unavailability of crucial ingredients, compounded by intensified market competition and food contamination risks within the international supply chain. The beverage and alcoholic drinks sector is uniquely influenced by evolving consumer preferences risks, as well as risks from evolving policy and regulatory landscapes. Lastly, the fishery and aquaculture sector faces several threats. The most pressing include innovation deficits, climate change, extreme weather events, financial liquidity constraints, and rising input costs.

4.2.4 Risks by stage of the supply chain

This section presents the analysis of the key risks faced by each stage of the supply chain. The food supply chain represents a network of actors, organised through a series of interconnected stages, which operate within, between and beyond the EU Member States. The stages distinguished in this study, though, represent a simplification of reality, whereby different stages can be aggregated and conducted by the same operator. Such level of articulation is also reflected in the sample of participants in this study, which accounts for organisations operating at multiple stages of the supply chain. Stakeholders' perceptions of risk, in fact, were elicited in relation to their businesses or organisations, thus they refer to the multiple stages in which the business/organisation operates. As for the analysis of risk by sector, this poses a limitation, as an exact distinction of risk perceptions between sectors through the Risk Index is not possible. However, the Risk Index helps assess the extent to which different risk categories could threaten a stage of the supply chain, whereas the content analysis of the interviews and the literature serve to substantiate the identification of main risks within the stage. The values of the Risk Index by stage of the supply chain are reported in Annex 12.

The assessment of the Risk Index shows that packaging and logistic operators, and input suppliers are, on average, the most threatened by the identified risks. Input suppliers and packaging operators, in particular, show critical values of the Risk Index for several risk categories. The other stages of the supply chain show lower Risk Indexes, on average. The analysis also indicates that key risks affecting multiple stages of the food supply chain include *Environmental pollution*, *Generational renewal*, *Financial crises*, *Extreme weather events*, and the lack of *Information, knowledge, and innovation*. These risks are interconnected, whereby a risk impacting one stage can cascade to subsequent stages. Environmental pollution affects food production directly and has ripple effects through the supply chain. Extreme weather events, particularly impacting agriculture, result in reduced product quality and availability, affecting pricing and market placement. Financial crises, by nature, have broad impacts across the supply chain, while a growing digital landscape necessitates increased knowledge and innovation throughout the whole food system. Notably, the challenge of generational renewal extends beyond just agriculture, indicating a broader need for younger professionals throughout the entire food supply chain.

Below, the analysis of the specific risks faced by each stage is presented. Logistic operators, wholesalers and traders, and retailers, face similar risk profiles, and are assessed together.

Input suppliers

According to the Risk Index, main risks faced by input suppliers are Economic and Market risks such as *Market instability*, *Financial liquidity (lack of)*, and *Input cost increase or reduced availability*. Fluctuations in the prices of commodities, energy, and other inputs (such as steel for agricultural machinery and other material) can impact suppliers' costs and profit margins, as well as their capacity to invest. As confirmed in the interviews, input suppliers often require significant investment to upgrade their machinery, adopt new technologies, or expand their operations. Accessing the necessary finance can be a challenge. This could negatively affect farmers' financial support, as in many Member States, input suppliers finance part of the working capital needs of farmers (fi-compass, 2020).

As indicated by the Risk Index, also Biophysical and Environmental risks, such as *Extreme weather events* and *Changing climate and weather patterns*, affect input suppliers. According to the literature, climate change can alter the geographical areas where certain crops can grow optimally (Schlenker and Roberts, 2009). For seed suppliers, this could mean having to shift their product range to cater to these changes (Mba et al., 2012). It could also impact the spatial distribution of feed and ingredients crops (Lobell and Field, 2007), which could result in increased transportation costs or sourcing difficulties for feed suppliers.

A high risk is perceived for *Policy changes and regulatory requirements*. The development of EU and national regulations (such as those stemming from the Green Deal strategies), which respond to major societal goals,

serve to improve the sustainability and resilience of food systems. Policy changes, however, might come with uncertainties as regards the ways input materials can be produced and supplied. As reported in the interviews, complying with new rules can be challenging for input suppliers, at least in the initial phase, due to possible additional costs, administrative burden, or technological constraints (e.g. gene editing). Finally, *Food contamination and waste* risk also affects input suppliers. While, at the production level, contamination can occur on the farm through pesticide and chemicals over-application (Aktar et al., 2009), contamination is also a concern for suppliers (e.g. chemicals, ingredients) which suffer the inherent risk of unintended food contaminations (Minor and Calvin, 2010; Trienekens and Zuurbier, 2008).

Producers

The main risks faced by producers, according to the Risk Index, are Biophysical and Environmental risks, such as *Extreme weather events*, *Changing climate and weather patterns*, *Water pollution and scarcity*, and *Pests, diseases, and invasive species*. This is strongly consistent with the literature and the interviews. Food production is especially exposed to climate change and climate risk because it is fundamentally dependent on climate conditions. Changes in temperature, precipitation, CO_2 concentration, and the occurrence of extreme weather events can directly affect the growth, development, and yield of crops and the health and productivity of livestock and fishery (Lesk et al., 2016; Lobell et al., 2011; Ainsworth and Long, 2005). Moreover, water is key in food production, for instance for irrigation or for breeding livestock. The lack of water becomes an even more relevant risk under climate change conditions (Wheeler and Braun, 2013). Warmer and wetter conditions can also lead to increases in pests and diseases, which can damage crops and harm livestock. It can also lead to the spread of pests and diseases to new areas. The spread of new diseases, pests and invasive species is also favoured within the context of globalisation and market liberalisation.

Economic and Market risks, such as *Input costs increase or reduced availability* and *Financial liquidity (lack of)*, also affect producers. Food production is reliant on the use of key inputs, such as fertilisers, pesticides, and feed. The production of these inputs, in turn, is strongly related to energy prices. Consequently, agriculture and fishery are strongly exposed and vulnerable to increases in input costs. Not less importantly, the lack of finance remains a widespread risk in agriculture, fishery, and aquaculture according to the interviewees. Both farming, fishing and aquaculture often require a significant upfront investment in equipment, supplies, and sometimes land or fishing rights. These costs must be paid before generating income, creating a potential liquidity challenge. The financing gap in agriculture, for example, is large in many EU regions (fi-compass, 2020).

Processors

Food processors are affected by Economic and Market risks, in particular *Financial and economic crises*, and *Input cost increase and reduced availability*. Changes in consumer preferences, increased competition, fluctuations in food prices, and economic downturns can affect product demand and profitability. Food systems are globally interconnected. Events in one part of the world can affect markets elsewhere. For instance, as exemplified by an interviewee, a poor harvest in a major grain-exporting country can increase grain prices worldwide. Moreover, rising demand for healthier, organic, ethically sourced, and environmentally friendly products, or those catering to specific dietary needs (like gluten-free or vegan) (Willer and Lernoud, 2018; Biesiekierski, 2017; Janssen et al., 2016), requires constant innovation and adaptation. Food processors rely on a steady supply of raw materials. Any disruptions, due to geopolitical conflicts and trade restrictions, or other factors, can pose a risk. In addition, there is a risk associated with supplier non-compliance with safety and quality standards.

Policy changes and regulatory requirements are perceived as an important risk for Processors. Food Processors are responsible for ensuring the safety and quality of their products. This involves adhering to EU regulations on food safety, nutrition and labelling, which are stringent. Any changes to these regulations can pose risks if food processors are not prepared to adapt quickly. Non-compliance can lead to penalties, product recalls, and reputational damage.

Processors are also affected by *Changing climate and weather patterns*, and *Extreme weather events*. Climate change can affect the quantity and quality of agricultural produce available for processing. Changes in temperature and precipitation can affect crop yields, while extreme weather events can cause immediate and significant losses. As explained in the interviews, this can lead to increased costs and instability in the supply of raw materials. *Water pollution and scarcity* is an important risk also for Processors. Water is a key component (as well as the basic ingredient) in manifold food processing operations. This is the case, for example, of the production of yeasts, beverages, or preparations based on fruit and vegetables. The availability of drinking water is crucial at these stages.

Packaging operators

Packagers are strongly concerned by *Policy changes and regulatory requirements* risks. Because of the potential environmental risks brought by certain packaging materials, and the potential risk of contamination from food contact materials, new policies and regulations (or revisions of existing policies) are growingly debated ([20]). The need for regulating the environmental and health-related risks comes with increasing uncertainties for the sector with regard to what can be used, and in which segments of the food supply chain can be used. Secondly, the packaging sector is highly dependent on external sources (often Asian countries) for the supply of key inputs. Hence, packaging operators are more exposed to disturbances in trade and geopolitical instability (Gold et al., 2010). The COVID-19 crisis led to look critically at how the supply chain is organised, particularly in instances where sources of raw materials and intermediate products are highly concentrated and hence more susceptible to disruptions in supply (European Commission, 2020b). Correspondingly, examples made by interviewees are the raw material supply interruption during the COVID-19 crisis, and the paper board shortage due to Russian sanctions, and, which led to a reduction of the production capacity. Accordingly, risks related to *Up-stream supply failure* have a generally low Risk Index across stages, except for packaging operators.

Furthermore, *Environmental pollution* risks also affect food packaging. Packaging, particularly plastic packaging, generates a substantial amount of waste. This has increased pressure on food packagers to reduce packaging or switch to more sustainable options. This aspect has been discussed in the interviews. For instance, there is growing demand for sustainable and minimal packaging. Failing to adapt to such trends can lead to reduced market share and profitability. This can be challenging given the need to balance sustainability with the other packaging functions. Testing and developing new, more sustainable packaging solutions can be costly and time-demanding, but also risky as new materials can be employed (Realini and Marcos, 2014).

Logistic operators, Wholesalers and Traders, and Retailers

Logistic operators (including transportation and storage), wholesalers and traders, and retailers face similar risks. Logistics, transportation and storage operators ensure food and other intermediary products move efficiently throughout the supply chain. Wholesalers and traders are intermediaries between producers, processors, retailers, and consumers. By nature, these operators are intrinsically exposed to supply chain performance and market risks. Any disruption in the supply chain, such as production issues, transport disruptions, or supplier failures, can affect the ability to source and distribute products.

Market instability risks, for instance, can lead to disruptions in the availability of food products. This could be due to fluctuations in production levels and product prices. As described in the interviews, such disruptions can create challenges for logistics providers in terms of planning and managing transportation and storage, and for wholesalers in terms of managing their inventory and meeting the demands of their customers. Instability can lead to fluctuations in fuel prices as well, which can significantly affect the cost of transportation.

In addition, *Environmental pollution* and *Food contamination* risks also show a high Risk Index. These risks can be relevant because of the inherent risk of unintended contamination, compliance with increasing regulations made to contrast environmental pollution, or reputational damage. A contamination incident can cause a significant disruption in the food supply chain or make it more difficult for these operators to source products. Often, wholesaler and traders might have to increase their food safety testing and introduce additional safety measures. These can increase operational costs.

Cyberattacks risks particularly affect Logistics operators. Logistic operations (but also wholesalers and retailers) increasingly rely on technology, from automated warehousing systems to GPS tracking. These technologies bring their own risks, such as cybersecurity threats, system failures, or the risks associated with implementing new technologies. On the one hand, there is risk of obsolescence if operators fail to keep up with technological advances; on the other hand, cybersecurity risks increase as well. For example, the interviewees mentioned that a loss of internet availability on a large scale would severely impact logistics, and that cyberattacks on retailers (e.g. on the inventory management and pricing) might be increasing. Through the use of Internet of Things (IoT), food suppliers can rely on the sensing capacities of the technology to effectively and efficiently manage their procedures pertaining to food safety thereby increasing consumer trust in food products (Rejeb et al., 2020). Misfunctioning could imply a possible psychological effect on consumers by inducing lack of trust.

([20]) See for example the current discussion around the revision of the packaging and packaging waste directive (https://www.europarl.europa.eu/RegData/etudes/BRIE/2023/745707/EPRS_BRI(2023)745707_EN.pdf).

Risks related to *social disorders and unrest* are more important for retailers, wholesalers, and logistic operators, than for other operators. Likely, this is due to the proximity of these operators to the consumer, whereby social unrest can affect consumer demand, as well as the functioning of different operations at these stages. The interviewees mentioned, for example, strikes limiting transportations and employee's availability, or damages to infrastructures.

While this does not appear from the Risk Index, the interviews and the literature suggest that *Changes in consumer preferences* can be a serious threat for these operators, especially for retailers. For instance, shifts towards online shopping, healthy eating, or demand for locally sourced or organic products can affect what products retailers need to stock and how they market them (Aschemann-Witzel and Zielke, 2017; Verhoef et al., 2015). Economic downturns or uncertainties can affect consumer spending and thus retailers' profitability (Lamey et al., 2007).

Concluding remarks

Input suppliers are mainly affected by *Market instability* and *Financial liquidity (lack of)* risks, as well as by risks inherent to *Changing policy* and *food contamination*. Producers, on the other hand, are broadly exposed to Biophysical and Environmental risks like *Changing climate*, *Extreme Weather events*, *Water scarcity*, and *Pests and diseases*, with risks related to lack of *Financial liquidity* and *Generational renewal* remaining important. Processors and packaging operators are particularly affected by risks related to *Policy and regulatory changes*, *Environmental pollution*, *Up-stream input supply* and *Input costs and availability*. Similarly, logistic operators, wholesalers and traders, and retailers, are also affected by *Environmental pollution* and *Input costs and availability*, but they are especially impacted by *Cyberattacks*, *Changing consumers preferences*, and other Supply chain performance risks.

4.3 Risk perceptions among stakeholders

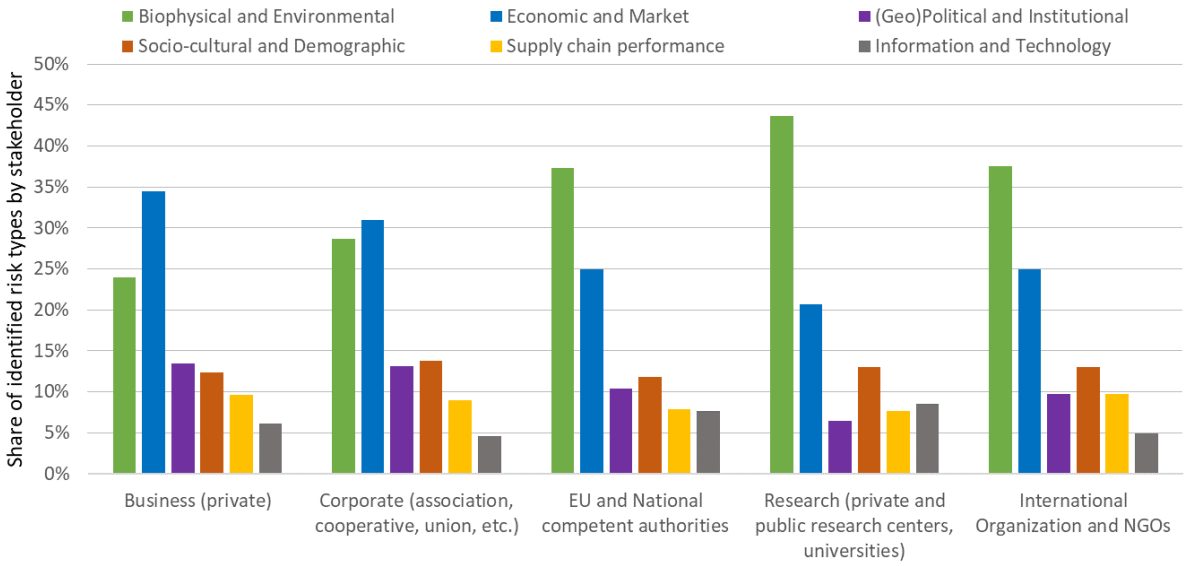
The previous sections presented the findings of the analysis of risks and vulnerabilities based on stakeholders' perceptions from the semi-structured interviews and online survey. However, risk perceptions can differ among stakeholders, whereby different stakeholders can be affected differently by risks. This section presents the findings of the analysis of the difference in risk perceptions between types of stakeholders and different business size categories, based on the online survey responses. For this analysis, the frequencies of identification and perceived Risk Index values are analysed by risk type across the different types of stakeholder and business size categories.

4.3.1 Risks by type of stakeholder

In the online survey, respondents were asked to select the 10 most important risks from a pre-defined list of 28 risk categories. Figure 27 shows the percentage shares of online survey respondents who identified risks under the different risk types, by type of stakeholder. Hence, the figure shows how perceptions differ among stakeholders as regards the importance of the different risk types.

Firstly, Biophysical and Environmental risks and Economic and Market risks are the most frequently selected risk types by all types of stakeholder, while, on the other hand, Supply chain performance risks and Information and Technology risks are the least selected. However, it can be noted that Economic and Market risks were selected by a notably high share of business stakeholders (i.e. private businesses and stakeholder organisations), whereas Biophysical and Environmental risks were selected by notably high shares of stakeholders from competent authorities, research organisations, and international organisations and NGOs tend to overemphasise Biophysical and Environmental type of risks.

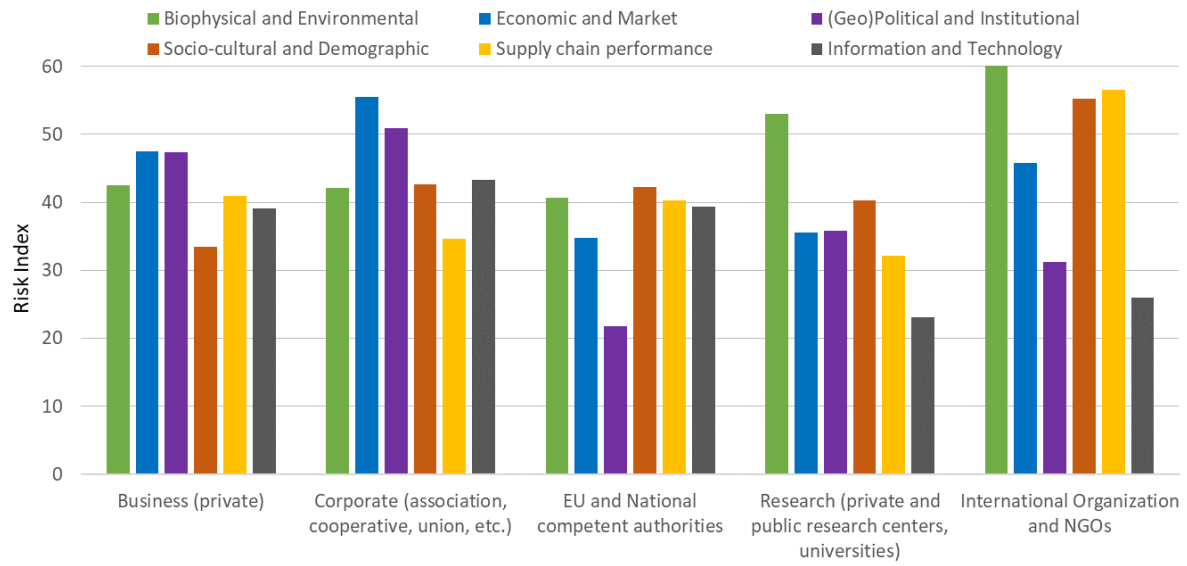
Figure 27. Frequencies of identification of risks under each risk type, by type of stakeholder



Source: Online survey.

Figure 28 reports the average Risk Index, for all risk type, as perceived by different types of stakeholders. The figure shows what are the most threatening risk types for each stakeholder. While for business stakeholders (i.e. private businesses and corporations) Economic and Market risks, and (Geo)Political and Institutional risks represent the greatest threat, for researchers and international organisations the Biophysical and Environmental risks are the major threat. Although the frequency of identification of (Geo)Political risks across stakeholders was similar, the perceived Risk Index becomes significantly higher for business stakeholders. Likewise, Information and Technology risks are identified by different stakeholders with similar frequency. Still, business stakeholders and competent authorities have a much higher Risk Index for this risk type. At least in part, this can be due to the effect of cyberattacks, which are recent phenomena that business stakeholders have increasingly experienced following Russia's unprovoked invasion of Ukraine, while it remains relatively unknown to non-business stakeholders.

Figure 28. Risk Index values for different risk types, by type of stakeholder



Source: Online survey.

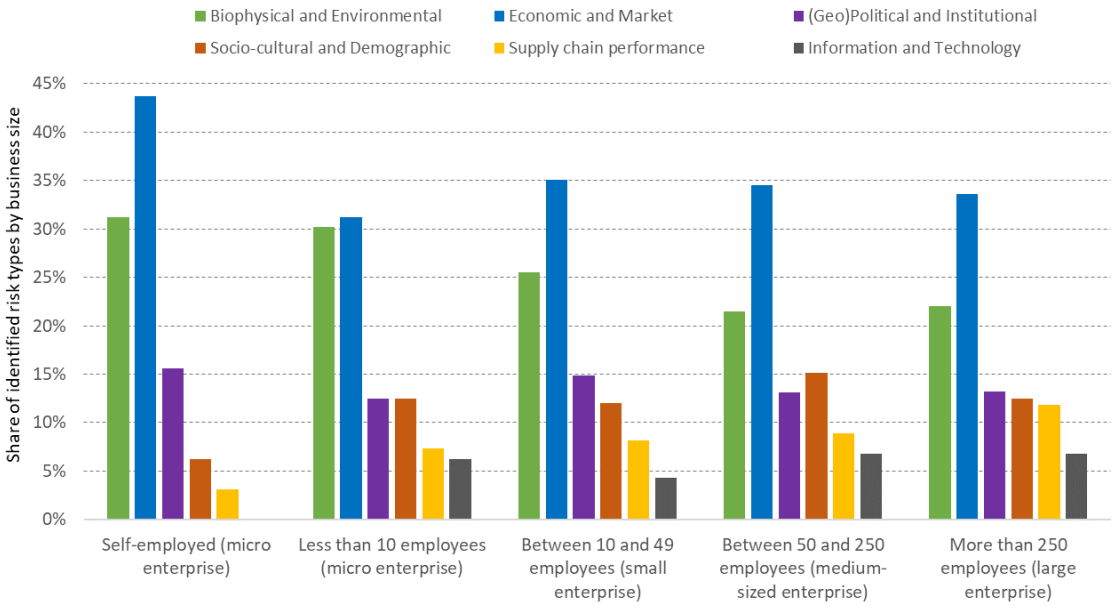
4.3.2 Risks by business size

Different categories of private businesses participated in the online survey. Figure 29 shows the percentage shares of online survey respondents who identified risks under the different risk types, by business size category. Hence, the figure shows what risk types are particularly important to micro, small, medium-sized and large enterprises.

Overall, Economic and Market risks, and Biophysical and Environmental risks, remain the most frequently identified by far across all business size categories. The share of identified risks under Economic and Market type, (Geo)Political and Institutional type, and Information and Technology type, are quite similar across business size categories, meaning that the importance attached to these risks is generally independent from the business size. However, self-employed enterprises show a significantly higher share of Economic and Market risks selected, and no Information and Technology risks identified. Likely, very small businesses have a lower technological or digital component (given the high costs of these assets), and greater issues related to economic competitiveness and financial capacity.

Notably, the figure shows some patterns for the remaining risk types. Firstly, the share of Biophysical and Environmental risks decreases as the business size increases, with self-employed enterprises assigning more importance to these risks, and large enterprises assigning lower importance. Secondly, the share of Socio-cultural and Demographic risks, and Supply chain performance risks, increases with the business size, whereby self-employed enterprises are less concerned about these risks, and large enterprises a more concerned about them. Coherently, large businesses rely on more complex logistics operations and relationships along the supply chain, which make them more exposed to disruptions in up-stream supply, transportations and logistics in general, as well as to social disorders and unrest. For example, a higher number of employees can imply higher exposure to strikes. On the other hand, smaller businesses might be more vulnerable to climate-related adverse events.

Figure 29. Frequencies of identification of risks under each risk type, by business size category



NB: The figure refers only to the private business companies that participated in the survey (90 respondents covering 17 Member States), of which half were from Spain and Austria. See Annex 6 for the composition of the sample.

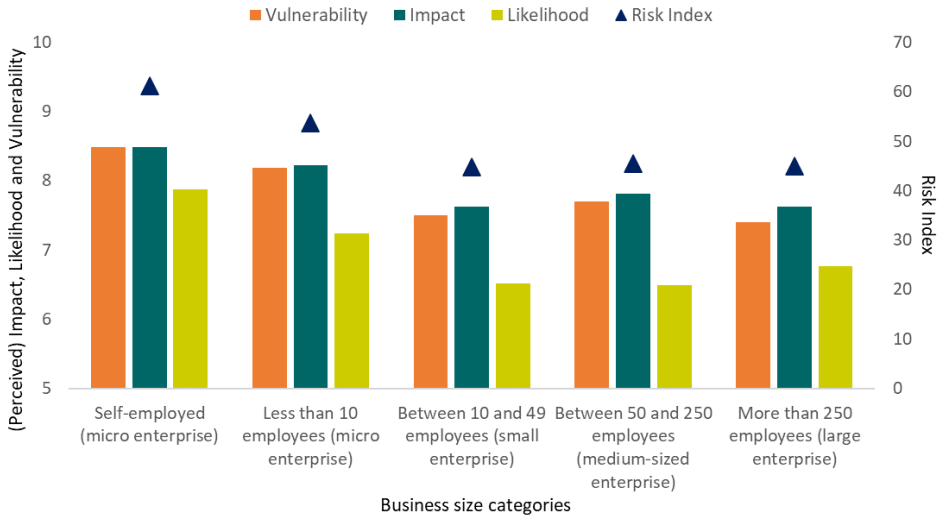
Source: Online survey.

Figure 30 shows the Risk Index, as well as the vulnerability, impact, and likelihood as perceived by stakeholders across five different business size categories, according to the online survey results.

According to the data, smaller enterprises feel more vulnerable to risks, hence scores for likelihood, vulnerabilities, impact and Risk Indexes are higher for these companies than for bigger enterprises. This is evident when comparing the following three groups of categories together: the self-employed businesses, the

micro enterprise (less than 10 employees), and the small enterprises. The three bigger categories (small, medium-sized, and large enterprises) have very close indexes. This last group of the three biggest categories also has very close values for likelihood, impact and vulnerability. An exception to this is likelihood which is higher for large enterprises than for small and medium-sized ones. This could be due to the larger geographical and sectoral scale of work that larger enterprises with more than 250 employees deal with, leaving them with a higher perceived likelihood of risks.

Figure 30. Risk Index, potential impact, likelihood of occurrence, and vulnerability by business size



NB: The figure refers only to the private business companies that participated in the survey (90 respondents covering 17 Member States), of which half were from Spain and Austria. See Annex 6 for the composition of the sample.

Source: Online survey.

5 Conclusions

EU food systems operate, nowadays, under a state where volatility, uncertainty and crisis fatigue have become the 'new normal' (Borges de Castro et al., 2021). The growingly complex and cumulating challenges affecting the EU food supply chain draws attention towards the future capacity to secure a sufficient and varied supply of safe, nutritious, affordable and sustainable food in the EU. Recent crises originating from the COVID-19 pandemic and Russia's unprovoked invasion of Ukraine made the disruptive potential of unexpected or unknown challenges even more evident (European Parliamentary Research Service, 2022a; European Policy Centre, 2022) and gave rise to an EU initiative for developing a European preparedness and crisis management strategy to ensure food supply and security in the face of future threats (European Commission, 2021a).

This study aimed to draw a comprehensive picture of the range of perceived risks and vulnerabilities that may affect food supply and security in the EU. In particular, this study aimed to provide indications of the diversity of risks, where they might originate from and when they might occur, whether certain risks merit special attention, and how vulnerable the EU food supply chain is (and why) with regard to these risks. However, it must be noted that this study was based on analyses of stakeholders' perceptions and is not meant to reflect objective risks or to quantitatively assess them.

The analysis first reminds us that a large diversity of risks can affect the food supply chain. While for certain risks, the geographical origin and time horizon of potential occurrences remain unclear or varied, for other risks it is possible to discern more clearly whether they might originate within or outside the EU, and whether they might occur in the short or long term. Such characterisation helps us to understand possible areas of intervention around the source of the risk.

Biophysical and environmental risks and Economic and market risks are the most frequently identified by stakeholders, and are those to which the food supply chain seems to be most exposed overall. These risks are generally well understood by stakeholders and have been widely studied in research. While economic and market risks and biophysical and environmental risks can have concurrent impacts on the food supply chain, the interviews suggest that a dichotomy between these risk types is perceived in the potential trade-offs in dealing with one or the other.

Alongside 'well-known' risks, relatively novel risks emerge from the stakeholder perspective. This is the case, for instance, for risks related to cybersecurity, new technologies, pests and diseases, and climate and weather patterns, which are being increasingly recognised by stakeholders (but, with the exception of climate and weather risks, are relatively poorly addressed in the literature). These risks are expected to increase in the near future. Recent circumstances linked to the Russian war of aggression against Ukraine and the COVID-19 pandemic have also increased recognition by stakeholders of the importance of market, geopolitical and health-related risks. Yet, certain risks that are widely mentioned in the literature are less frequently identified by stakeholders (e.g. those related to water scarcity and the disruption of transportation and logistics), which might point to a possible underestimation of some risks by stakeholders.

Based on our Risk Index, Economic and market risks and Biophysical and environmental risks stand out as prominent threats to the EU food supply chain overall. However, the analysis also highlights that those risks are not necessarily relevant across all Member States, sectors, or stages of the supply chain, whereas other risks that appear less threatening overall seem to be very important in specific contexts. For example, risks differ across Member States. Southern Member States (e.g. Malta, Italy, Spain) appear to be more affected by Biophysical and Environmental risks (especially climate risks), whereas eastern and island Member States (e.g. Cyprus, Malta, Ireland, Hungary, Poland) seem to be more affected by Supply chain performance risks. Southern and eastern Member States (e.g. Hungary, Czechia, Cyprus, Malta, Romania) seem to be more affected by Socio-cultural and Demographic risks. The risk profile of Member States depends on certain factors, including geographical location, weather patterns, how developed the transport infrastructure is and demographic trends. Consequently, responses to and preparedness for risks and crises should be flexible across the EU.

Systemic risks affecting many sectors, such as those related to *Input costs increase*, *Changing climate patterns* or *Extreme weather events*, might raise most concerns when taken from an EU angle. Nonetheless, the analysis also highlights risks that are specifically relevant for certain sectors. These risks merit equal attention, not only because they could have severe implications within specific (local or sectoral) contexts, but also because localised disruptions in the EU supply chain could have repercussions throughout the entire system (e.g. through transmission or cascade effect).

Risks do not only affect the 'usual suspects'. While food production remains the stage most exposed to climate-related risks, stakeholders at other stages of the supply chain are becoming increasingly concerned about these

risks, and the cascade effects that they can have on the whole chain. For instance, risks related to water degradation and scarcity risks are not only an issue for agricultural production but also for other stages of the supply chain (e.g. food processing and in specific cases food transport). Similarly, stakeholders at different stages of the supply chain noted risks related to generational renewal, which so far have mostly been linked to agricultural and fishery production.

Risk perception also differs among different types of stakeholders and business size categories. Business stakeholders (i.e. private businesses and corporates) have a higher perception of Economic and Market risks, whereas stakeholders from competent authorities, research organisations and international organisations have a higher perception of Biophysical and Environmental risks. Likewise, while stakeholders from smaller enterprises have a higher perception of risk overall, and in particular a higher perception of Biophysical and Environmental risks, stakeholders from larger enterprises show a higher perception of Socio-cultural and Demographic risks, and Supply chain performance risks.

The EU food supply chain seems to be vulnerable to the risks identified to varying extents. While structural factors determining the degree of vulnerability were identified, no particular factor appears to be the most relevant overall (i.e. the frequencies of identification are similar across different factors of vulnerability). Yet, the analysis suggests that the relevance of a factor actually depends on the type of risk; hence, a factor might determine the degree of vulnerability to a (few) risk type(s) but not to others. The factors *Lack of financial resources*, the *Low flexibility to change* and the *Lack of natural resources*, in particular, seem to increase the degree of vulnerability to multiple risk types, including the Biophysical and Environmental, Economic and Market risks, (Geo)Political and Institutional and Socio-cultural and Demographic types. On the other hand, factors of vulnerabilities that are on the rise in current debates (e.g. those related to the dependency on foreign sources) are not found to determine degree of vulnerability to any risk types. It is interesting to note, for example, that no correlations are found between the factors *Low diversity of input suppliers or clients* and *High dependency on import/export* and the degree of vulnerability to any specific risk type.

The findings of this study lay down the basis for further discussion and analysis of the risks and vulnerabilities in the EU food supply chain. In particular, this study will support the EFSCM in formulating recommendations on ways to address or mitigate risks and vulnerabilities, including structural issues that drive food supply chain risks.

Lessons can be learned regarding the setting and array of possible strategic alternatives to prevent, prepare for, and cope with future risks and crises. For instance, the significant diversity of the risks identified and their heterogeneity across Member States and sectors, point to the need for a coordinated strategy involving all actors operating at different levels of the food supply chain. Likewise, because the scope of the risk types identified is very broad, a strategy to tackle crises should adequately account for and be coherent with all other relevant (policy) initiatives in the EU. Given the unique risk profiles of the outermost regions, an ad hoc strategic approach may be required for them, while addressing emerging and rapidly growing risks (e.g. cybersecurity) may need increasing efforts and novel instruments.

Different types of strategies could be set up to deal with risks, depending on their characteristics. The findings of this study, for example, could help to determine whether it would be more effective to take actions that target the risk origin, likelihood or impact, or the factors making a sector vulnerable to that particular risk. Relevant strategies are available to reduce the vulnerabilities of the food supply chain. For example, some stakeholders pointed to the diversification of food production, supply chain operations, trade relationships and suppliers, as a key strategic principle for dealing with high dependency or a low degree of flexibility to change. When it comes to addressing vulnerabilities originating in the global supply chains and the increasing reliance on foreign supply chain operators, the development of short or local supply chains can certainly play a role. Likewise, the discussion of EU strategic autonomy is becoming ever more relevant. On the other hand, international trade and the single market can present opportunities for dealing with local or regional risks and vulnerabilities.

Ultimately, an important lesson that can be learned from this study, which is in line with recent experiences of the COVID-19 pandemic and the Russian war of aggression against Ukraine, is the crucial need to be prepared to deal with the unknown. For truly effective crisis preparedness, it is crucial to not limit efforts to what is known or can be expected but to instead put in place the best possible arrangements to enable resilience against unknown events. Relevant EU policies, such as the Common Agricultural Policy and the Common Fisheries Policy, support the implementation of the European Green Deal and the Farm to Fork and Biodiversity strategies. This array of policy initiatives can be leveraged to mitigate risks by improving the sustainability and resilience of food systems.

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List of abbreviations

EU	European Union
EFSCM	European Food Security Crisis preparedness and response Mechanism
EFSA	European Food Safety Authority
NGO	non-governmental organisation

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Annexes

Annex 1. Methodology for data collection and analysis

Data collection

The systematic literature review

The approach for the review was based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). Scientific literature was identified through an extensive keywords search in Web of Science, whereas grey literature was identified through a targeted search on the internet. As a result, 183 scientific and 38 institutional documents were initially identified. While all institutional documents have been retained for analysis, only 101 of the 183 scientific papers were analysed after screening of titles, abstracts and full papers. The list of analysed documents is reported in Annex 2, while the keywords used for the search are reported in Annex 3.

The semi-structured interviews

The aim of the semi-structured interviews was to identify and describe, based on the stakeholders' perceptions, the range of possible risks that could affect the EU food supply chain.

A total of 152 stakeholders were interviewed. The composition of the sample of participants is reported in Annex 5. The interviews lasted maximum 45 minutes and were conducted mainly in English, but also in other EU languages (including French, Italian, Spanish, Portuguese, Polish, Bulgarian and Dutch). The interviews were conducted through video calls. Before the interview, interviewees were provided with the questionnaire and instructions for the interview. The following information were gathered through the interview:

- a list of possible risks that could affect the EU food supply chain (open question);
- a description of the adverse event causing each risk and of the impact of the risk (open question);
- the definition of the time horizon of possible occurrence and the geographical origin of the risk (single choice question);
- a description of the vulnerabilities to the risks identified (open question);
- an estimation of the degree of vulnerability to the risks identified (single choice question).

The questionnaire used for the interviews is shown in Annex 4.

The online survey

The aim of the online survey was to quantify key properties of the risks and vulnerabilities previously identified in the interviews.

The survey was designed to last for a maximum of 30 minutes, and was made available in all EU languages on the EUSurvey platform. The online survey remained accessible for a duration of about 2 months. Through the consultation, 278 full responses were gathered. Annex 5 shows the composition of the sample of respondents. The following information was gathered through the online survey:

- details of the 10 main risks selected by respondents as affecting their sectors from a predefined list of 28 risk categories (multiple-choice question);
- information to enable the quantification, for each risk selected, of the likelihood of occurrence, potential impact and degree of vulnerability, based on respondents' perceptions (Likert scale);
- information to enable the identification of the factors determining the vulnerability to each of the risks selected, from a predefined list of 10 factors of vulnerability (multiple-choice question).

The questionnaire used for the online survey is shown in Annex 5.

Data analysis

Analysis of geographical origin and time horizon of occurrence from the semi-structured interviews

In the semi-structured interviews, stakeholders were asked to categorize each identified risk, based on their perception, as either originated domestically (within the country), within the EU, outside the EU (foreign country/region), or globally. Likewise, stakeholders were also asked to categorize each identified risk based on the potential time horizon of occurrence (as perceived by stakeholders), notably within 1, 5, 10, or 20 years.

Geographic origin and time horizon of occurrence are analysed through the frequency of responses across the possible options.

Analysis of likelihood of occurrence, potential impact and risk exposure based on the online survey

In the online survey, respondents were asked to score, for each risk selected, the potential impact and likelihood of occurrence on a scale from 0 to 10 (with 10 being the maximum impact/likelihood). Average scores were used for the analysis.

Based on most common risk assessment techniques (ISO, 2019), a risk exposure indicator was calculated by multiplying impact and likelihood scores, as follows:

Risk Exposure (0-100) = Potential Impact (0-10) X Likelihood of Occurrence (0-10)

where risk exposure assumes values between 0 and 100 (with 100 being the highest exposure). The higher the exposure to a risk, the higher the hazardousness of that risk.

Analysis of degrees of vulnerabilities

In the semi-structured interviews, stakeholders were asked to classify the perceived degree of vulnerability to each of the risks identified into one of four categories: low, medium, high or extreme. The frequency of selection of each of the four options was used to assess the degree of vulnerability to the 28 risk categories.

Analysis of factors of vulnerability

In the online survey, respondents were asked to select the factors determining the vulnerability to each risk selected, from a predefined list of 10 factors. An analysis of the correlation between the factors of vulnerability and the degrees of vulnerability to the different risk types was conducted by means of linear regression analyses. Six linear regression analyses were conducted separately for each risk type and an overall linear regression analysis was conducted on the overall sample, disregarding the risk type. Standard errors were clustered around respondents' countries to ensure robustness of estimation. Magnitude of correlation and statistical significance were used to identify key factors of vulnerability. Linear regression analyses were conducted in RStudio.

Measurement of the Risk Index

Respondents to the online survey were also asked to score, for each risk selected, the degree of vulnerability to the risk on a scale from 0 to 10 (with 10 being the maximum degree of vulnerability).

A normalised Risk Index is calculated to account for the capacity of the food supply chain to deal with risks by combining risk exposure and perceived vulnerability, as follows:

Risk Index (0-1000) = Risk Exposure (0-100) X Vulnerability (0-10)

where the Risk Index is normalised to assume values between 0 and 100 (with 100 being the highest damage possible from the risk). Some risks might have a high index value because of a high exposure value despite having a low degree of vulnerability value, and vice versa. The analysis of exposure and vulnerability, thus, can be helpful in guiding the risk management strategy, which could either intervene at the source of the risk or at the source of vulnerability. The Risk Index was used to prioritise risks, that is, to identify those risks warranting major attention.

Use of weighting factors

For the analysis of potential impact, likelihood of occurrence, risk exposure and the Risk Index, weighting factors were applied to remove the distortions brought about by countries over-represented in the sample. First, weighting factors for each country were calculated. Each country weighting factor was calculated as the reciprocal of its probability of selection into the sample (Yansaneh, 2003). In mathematical notation, if a country $\boldsymbol{i}$ is included in the sample with probability $\boldsymbol{P_i}$, then its base weight, denoted by $\boldsymbol{W_i}$, is given by:

$$\boldsymbol{W_i} = 1/\boldsymbol{P_i}$$

The impact, likelihood, exposure and Risk Index values were then multiplied by the weighting factors (based on the country to which they are related). Average values for the analysis were calculated by dividing the sum of weighted values by the sum of weighting factors.

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Annex 3. List of keywords used for the literature review

The search stage of the literature review was conducted on the Web of Science database for publications from the 2013–2022 period.

The research was based on the following three dimensions:

1. food supply chain,
2. risk and vulnerability,
3. relevance.

Two separated Booleans were used to search on title and keywords.

The first was as follows.

(('food supply' OR 'food system*' OR 'food chain*' OR 'Fish*' OR 'seafood' OR 'Dairy' OR 'Meat' OR 'Fruit and Vegetable*' OR 'Cereal*' OR 'Sugar' OR 'input suppl*')
AND ('risk*' OR 'shock*' OR 'stress' OR 'vulnerabilit*' OR 'resilience' OR 'weakness')
AND ('food security' OR 'crisis'))

The second was as follows.

(('food supply' OR 'food system*' OR 'food chain*' OR 'Fish*' OR 'seafood' OR 'Dairy' OR 'Meat' OR 'Fruit and Vegetable*' OR 'Cereal*' OR 'Sugar' OR 'input suppl*')
AND ('risk*' OR 'shock*' OR 'stress' OR 'vulnerabilit*' OR 'resilience' OR 'weakness')
AND ('foresight*' OR 'future*'))

The latter was intended to broaden the scope of the search to include foresight studies (see the latter raw of the Boolean) even though not referring to relevant risks and vulnerabilities. The latter goal is pursued by removing the search string ('food security' OR 'crisis')).

Annex 4. Questionnaire of the semi-structured interviews

Section A - Introductory questions (for business/corporate stakeholders only) [2 minutes]

Q0: Could you describe your organisation according to the following categories?

- Could you identify in which of the following sectors your organisation (or the organisations you represent) operates? (multiple choices possible)

☐ *Fishery and aquaculture products and their preparations (including fats and oils)*
☐ *Meat and their preparations*
☐ *Dairy (including eggs, honey, fats, and other animal products) and their preparation*
☐ *Fruit & Vegetables and their preparations*
☐ B*everage and alcohol*
☐ *Cereals, Legumes and Oleaginous and their preparations (including vegetal oils)*
☐ *Sugar and miscellaneous (including coffee, tea, cocoa, spices)*

- Could you identify in which of the following stages of the supply chain your organisation (or the organisations you represent) operates? (multiple choices possible)

☐ *Input suppliers for primary producers (like suppliers of fertilisers and pesticides to agriculture, or suppliers of feed to aquaculture or livestock sectors)*
☐ *Producers (including farmers and fishers)*
☐ *Processors*
☐ *Packaging*
☐ Logistics (including transportations and storage)
☐ *Wholesalers & traders*
☐ *Retailers*

- Where relevant, could you identify in which EU Member State your organisation (or the organisations you represent) operates?
- Does your organisation (or the organisation you represent) operate mainly in any of the following EU outermost regions? Please, select which ones:

☐ *Martinique*
☐ *Mayotte*
☐ *Guadeloupe*
☐ *French Guiana*
☐ *Réunion*
☐ *Saint Martin*
☐ *Madeira and the Azores*
☐ *the Canary Islands*

Section B – Identification of risks (in relation to sectors and stages of the supply chain) [5 minutes]

Q1: In your opinion, what are the main risks the sector where your organisation (or the organisations you represent) operates will face in the short, medium-, and long-term time horizon, from the most to the least relevant? If you do not belong to/operate in a specific segment or sector, what are the main risks that specific segments or sectors of the EU food supply chain will face in the short-, medium-, and long-term time horizons, from the most to the least relevant? Can you include at least one low probability and high impact risk (black swan)?

Section C – Description of the risks identified and linked vulnerabilities [35 minutes]

Q2: For each risk listed in Q1, what are the characteristics of risk and vulnerabilities?

Q2.1 - What are the characteristics of the risk?

- What is the adverse event?
- Could you describe the potential impact of the adverse event occurring, in terms of consequences on the sector where your organisation (or the organisations you represent) operates and its capacity to supply affordable food? How could it affect the supply of food (food availability in the market)? How could it affect food security (food affordability, e.g. price)?
- What is, in your perception, the time horizon within which this adverse event could materialise (occurrence of the adverse event)? (single choice)

☐ *Within the next year*
☐ *Within the next 5 years*
☐ *Within the next 10 years*
☐ *Within the next 20 years or more*

- What is the geographic origin of the risk? (single choice)

☐ *Domestic (within a country)*
☐ *Intra-EU (within EU countries)*
☐ *Extra-EU (outside EU countries, for example trade barriers in a third country)*
☐ *Global (EU + the rest of the globe, for example climate change)*

- What other stages of the supply chain do you think it might significantly affect? (multiple choices)

☐ *Input suppliers*
☐ *Producers (including farmers and fishers)*
☐ *Processors*
☐ *Packaging*
☐ Logistics (including transportations and storage)
☐ *Wholesalers & traders*
☐ *Retailers*

- How many other sectors could be significantly affected? (multiple choices)

☐ *Fishery and aquaculture products and their preparations (including fats and oils)*
☐ *Meat and their preparations*
☐ *Dairy (including eggs, honey, fats, and other animal products) and their preparation*
☐ *Fruit & Vegetables and their preparations (including vegetal oils)*
☐ *Beverage and alcohol*
☐ *Cereals, Legumes and Oleaginous and their preparations*
☐ *Sugar and miscellaneous (including coffee, tea, cocoa, spices)*

Q2.2 – How vulnerable is the sector where your organisation (or the organisations you represent) operates, and what are the factors causing the vulnerability?

- How vulnerable do you think the sector is to this risk? (single choice)

☐ *Slightly vulnerable*
☐ *Moderately vulnerable*
☐ *Highly Vulnerable*
☐ *Extremely vulnerable*

- Can you describe the factors determining the vulnerability of the sector?

Section D – Complement the list of risks and their description (OPTIONAL)

Q3: Could you please identify and discuss additional risks we have identified through a literature review?

Annex 5. Questionnaire of the online survey

1- Stakeholder identification

*****Which type of stakeholder you are?

Business (private)
Corporate (association, cooperative, union, NGOs, etc.)
EU & National Competent Authorities
International Organisation and NGOs
Research (private and public research centers, universities)

*****In which of the following sectors your organisation (or the organisations you represent) operates?

Fishery and aquaculture products and their preparations (including fats and oils)
Meat and their preparations
Dairy (including eggs, honey, fats, and other animal products) and their preparation
Fruit & Vegetables and their preparations
Beverage and alcohol
Cereals, Legumes and Oleaginous and their preparations (including vegetal oils)
Sugar and miscellaneous (including coffee, tea, cocoa, spices)

*****In which of the following stages of the supply chain your organisation (or the organisations you represent) operates?

Input suppliers for primary producers (like suppliers of fertilisers and pesticides to agriculture, or suppliers of feed to aquaculture or livestock sectors)
Producers (including farmers and fishers)
Processors
Packaging
Logistics (including transportations and storage)
Wholesalers & traders
Retailers

*How many employees does your organisation or the organisations you represent have?

On average when several businesses belong to the same organisation

More than 250 employees (large enterprise)
Between 50 and 249 employees (medium-sized enterprise)
Between 10 and 49 employees (small enterprise)
Less than 10 employees (micro enterprise)
Self-employed (micro enterprise)

***** In which country are your headquarters located?

Austria	Germany	Poland
Belgium	Greece	Portugal
Bulgaria	Hungary	Romania
Croatia	Ireland	Slovak Republic
Cyprus	Italy	Slovenia
Czechia	Latvia	Spain
Denmark	Lithuania	Sweden
Estonia	Luxembourg	Other
Finland	Malta	
France	Netherlands	

If other, please specify**:**

***** In which countries does your organisation (or the organisations you represent) operate?

Please select ''Other'' if you also operate outside the EU

Austria	Germany	Poland
Belgium	Greece	Portugal
Bulgaria	Hungary	Romania
Croatia	Ireland	Slovak Republic
Cyprus	Italy	Slovenia
Czechia	Latvia	Spain
Denmark	Lithuania	Sweden
Estonia	Luxembourg	Other
Finland	Malta	

France	Netherlands	

If other, please specify:

***** Does your organisation (or the organisation you represent) operate mainly in any of the following EU outermost regions?

Martinique	Saint Martin
Mayotte	Madeira and the Azores
Guadeloupe	the Canary Islands
French Guiana	Not Applicable
Réunion	

2- Risks selection

***** From the following list of risks, please select at least 10 risks that may affect your sector the most in future

at least 10 choice(s)

Up-stream supplies disruption or unavailability
Water pollution and/or scarcity
Food contamination and waste
Financial liquidity (lack of)
Information, knowledge and innovation (lack of)
Market contraction, concentration and (unfair) competition
Extreme weather events (increased frequency/intensity of droughts, heatwaves, etc.)
Land (lack or degradation of)
Environmental pollution (including nuclear contamination)
Labour availability/accessibility (lack of or increased cost)
Change in consumers preferences and public image
Trade barriers and distortions in trade flows
Changing climate and weather patterns (e.g. temperature, precipitation, sea level, CO2, snowpack, wind etc.)
Market instability (price fluctuations, inflation, increased uncertainties, threats to single market, etc.)
Generational renewal and sector attractiveness (lack of)
Technological risk (technological fatigue, lack of technology or equipment, new biotechnologies risks, etc.)
Cyberattacks and internet blackouts
Transport, infrastructure and logistics (lack of or failure)
Financial and economic crisis
Policy changes & regulatory requirements
Pests and diseases (plants and livestock) and invasive species
Population growth, displacement and migration
(Geo)Political instability, conflict (war) and terrorism
Energy, raw materials and input cost increase and reduced access/availability
Social disorders and unrest
Natural disasters (like earthquakes , floods, hurricanes etc.)
Natural resources and biodiversity (loss, overuse and degradation)
Pandemic and human health

3- Risks analysis

For each of the (at least) 10 risks identified in section 2 above, you should answer the following questions.

In your perception, how likely is it that the risk of ''*Risk identified*'' will occur?

(1 is very unlikely and 10 is very likely)

Risk likelihood refers to the possibility of a potential risk occurring within a specific time range.

	1	2	3	4	5	6	7	8	9	10
***Within the next 3 years**										
***Within the next 10 years**										

*****In your perception, how do you quantify the potential impact of ''*Risk identified* '' on your sector?

The potential impact of a risk is defined as the direct and indirect consequences of a risky event occurring on the supply of sufficient (quantity), affordable (price), and safe (healthy) food in the market.

*****In your perception, how vulnerable is your sector to ''*Risk identified* ''?

Low vulnerability means higher capacity to recover from or adapt to the impact of the risk. Vulnerability measures the degree to which the sector is able or unable to successfully recover from or adapt to the impact of the adverse event without major disruption.

***** In your opinion, which of the following factors contribute to determine the vulnerability of your sector to ''*Risk identified* ''?

Low diversity of input suppliers and/or clients (high concentration)
High dependency on certain imports and/or export markets
Low flexibility to change (due to fixed assets, dependence on climate or on specific inputs, etc.)
Lack of financial resources or limited economic margins to mitigate risk impact
Lack of natural resources available/accessible (land, marine areas, raw materials, etc.)
Lack of human capital available (skills, know-how, workers, etc.)
Lack of (technological) alternatives, research or infrastructure to cope with the risk
Weak supply chain cooperation, unbalanced bargaining power or competition, strong operators' interdependence
Policy and regulatory constraints, disharmonised rules, or lack of risk awareness or communication
Other

4- Additional information

***** Has your organisation been already interviewed within the scope of this study?

Yes
No
I don't know

Annex 6. Composition of the sample of participants in the interviews and online survey

Composition of the sample of participants in the semi-structured interviews.

		Sectors						Stages of the supply chain					Type of stakeholder				
	Total	Fishery and aquaculture products and their preparations (including fats and oils)	Meat and their preparations	Dairy (including eggs, honey, fats, and other animal products) and their preparation	Fruit & Vegetables and their preparations	Cereals, Legumes and Oleaginous and their preparations (including vegetal oils)	Sugar and miscellaneous (including coffee, tea, cocoa, spices)	Input suppliers for primary producers	Producers (including farmers and fishers)	Processors and packaging	Distribution, traders & logistics	Retailers	Business (private)	Corporate (association, cooperative, union, NGOs etc.)	EU & National Competent Authorities	Research	International organization
Total	**152**	**53**	**38**	**42**	**41**	**40**	**35**	**14**	**35**	**27**	**21**	**14**	**6**	**98**	**25**	**19**	**3**
Austria	**3**	1	1	1	2	2	2	1	0	0	0	1	1	1	1	0	0
Belgium	**9**	2	2	3	2	2	2	0	3	1	0	0	0	5	3	1	0
Bulgaria	**1**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Cyprus	**1**	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Cezchia	**1**	1	1	1	1	1	1	0	0	0	1	1	0	1	0	0	0
Germany	**2**	1	0	0	0	0	0	0	0	0	1	0	0	1	0	1	0
Denmark	**3**	2	0	0	0	0	0	0	2	0	0	0	0	2	1	0	0
Estonia	**2**	0	0	0	0	0	0	0	0	0	1	1	0	1	1	0	0
Greece	**1**	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Spain	**10**	5	2	3	3	2	3	1	4	5	3	0	0	9	0	1	0
Finland	**2**	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
France	**6**	2	1	1	1	1	1	0	1	1	0	0	0	2	0	4	0
Croatia	**1**	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Hungary	**2**	0	0	0	1	0	0	0	0	0	1	0	0	1	1	0	0
Ireland	**4**	2	1	2	1	1	1	0	2	0	0	1	0	4	0	0	0
Italy	**13**	1	1	2	1	2	1	0	0	2	1	1	5	5	0	3	0
Lithuania	**3**	0	0	0	0	0	0	0	0	1	1	0	0	1	1	1	0
Luxembourg	**2**	1	1	1	1	1	1	0	0	0	0	1	0	1	1	0	0
Latvia	**3**	1	1	1	1	1	1	0	1	0	0	0	0	1	1	1	0
Malta	**1**	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Netherlands	**7**	4	1	1	1	1	1	0	1	1	1	0	0	4	1	1	0
Poland	**1**	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Portugal	**8**	3	4	4	4	4	3	1	2	1	1	1	0	6	2	0	0
Romania	**4**	1	0	0	0	1	0	0	2	0	0	0	0	2	1	1	0
Sweden	**4**	1	1	1	1	1	1	0	2	0	1	0	0	2	2	0	0
Slovenia	**1**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Slovakia	**2**	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
EU-27	**49**	22	20	20	20	19	16	11	14	14	8	6	0	45	3	1	0
Other	**6**	3	1	1	1	1	1	0	1	1	1	1	0	3	0	0	3

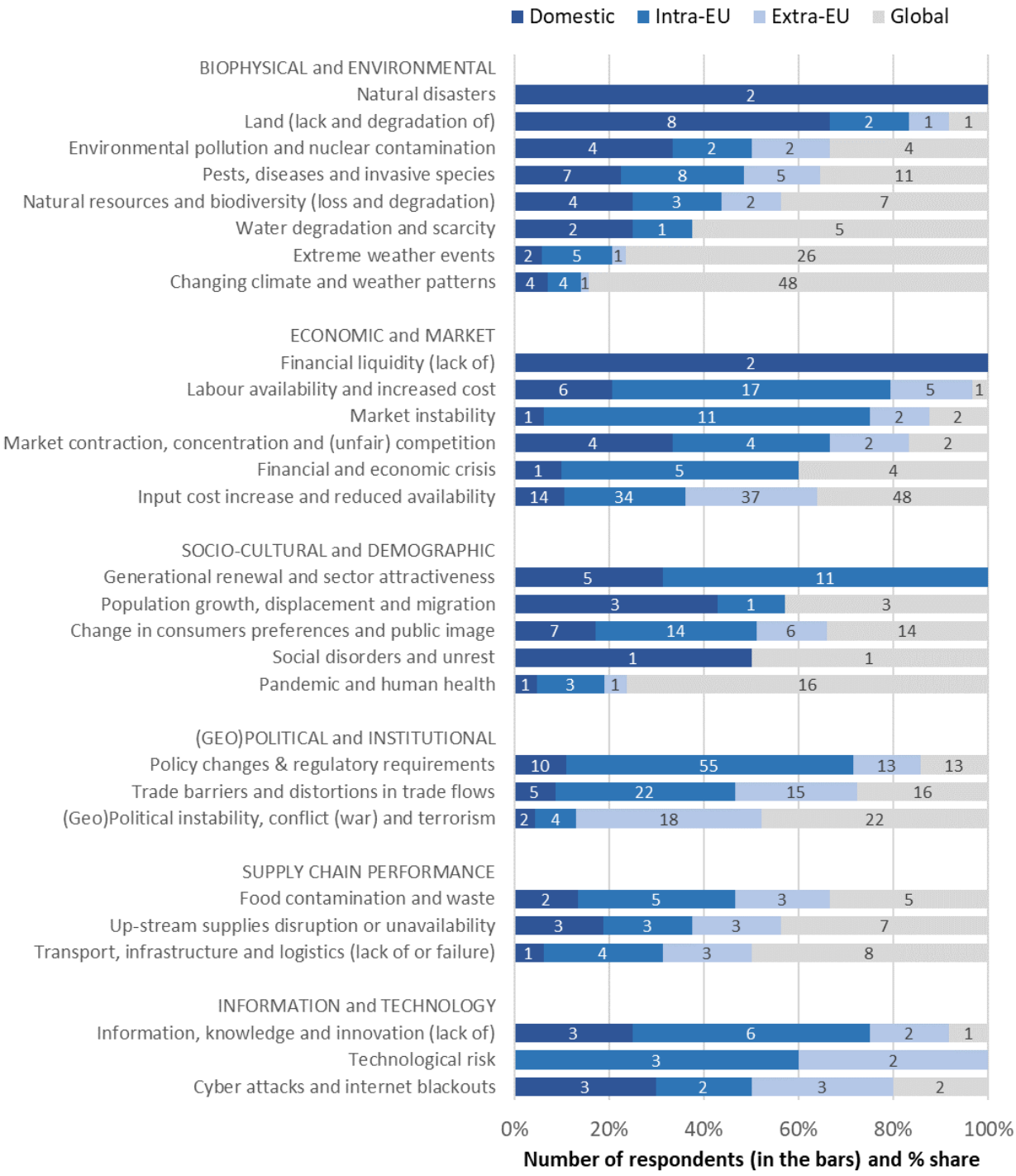
1. Stakeholders can cover multiple sectors and stages of the supply chain, therefore the shares of respondents by sector and stages does not sum up to 1.

Composition of the sample of participants to the online survey.

		Sectors							Stages of the supply chain							Type of stakeholder				
	Total	Fishery and aquaculture	Meat	Dairy	Fruit & Vegetables	Beverage and alcoholics	Cereals, Legumes and Oleaginous	Sugar and miscellaneous (coffee, tea, cocoa, spices)	Input suppliers	Producers	Processors	Packaging	Logistics (including transportations and storage)	Wholesalers and traders	Retailers	Stakeholder organizations	Business (private companies)	EU and National competent authorities	Research organizations (private and public)	International organization and NGOs
Total	**278**	**96**	**105**	**93**	**112**	**52**	**116**	**63**	**74**	**179**	**130**	**47**	**61**	**65**	**55**	**89**	**90**	**54**	**29**	**16**
Austria	**25**	5	10	9	12	5	11	6	9	12	11	1	4	4	2	4	14	5	0	2
Belgium	**20**	8	10	8	9	5	13	10	8	9	11	2	2	4	6	16	1	0	1	2
Bulgaria	**4**	0	2	0	1	1	0	0	0	1	4	0	1	1	1	2	1	1	0	0
Cyprus	**4**	1	1	1	3	2	3	2	0	1	2	2	2	2	2	0	1	3	0	0
Czechia	**1**	0	0	0	1	1	1	1	0	1	1	0	0	0	0	0	0	0	1	0
Germany	**8**	3	4	4	2	0	3	1	2	3	2	0	3	2	0	3	5	0	0	0
Denmark	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Estonia	**6**	0	3	5	2	1	3	1	2	3	4	1	2	0	1	0	4	2	0	0
Greece	**6**	3	0	1	0	0	1	1	1	4	3	3	2	3	3	0	5	1	0	0
Spain	**98**	33	29	20	33	18	32	16	21	66	48	19	21	24	16	38	30	17	7	6
Finland	**3**	1	3	2	3	2	2	2	0	1	2	2	1	1	1	1	1	1	0	0
France	**5**	5	0	0	0	0	0	0	1	4	1	0	1	1	0	3	1	0	0	1
Croatia	**3**	2	1	1	2	1	1	1	2	2	1	1	1	2	1	1	2	0	0	0
Hungary	**2**	0	1	1	1	1	2	1	2	1	1	1	2	2	1	0	1	1	0	0
Ireland	**8**	2	2	4	1	2	3	1	1	4	3	1	1	2	2	3	5	0	0	0
Italy	**27**	15	10	11	16	4	15	6	13	24	10	6	4	6	9	3	0	8	14	2
Lithuania	**2**	0	2	2	2	0	2	0	0	2	0	0	0	0	0	1	0	0	1	0
Luxembourg	**1**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	0	0
Latvia	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Malta	**1**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	0	0
Netherlands	**3**	3	2	2	1	1	2	1	2	3	2	1	2	2	2	2	0	1	0	0
Poland	**10**	1	5	3	1	0	3	1	1	6	3	0	2	0	1	1	7	1	0	1
Portugal	**9**	7	0	1	1	0	2	1	1	3	1	1	3	3	0	5	3	1	0	0
Romania	**7**	2	4	1	0	0	1	0	1	6	3	1	1	1	1	3	1	0	1	2
Sweden	**1**	0	1	1	1	1	1	1	0	1	0	0	0	0	0	0	0	1	0	0
Slovenia	**7**	0	4	5	6	1	4	0	1	6	3	1	0	0	0	1	0	3	3	0
Slovak Republic	**2**	0	2	2	1	0	2	2	0	2	2	0	0	2	2	0	0	2	0	0
Other	**15**	3	7	7	11	4	7	6	4	12	10	2	4	1	2	2	8	4	1	0

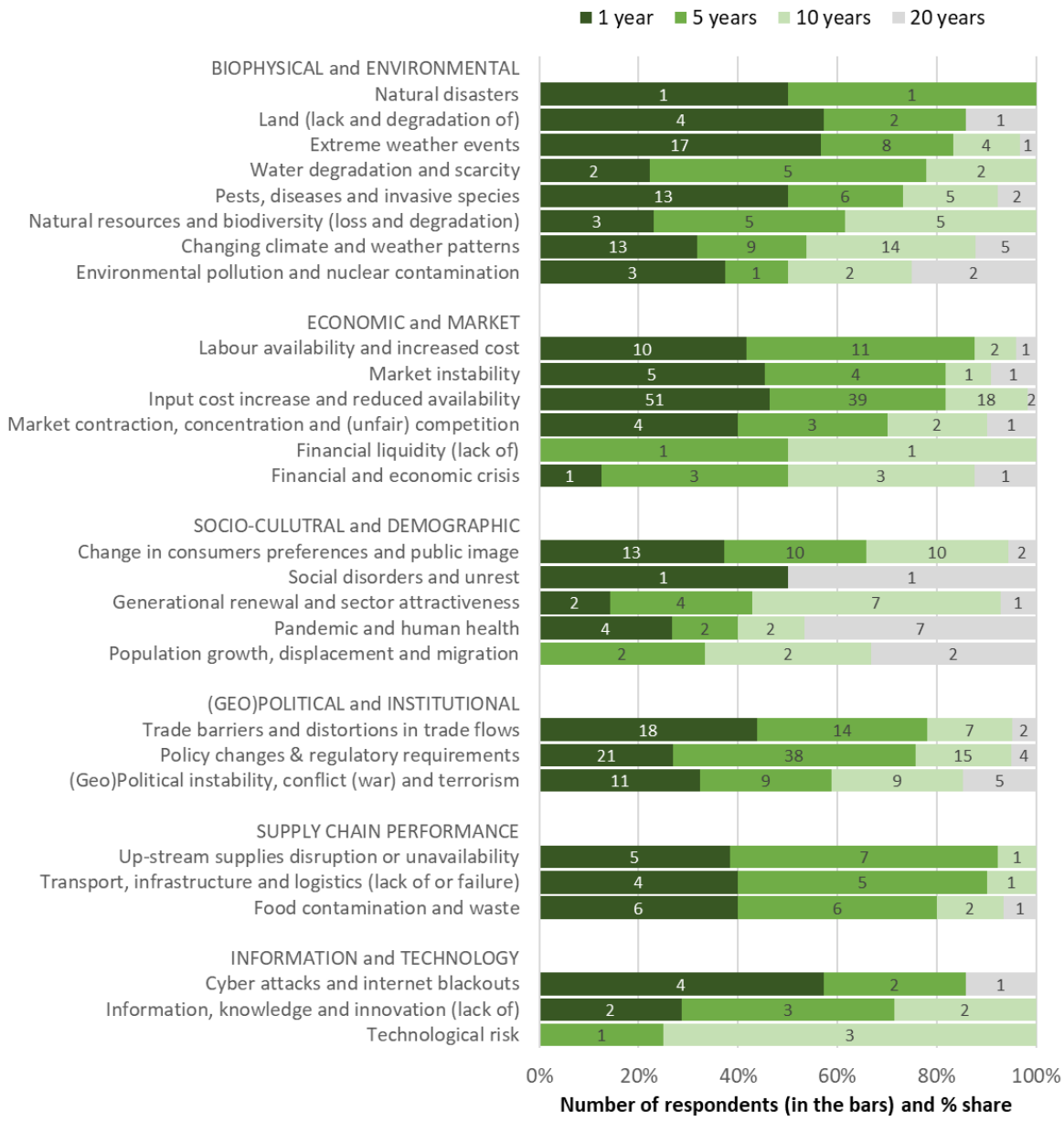
1. Stakeholders can cover multiple sectors and stages of the supply chain, therefore the shares of respondents by sector and stages does not sum up to 1.

Annex 7. Perceived origins, for all risk types and categories.



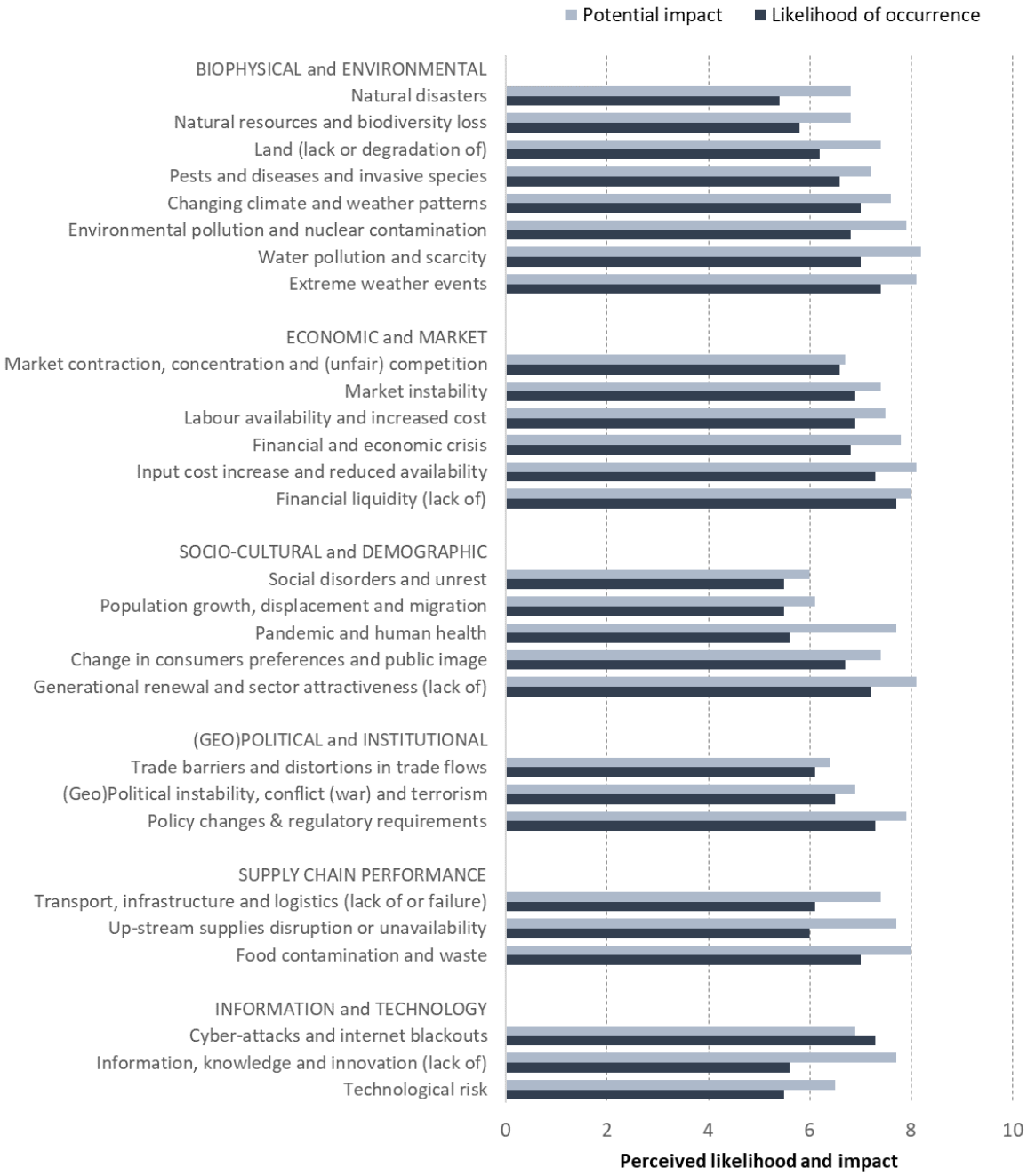
Source: semi-structured interviews.

Annex 8. Perceived time horizons of occurrence, for all risk types and categories.



Source: semi-structured interviews.

Annex 9. Perceived likelihoods of occurrence and potential impacts, for all risk types and categories.

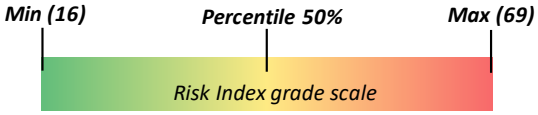


Source: online survey.

Annex 10. Risk Index values by Member State and by risk type

Member State	Overall Risk Index	Biophysical and Environmental	Economic and Market	(Geo)Political and Institutional	Socio-cultural and Demographic	Supply chain performance	Information and Technology
Austria	46	49	46	55	37	37	40
Belgium	40	36	47	45	35	32	34
Bulgaria	47	35	51	49	43	42	
Croatia	48	44	51	56		19	
Cyprus	41	39	39	36	58	45	42
Czechia	50	63			64		10
Denmark	-	-	-	-	-	-	-
Estonia	31	41	30	45	23	17	18
Finland	40	25	48	66	28	37	47
France	39	42	37	41	33	42	34
Germany	34	28	33	39	32	32	58
Greece	44	38	51	35	45	44	32
Hungary	67	63	70	43	73	59	81
Ireland	41	39	46	53	23	41	37
Italy	43	50	43	25	34	38	43
Latvia	-	-	-	-	-	-	-
Lithuania	38	42	36	37	28		
Luxembourg	26	31	21		21		25
Malta	67	82			58	65	62
Netherlands	39	34	57	19	48	5	5
Poland	46	42	51	41	41	48	28
Portugal	47	39	60	38	46	44	37
Romania	54	59	49	57	57	44	51
Slovakia	17	20	17	8			
Slovenia	39	48	39	37	28		16
Spain	54	59	53	52	54	47	44
Sweden	44	50	40			29	

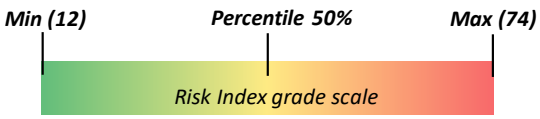
Annex 11. Risk Index values by sector



Risk type	Risk categories	Risk Index by sector: Fishery and aquaculture	Meat	Dairy and other animal products	Fruit and Vegetables	Beverage and alcoholics	Cereals, Legumes and Oleaginous	Sugar and miscellaneous
(Geo)Political and Institutional	(Geo)Political instability, conflict (war) and terrorism	36	31	30	29	33	30	32
	Policy changes & regulatory requirements	53	53	59	57	66	59	59
	Trade barriers and distortions in trade flows	30	24	22	28	36	22	21
Biophysical and Environmental	Changing climate and weather patterns	43	48	46	48	52	47	50
	Environmental pollution and nuclear contamination	61	60	55	57	64	54	60
	Extreme weather events	55	59	57	52	46	55	49
	Land (lack or degradation of)	53	34	33	43	48	39	39
	Natural disasters	32	26	26	25	30	23	24
	Natural resources and biodiversity loss	37	28	26	25	23	28	22
	Pests and diseases and invasive species	38	44	40	41	37	41	38
	Water pollution and scarcity	45	45	45	52	59	54	58
Economic and Market	Financial and economic crisis	60	51	48	49	60	48	54
	Financial liquidity (lack of)	59	44	44	46	44	42	42
	Input cost increase and reduced availability	58	51	49	48	53	49	45
	Market contraction, concentration and (unfair) competition	31	27	25	32	31	33	23
	Market instability	46	38	36	36	41	42	38
	Labour availability and increased cost	47	41	38	41	39	40	41
Supply chain performance	Food contamination and waste	48	53	58	49	56	52	58
	Transport, infrastructure and logistics (lack of or failure)	44	36	33	34	34	32	32
	Up-stream supplies disruption or unavailability	38	36	32	39	45	35	35
Research and Technology	Information, knowledge and innovation (lack of)	57	55	53	49	55	53	69
	Technological risk	39	33	35	29	27	28	29
	Cyber-attacks and internet blackouts	37	42	36	36	32	34	29
Socio-cultural and Demographic	Change in consumers preferences and public image	36	41	39	43	51	42	48
	Generational renewal and sector attractiveness (lack of)	63	53	49	50	56	51	55
	Pandemic and human health	30	36	30	29	36	34	27
	Population growth, displacement and migration	19	25	24	24	19	25	20
	Social disorders and unrest	40	16	27	40	39	27	31

Source: online survey.

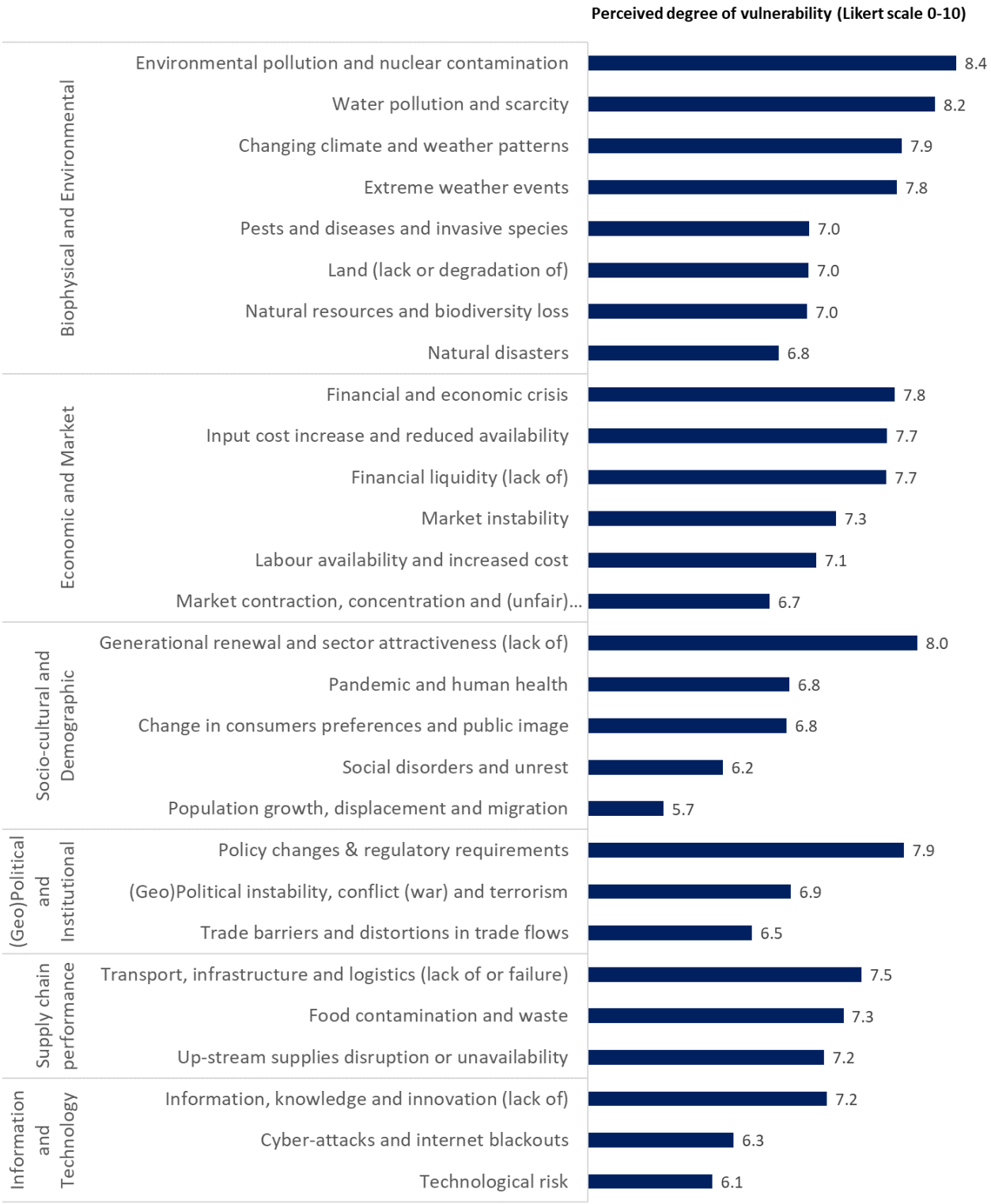
Annex 12. Risk Index values by stage of the supply chain



Risk type	Risk categories	Risk Index by stage: Input suppliers	Producers	Processors	Packaging	Logistics, transport and storage	Wholesalers and traders	Retailers
(Geo)Political and Institutional	(Geo)Political instability, conflict (war) and terrorism	40	35	39	45	38	33	36
	Policy changes & regulatory requirements	49	51	49	56	44	44	45
	Trade barriers and distortions in trade flows	25	24	30	39	30	21	17
Biophysical and Environmental	Changing climate and weather patterns	39	47	44	43	40	39	38
	Environmental pollution and nuclear contamination	67	52	53	74	68	69	66
	Extreme weather events	56	52	47	60	55	50	53
	Land (lack or degradation of)	53	40	39	54	53	34	34
	Natural disasters	34	31	28	52	33	28	30
	Natural resources and biodiversity loss	38	33	29	34	37	31	32
	Pests and diseases and invasive species	52	44	48	57	45	41	49
	Water pollution and scarcity	48	53	51	46	47	46	43
Economic and Market	Financial and economic crisis	59	50	58	65	58	62	67
	Financial liquidity (lack of)	50	50	44	50	51	51	52
	Input cost increase and reduced availability	47	49	49	57	53	48	49
	Market contraction, concentration and (unfair) competition	38	32	24	28	36	30	20
	Market instability	49	39	45	54	56	47	44
	Labour availability and increased cost	44	42	45	51	49	47	48
Supply chain performance	Food contamination and waste	59	56	48	54	51	45	50
	Transport, infrastructure and logistics (lack of or failure)	27	33	36	39	41	46	42
	Up-stream supplies disruption or unavailability	17	34	38	50	34	31	31
Research and Technology	Information, knowledge and innovation (lack of)	58	48	50	56	62	56	57
	Technological risk	40	30	28	48	41	41	42
	Cyber-attacks and internet blackouts	35	27	36	45	46	42	39
Socio-cultural and Demographic	Change in consumers preferences and public image	41	41	46	50	47	46	45
	Generational renewal and sector attractiveness (lack of)	61	54	49	70	61	61	67
	Pandemic and human health	29	30	37	26	31	25	24
	Population growth, displacement and migration	29	26	24	26	26	24	25
	Social disorders and unrest	36	31	12	47	45	48	43

Source: online survey.

Annex 13. Perceived degrees of vulnerability from the online survey, by risk category



Source: online survey.

Annex 14. Results of the linear regressions: correlation between factors of vulnerability and the degree of vulnerability to different risk types.

	Risk types					
Factors of vulnerability	**Biophysical and Environmental**	**Economic and Market**	**(Geo)Political and Institutional**	**Socio-cultural and Demographic**	**Supply chain performance**	**Information and Technology**
	Coef. *(st. dev.)*	Coef. *(st. dev.)*	Coef. *(st. dev.)*	Coef. *(st. dev.)*	Coef. *(st. dev.)*	Coef. *(st. dev.)*
Low diversity of input suppliers and/or clients	-0.04 *(0.15)*	0.17 *(0.13)*	-0.13 *(0.21)*	-0.02 *(0.17)*	0.05 *(0.18)*	-0.31 *(0.40)*
High dependency on import/export	-0.12 *(0.24)*	0.08 *(0.11)*	-0.15 *(0.17)*	-0.44* *(0.2)*	0.32 *(0.24)*	-0.18 *(0.43)*
Low flexibility to change	0.06 *(0.15)*	0.34** *(0.13)*	0.15 *(0.17)*	0.65*** *(0.15)*	0.41 *(0.25)*	0.59* *(0.35)*
Lack of financial resources or limited economic margins	0.28* *(0.14)*	0.18* *(0.08)*	0.28 *(0.18)*	0.82*** *(0.14)*	-0.07 *(0.23)*	0.61* *(0.34)*
Lack of natural resources available/accessible	0.72*** *(0.11)*	0.32* *(0.13)*	0.63** *(0.2)*	0.12 *(0.29)*	0.37 *(0.26)*	-0.16 *(0.65)*
Lack of human capital	0.15 *(0.23)*	0.31 *(0.19)*	0.09 *(0.2)*	0.93*** *(0.19)*	0.14 *(0.28)*	0.50* *(0.28)*
Lack of (technological) alternatives, research or infrastructure	0.39* *(0.22)*	0.02 *(0.13)*	0.3 *(0.25)*	0.37* *(0.19)*	0.56** *(0.19)*	0.12 *(0.28)*
Weak supply chain organization	0.45** *(0.16)*	0.16 *(0.16)*	-0.07 *(0.19)*	0.2 *(0.3)*	0.48* *(0.27)*	0.19 *(0.27)*
Policy and regulatory constraints and risk awareness/communication	0.28 *(0.23)*	0.18 *(0.19)*	0.79** *(0.24)*	0.16 *(0.31)*	0.38* *(0.2)*	0.26 *(0.51)*
Other factors	1.58*** *(0.21)*	0.96*** *(0.29)*	0.47 *(0.42)*	0.39 *(0.47)*	-0.19 *(0.85)*	2.14** *(0.71)*
Constant	*6.94**** *(0.31)*	*6.98**** *(0.16)*	*6.80**** *(0.39)*	*6.25**** *(0.31)*	*6.50**** *(0.18)*	*6.03**** *(0.40)*

*Significance levels by p.value: *** < 0.001; ** <0.01; * < 0.1*

Fit statistics	**Biophysical and Environmental**	**Economic and Market**	**(Geo)Political and Institutional**	**Socio-cultural and Demographic**	**Supply chain performance**	**Information and Technology**
R^2	0.097	0.054	0.10	0.155	0.101	0.093
adj. R^2	0.086	0.042	0.073	0.129	0.059	0.028
logLik	-1748	-1544	-568	-693	-463	-314
Test statistic	9.15	4.53	3.41	5.96	2.45	1.43
Deviance	2957	2223	746	1215	752	576
p.value	1.83e-14	2.96e-6	0.0003	2.68e-8	0.008	0.17
No. of observations	858	800	304	336	230	150
df	10	10	10	10	10	10
df.residual	847	789	293	325	219	139

Source: online survey.

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