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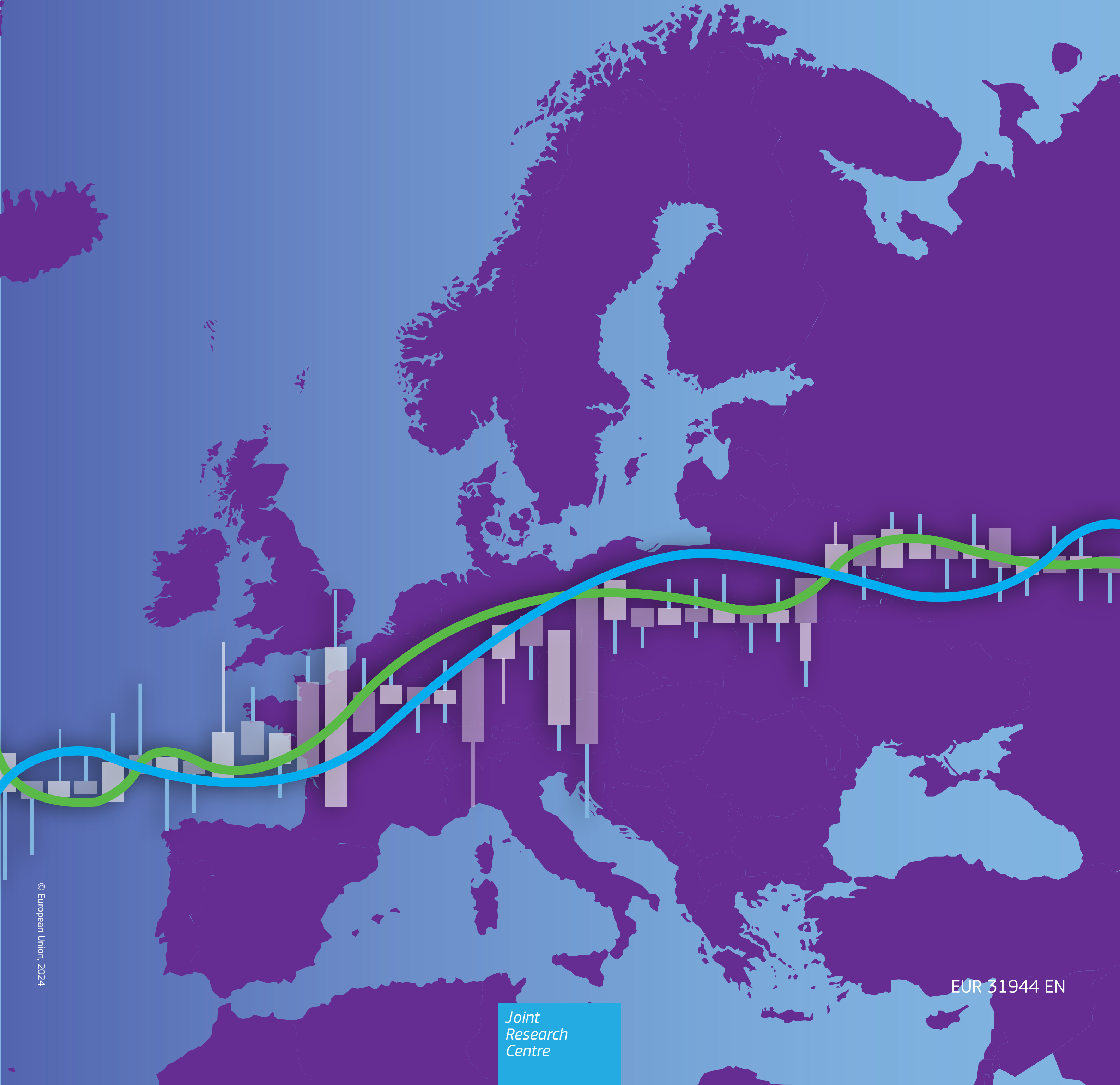
European Commission

Cross-border and emerging risks in Europe

Overview of state of science, knowledge and capacity



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Index

Foreword by the European Commissioner for Crisis Management and by the European Commissioner for Innovation, Research, Culture, Education, and Youth

As Europe faces a complex landscape of cross-border and emerging risks, ranging from disasters caused by natural hazards and exacerbated by climate change to technological accidents and societal challenges, the need for a coherent, science-based approach to understanding disaster risks and mitigating their impacts has never been more acute. The European Commission, through the work of its Joint Research Centre, endeavours to deepen our understanding of the multifaceted nature of disasters that know no borders.

Central to our approach is the recognition of science as a fundamental pillar for assessing risks and anticipating their impacts. The JRC, which is the Commission's science and knowledge service, plays a pivotal role in this domain. Through cutting-edge research and technological advancements, the JRC provides invaluable insights that inform our strategies and policies. Its work exemplifies the seamless integration of scientific excellence into the policymaking process, ensuring that our decisions are grounded in robust evidence and expertise.

In this context, the "Science for Policy Report on Cross-border and Emerging Risks in Europe" embodies our dedication to employing scientific insights to support policy-making in the field of disaster risk management across Europe. This effort underscores the need to develop harmonized methods for large-scale risk assessment. Such a framework will enable us to prevent and mitigate risks more effectively, while ensuring cohesive and coordinated response to disaster events.

Moreover, this report champions the principle of open access to data. Open access data and methodologies are crucial for maintaining transparency in our processes and for the reproducibility of results, both of which are fundamental to building trust and understanding among stakeholders and the public. By sharing data freely, we enhance the capacity for collective scrutiny and independent analysis, which are essential for advancing our scientific and policy objectives.

In navigating through the challenges posed by cross-border and emerging risks, it is imperative to recognize the importance of shared knowledge and collaborative analysis. This report, enriched by the scientific rigour and expertise of the JRC, sheds light on the intricate web of drivers that contribute to the risk landscape in Europe. It underscores the need for an integrated approach that combines disaster risk reduction, climate change adaptation, and technological innovations to effectively prevent and mitigate risks.

As we present this report, it is crucial to acknowledge that the challenges we face are evolving at an unprecedented pace. Cross-border and emerging risks demand a proactive and collaborative response, not just at a European level but globally. This report is a testament to our ongoing efforts to build a resilient Europe, one that can withstand the crises of today and tomorrow.

The insights presented here are instrumental for the Union Civil Protection Mechanism's efforts to anticipate disasters and enhance the overall resilience of the Union. They represent a significant contribution to the implementation of Union Disaster Resilience Goals by providing a robust scientific foundation for preventing and mitigating potential risks. They reflect also the Union Civil Protection Knowledge Network's vision of a collaborative and informed civil protection community, where the sharing of scientific knowledge is an integral component of our collective capacity to face the challenges ahead.

The path forward demands a continued commitment to leveraging scientific evidence and encouraging cooperation across borders and sectors. By doing so, we can aspire to a safer, more resilient Europe that is prepared to confront the ever-changing landscape of risks and disasters.

Let this report serve as a call to action for all stakeholders involved in disaster risk management and crisis response. Together, with science as our guide, we can build a Europe that stands resilient in the face of emerging risks and united in its efforts to protect its citizens and their livelihoods.

Iliana Ivanova
European Commissioner for Innovation,
Research, Culture, Education and Youth

Janez Lenarčič
European Commissioner for
Crisis Management

Abstract

In this report, the Joint Research Centre (JRC) expands its exploration of complex disaster risks that transcend national borders and introduce novel challenges to the European Union. Taking stock of previous JRC flagship reports on understanding risks (Science for Disaster Risk Management Book Series and the Recommendations for National Risk Assessment versions 0 and 1), this document addresses the multi-faceted nature of cross-border and emerging risks in Europe. The report collects the contributions from expert teams across 8 JRC directorates and external partners. It analyses the current landscape of risks characterized by their potential for widespread impact across the continent, necessitating a coordinated European response. The work leverages historical data and recent scientific advances that address both cross-border risks such as natural disasters and anthropogenic crises, and emerging risks that include technological and socio-economic challenges.

This comprehensive assessment helps in understanding and managing cross-border and emerging risks, including environmental, health, and technological threats. It emphasizes the importance of integrated approaches and improved data sharing to better anticipate and prepare for potential disasters. The findings advocate for the incorporation of transboundary considerations in risk management strategies to effectively handle the interconnected and complex nature of today's risks. Emerging from an increased need for an integrated approach in disaster risk management (DRM), this report underscores the importance of the EU's continued research on understanding the root causes of risks and in adaptation and mitigation strategies to enhance resilience.

Acknowledgements

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Executive summary

The escalating frequency and severity of disasters, fuelled by climate change, technological mishaps, and urban population growth, underscore the need for robust, coordinated disaster risk management strategies across Europe. These disasters often transcend national borders, necessitating a unified approach to enhance the resilience of the European Union (EU) through collaborative prevention, preparedness, and response efforts. Given this backdrop, the European Union's legislative framework has evolved to include comprehensive reporting and action requirements for Member States, fostering a proactive approach to disaster risk management.

The purpose of this report is to identify the risks with cross-border implications and the emerging challenges that Europe will confront in the years ahead.

Policy context

EU Member States are required since 2013, within the framework of Union Civil Protection Mechanism (UCPM) Decision No 1313/2013/EU to report to the Commission on their disaster risk management activities. The amendment of the European Union Civil Protection Mechanism of March 2019 (Decision (EU) 2019/420) introduced joint reporting on (1) national risk assessment, (2) risk management capability assessment (RMCA) and (3) information on the priority prevention and preparedness measures needed to address key risks with cross-border impacts, and, where appropriate, low probability risks with a high impact. To facilitate the reporting, "Reporting Guidelines on DRM, Art. 6(1) d of Decision No.1313/2013/EU," (2019/C 428/07) have been adopted.

The 2013 European adaptation strategy encouraged all EU Member States to adopt comprehensive climate adaptation strategies. The new EU strategy on Adaptation to Climate Change calls the Commission to improve the state of the art on adaptation modelling, risk assessment and management tools – towards "asset-level modelling" and promotes the access to climate-related risk and loss data for stakeholders.

In 2023, the European Commission (EC) adopted Union Disaster Resilience Goals to establish common goals (anticipate, prepare, alert, respond and secure) to boost disaster resilience in the area of civil protection. The Union's disaster resilience goals advocate for enhanced risk assessment by promoting the development of more sophisticated tools and methods to accurately identify, analyse, and evaluate potential hazards. The first goal "Anticipate" aims to improve the Union and the Member State's capability to identify and assess complex disaster risks. It encourages a proactive approach to understanding risks, thereby aiding in the preparation and mitigation strategies that can effectively reduce the impact of disasters on communities and infrastructure.

The EU sustainable finance framework aims to mobilise private finance to mitigate climate risks, adapt to climate change, and reduce associated risks in the financial sector.

Against this policy background, the report builds on a concerted effort within the JRC to assess and map disaster risks by addressing the nuances of cross-border and emerging risks. It builds on the JRC's interdisciplinary research to outline the current, complex disaster risks the EU faces, considering their cascading nature and interdependencies.

Key conclusions

The analysis and mapping of the different risks presented in the report required different methodologies depending on the nature of the hazard. It would be wrong to pretend that we fully understand all the hazards that society faces and their potential consequences. The common denominator for many of the outcomes of risk analysis described in this report is the framework that follows a structured approach: identification of potential hazards and their probability, knowledge of what is exposed to that hazard and the vulnerability of that exposure to the hazard. A combination of both quantitative (e.g. probabilistic or stochastic models) and qualitative methods (e.g. deterministic scenario impacts) has been adopted in the risk assessment processes underpinning the results presented in this report. Essentially, these approaches for assessing risk are applicable in the context of known cross-border risks. Other assessment approaches were used for emerging risks which have a high degree of uncertainty in terms of probability of occurrence: horizon scanning, expert elicitation, scenario analysis, stress testing and simulations, Delphi methods, etc.

The report outlines an array of methods, tools, and strategies for risk assessment, highlighting the necessity for harmonized frameworks for the identification, assessment, and evaluation of emerging risks. Harmonisation of risk metrics is another crucial aspect of risk assessment and analysis enabling risk comparison across various dimensions and informing multi-hazard risk assessments that consider cascading effects.

In response, the Commission should persist in its effort to develop and update the guidelines that tailor risk assessment methodologies to the relevant scope, whether local, regional, or national. Establishing EU-wide systems and legal structures for crisis management and risk prevention is crucial, alongside fostering regional collaboration and support among Member States. Such a unified approach is not only cost-effective and secure but also enhances the resilience of the entire EU.

The report supports the continued development and expansion of the Disaster Risk Management Knowledge Centre (DRMKC) and the Union Civil Protection Knowledge Network (UCPKN), which play a pivotal role in fostering effective training, innovation, and cooperation among EU Member States' national civil protection authorities. These efforts will support building the knowledge base on cross-border and emerging risks as essential components for enhancing the overall disaster resilience of the European Union, making it better prepared to face future challenges.

Main findings

The document highlights the necessity of regular EU-wide risk analysis to inform risk management policies, aiming for a proactive, coordinated response to the evolving risk landscape.

This comprehensive assessment helps in understanding and managing cross-border and emerging risks, including environmental, health, and technological threats. It emphasizes the importance of integrated approaches and improved data sharing to better anticipate and prepare for potential disasters. The findings advocate for the incorporation of transboundary considerations in risk management strategies to effectively handle the interconnected and complex nature of today's risks.

The report sheds light on the root causes and potential impacts of these risks, enabling policymakers to devise more effective strategies for governance and resilience-building. A deeper understanding of risk drivers is vital not only for model improvement but also for identifying actionable disaster risk reduction measures. This understanding can be enriched by learning from past incidents, accidents, and disasters, fostering collaboration across disciplines and translating research insights into practical applications.

The contributions illustrate how science-based policy research can aid in detecting early warning signs and developing innovative solutions to mitigate the impact of cross-border and emerging risks, ensuring the safety and security of the EU and its citizens in the face of complex and interconnected challenges.

The complexity, interconnectedness and dynamic nature of risks are a reason for keeping this report alive and updating it as new data becomes available to identify and model new risks.

Related and future JRC work

The DRMKC plays a crucial role in the European Union's approach to Disaster Risk Management (DRM). Its mission is multifaceted and centred around the integration and coordination of DRM efforts across EU member states. The DRMKC platform facilitates information and knowledge sharing through dedicated tools and systems addressing harvesting data on disaster risks from multiple types of hazards (i.e. the Risk Data Hub, INFORM suite, the Science4Peace portal). Copernicus Emergency Management Service (CEMS) coordinated by the JRC is a European Union (EU) program designed to support emergency response in various situations, including natural disasters and man-made emergency events. It plays a pivotal role in risk assessment and disaster risk management mainly through 1) Risk and Recovery Mapping: These services provide analyses of disaster risk and potential impacts 2) Early warning and monitoring systems: Copernicus Emergency Management Service (CEMS) continuously monitors environmental and man-made hazards across the globe, using satellite data to assess the risks of disasters. The service provides valuable insights into vulnerability, exposure, and hazard characteristics, contributing to a more comprehensive understanding of disaster risks.

The objective is to continually update this report as new data becomes available, enabling the identification, evaluation and modelling of new and evolving risks.

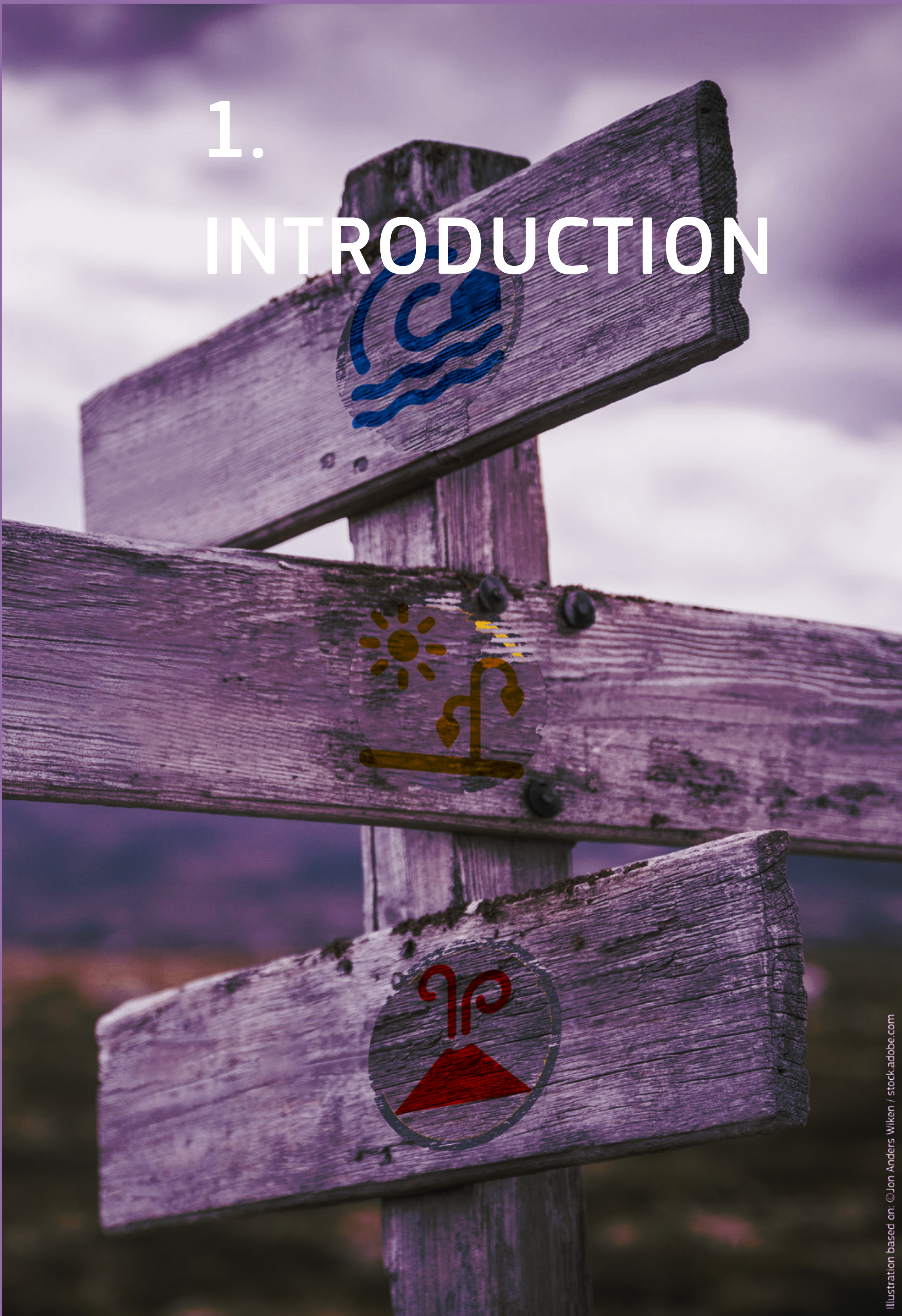
Quick guide

The EC, through the work of its JRC, aims to deepen the understanding of the multifaceted nature of disasters that know no borders. Science is a fundamental pillar for assessing risks and anticipating their impacts. The JRC which is the Commission's science and knowledge service, plays a pivotal role in this domain. Through research and technological advancements, the JRC provides invaluable insights that inform our strategies and policies. Its work exemplifies the seamless integration of scientific excellence into the policymaking process, ensuring that our decisions are grounded in robust evidence and expertise.

The report collects the contributions from expert teams across 8 JRC directorates and external partners which prepared specific chapters for the different cross-border risks and emerging risks. The cross-border risks covered are wildfires, droughts, floods, earthquakes, chemical industrial, nuclear and radiological accidents, Natech events, risks to critical infrastructures and health risks. Furthermore the emerging future risks covered are food security, energy, hybrid threats, biodiversity loss, financial risks, armed conflict risks and disinformation.

The report summarises the existing methods, tools, and strategies for risk assessment highlighting the importance of a harmonized frameworks to the identification, assessment, and evaluation of cross-border and emerging risks. It emphasizes the importance of centralised, integrated approaches and improved data sharing to better anticipate and prepare for potential disasters.

1. INTRODUCTION



Introduction

Europe is experiencing an ever more complex evolving risk landscape, with more frequent and intense hazards due to climate change, urbanisation, environmental degradation, changing security landscape and technological developments[1]. The EU and its UCPM have been leading efforts to create a more resilient Union that can effectively handle the increasingly complex and ever-changing risk landscape both now and in the future.

Risks are also more intricate and have a cascading nature that cannot be ignored (UNDRR & UNU-EHS, 2022; Girgin et al., 2019, Pescaroli et al., 2018; Menoni et al., 2023), and society must be prepared for these new challenges. Various projects[2,3] have been developed to focus on multi-hazards and systemic risks in order to identify and analyse them effectively. This highlights the need for an integrated situational awareness system and improved tools for Member States. Additionally, there is a growing need for enhanced anticipation, as risks become more systemic, compound, and cascading, requiring faster adaptation and risk prevention at the local level.

These challenges should be transformed into opportunities for enhancing scientific knowledge and operational preparedness, working more on improved data sharing, anticipation of emerging disasters, and preparedness for cascading effects.

In an effort to improve understanding of disaster risks in Europe, the European Commission (EC) requires EU Member States and UCPM participating states to report to the Commission on their DRM activities (Decision No 1313/2013/EU[4]). Article 6 of the legislation introduces a general framework on disaster prevention with the aim of achieving a higher level of protection and resilience against disasters and at fostering a culture of prevention that also considers the likely impacts of climate change.

The 2020 edition of the Overview of natural and man-made disaster risks the European Union may face (European Commission, 2021) offered a detailed examination of various risks, including those stemming from natural and man-made disasters. It unveiled trends in the risk landscape, discussing the major drivers shaping the risks of the future while presenting the key findings from the review of national risk assessments sent to the Commission in the 2018 reporting cycle. In addition to information from national authorities, the overview drew on the latest available evidence from the Commission's cross-sectoral policy, operational and scientific work on disaster risk. The overview was prepared in the midst of the COVID-19 pandemic and its devastating impacts in terms of fatalities and disruptions to the national healthcare systems, the public life and the generation of a major shock to economies worldwide. The analysis also highlighted the role of human activities in exacerbating flood risks, such as building on floodplains or reducing water-retaining surfaces, and points towards an increased likelihood of compound flooding across various European regions due to climate change-induced increases in extreme precipitation, storm surges, and sea levels. These drivers are not isolated but interact with each other, amplifying existing risks or leading to new ones. Specifically, it introduced the concept of 'emerging risks', which arise from new types of hazards, increased vulnerability and/or exposure, or decreased coping capacity, highlighting the uncertainty and potential damage these risks entail.

The recent Article 6 Progress Report[5] draws upon the summary reports provided by Member States and Participating States between end 2020 and September 2022. It highlights the importance of integrating climate considerations into all areas of policy and decision-making, facilitating the sharing of best practices and technologies, and enhancing transparency and accountability in climate

1 UCPKC – RISK DRIVERS https://civil-protection-knowledge-network.europa.eu/eu-overview-risks/risk-drivers
2 MYRIAD-EU https://www.myriadproject.eu/
3 BORIS2 https://www.borisproject.eu/
4 Decision 1313/2013/EU of the European Parliament and of the Council of 17.12.2013 on a Union Civil Protection Mechanism as amended, OJ L 347, 20.12.2013, p. 924, hereafter referred to as 'the UCPM Decision'.
5 COM (2024) 130 final https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2024%3A130%3AFIN&qid=1710242932481

actions. It also reaffirms the primary concerns since 2015 regarding disaster risks across EU Member States. These include natural and health-related risks such as floods, extreme weather events, pandemics, droughts, and wildfires. On the human-induced or technological front, nuclear and radiological incidents, industrial hazards, and critical infrastructure disruptions are significant. A noteworthy trend, highlighted in the Article 6 Progress Report, is the escalating concern over droughts, with twice as many states identifying them as a pertinent risk in 2020 compared to 2015. Most countries now recognize not only prevalent risks but also High Impact Low Probability (HILP) and emerging threats, which may vary by country. Nuclear/radiological incidents, industrial risks, and earthquakes are frequently cited HILP risks due to their potentially devastating impacts. Emerging risks often include extreme weather, floods, wildfires, pandemics, and cyber threats, among others. This shift underscores a broadened risk perception, incorporating factors like climate change and evolving vulnerabilities.

Several reports and studies, providing an overview of the status of knowledge and understanding of the key disaster risks that Europe is facing:

The European Climate Risk Assessment (EUCRA) (EEA, 2024) synthesized knowledge on climate impacts and risks across Europe. It leveraged findings from the Intergovernmental Panel on Climate Change (IPCC), the Copernicus Climate Change Service, the JRC, EU-funded projects, and national climate risk assessments. The study outlined the escalating climate risks confronting Europe, identifying 36 climate risks with potentially severe consequences across the continent. These range from extreme weather events, such as heatwaves and floods, to broader systemic challenges like food and water security, energy stability, and the health impacts on populations. Climate risks are determined by the interaction of climate-related hazards with non-climatic risk drivers. A critical aspect underscored is the multiplier effect of climate change, which exacerbates existing vulnerabilities and creates cascading risks across different sectors and regions. The assessment calls for urgent, coordinated action at all levels of governance, emphasising the need for rapid greenhouse gas emission reductions and effective adaptation measures to mitigate unavoidable climate impacts.

Science for Disaster Risk Management 2017 (Poljanšek et al., 2017) **and 2020** (Casajus Valles et al., 2020) produced by the Disaster Risk Management Knowledge Centre represents collaborative efforts of disaster risk experts from different sectors and disciplines. These works focused on a holistic understanding of disaster risk (hazards, exposure and vulnerability), disaster risk management, focusing on all four phases of disaster cycle through a systematic multi-hazard assessment overview of existing disaster risk knowledge, and the consequences of disasters on various assets at risk (population, economic sectors, critical infrastructures, ecosystem services and cultural heritage). Studying the impacts facilitates the preparation measures in order to prevent, mitigate and prepare for future events, by supporting anticipation and the planning of measures to manage risk.

Recommendations for National Risk Assessment for Disaster Risk Management in EU, 2019 and 2021 (Poljanšek et al., 2019; Poljanšek et al., 2021) which build on a collaborative effort within the JRC, have underscored the critical role that evidence garnered from Article 6 reporting plays in enhancing DRM strategies. The complexity and scope of the risk environment are ever-growing, fuelled by heightened recognition and more profound insights into various threats. The need for specialized risk assessment approaches is underscored by the diversity of hazards and the varying degrees of data availability and knowledge pertaining to each. The core objective is to gain a comprehensive understanding of the risks and their underlying factors, as well as to evaluate these risks in a manner that enables comparison in terms of intensity and likelihood. Consistent EU policy frameworks concerning different risks are vital for standardizing risk assessment methods, gathering data, and exchanging expertise. Furthermore, DRM policies are focused on harnessing synergies throughout the DRM cycle to foster an integrated approach to risk governance.

These are only some examples of Commission wide efforts to enhance our understanding of the current and future risks the EU is facing. These assessments highlighted the need to account for a broader spectrum of potential scenarios, including those influenced by factors beyond direct control when designing policies to mitigate and prevent disasters. This encompasses events with a low chance of occurring but potentially severe consequences, simultaneous or successive compound hazards, and cascading risks that cross national and sectoral lines. Considering the constantly changing risk landscape and the emergence of new risks, a regular assessment of disaster risks is necessary to adapt the policies and the capabilities to manage those risks. This ensures that policies and response capabilities remain effective and up-to-date. Moreover, consistently sharing information about risks at the EU level is essential for collective preparedness and management.

Understanding and acting on disaster risks in the EU requires a holistic approach that leverages scientific evidence and technological advancements. This is the scope of the JRC Work program for 2023-2024 under the portfolio dedicated to "Understanding and acting on risks of the future". All the portfolios in the Work program are built around the JRC's core strengths: anticipation, integration and impact. In order to be even more relevant to the Commission's priorities, the JRC aims to ensure that the work we do allows us to anticipate risks, as opposed to only managing the latest crisis, however significant that may be. At the same time, the JRC's work should help drive more integration and encourage links between different scientific and policy areas to respond to the complexities of current and future challenges.

The portfolio aims at understanding vulnerabilities and risks in- and outside Europe and how to increase resilience with risk mitigation and adaptation measures. It focuses on anticipating, quantifying and qualifying the potential risks of the future, triggered by natural hazards, climate change, geopolitical crises, conflict, financial shocks, biodiversity loss, health threats, migration, energy shocks or other drivers. Furthermore, the portfolio triggers more action on disaster risk reduction, climate change adaptation, resilience building and other mitigation actions. There is a need to better understand the evolving risk landscape and identify plausible scenarios for systemic impacts of well-known risks and foresight analysis of less well-known risks.

Aligned with the goals of this portfolio, the report utilizes JRC's interdisciplinary research to outline the current and complex disaster risks the EU faces, emphasizing their cascading nature due to increased hazards. By examining cross-border and emerging risks, including health, environmental, and technological threats, the report advocates for integrated approaches and better data sharing to anticipate and prepare for emerging disasters. It highlights the necessity of regular EU-wide risk assessments to inform risk management policies, aiming for a proactive, coordinated response to the evolving risk landscape.

Cross-border risks

The section on cross-border risks provides an overview of the complexities of cross-border risks in Europe, highlighting the challenges posed by natural and man-made disasters that extend beyond national borders due to their geographical nature. It discusses the dimensions of cross-border risks, including political boundaries, functional crises, and temporal aspects, as well as the multifaceted nature of these risks in risk assessments. The importance of cross-border cooperation in the European Union, where a significant portion of the population resides in border areas, is emphasised, along with the need for careful attention to cross-border concerns in national disaster risk assessment and management plans. Additionally, the section underscores the necessity of incorporating transboundary considerations in various forms to effectively manage cross-border risks.

Emerging risks

In the Overview of natural and man-made disaster risks in the EU (European Commission, 2021; European Commission 2017), and in the work presented by the OECD High Level Risk Forum to define the category new and emerging risks, is treated as a stand-alone topic and it requires further consideration both at EU and national level. Emerging risks are seen as the shift in risk, attributable to one or more of the underneath factors: (1) the novelty of the type of hazard e.g. the situation of a new process or understanding of a process or phenomena that was not considered before (2) increases in either vulnerability and/or exposure and (3) decrease in the coping capacity.

2.

THE SCIENCE-POLICY INTERFACE: EVIDENCE-BASED POLICIES

2 The science-policy interface: evidence-based policies

The need for data and therefore the need for science to analyse it in an attempt to anticipate future evolutions, has evolved significantly over the last several years. Key recommendations in building coherence between these EU policies, global agreements and agendas include:

- Increasing awareness with national and sub-national governments of how critical it is to align different frameworks, given the fact that the relative political weight of frameworks may affect collaboration and coherence.
- Facilitating key partnerships, which help to avoid duplication and maximise benefit. Institutional incentives to work together may also be required to reinforce joint collaboration across agreements.
- Instituting clear governance arrangements to ensure successful collective action and accountability.

Developing consistent definitions, particularly on resilience and risk, which feature as common themes across all of the agreements.

The science-policy interface is critically important in shaping evidence-based policies, particularly in the fields of disaster risk reduction and climate adaptation. In practical terms, the science-policy interface refers to translating complex scientific data and research findings into actionable policies and strategies.

As climate change intensifies, leading to more frequent and severe weather events, the need for effective disaster risk reduction measures becomes increasingly urgent. The science-policy interface ensures that these measures are informed by the latest scientific understanding of climate impacts, enabling policymakers to devise strategies that are both proactive and adaptive. By incorporating scientific insights, policies can be tailored to address specific vulnerabilities and build resilience in communities, infrastructure, and ecosystems.

Furthermore, evidence-based policies are essential for allocating resources efficiently, prioritizing interventions, and measuring their effectiveness over time. A strong science-policy interface is key to ensuring that disaster risk reduction and climate adaptation strategies are grounded in reality, scientifically sound, and capable of safeguarding communities against the escalating challenges posed by climate change.

At the global scale, the Sendai Framework for Disaster Risk Reduction 2015-2030 (UNISDR, 2015) emphasizes the importance of understanding disaster risk in all its dimensions through data, analysis, and research. It calls for a more scientific approach to risk assessment and the incorporation of risk scenarios into policy and planning. In the At EU level, the Strategy for climate adaptation[1] focuses on making Europe more climate-resilient, encompassing actions across various sectors and governance levels, informed by the latest climate data and projections. The Strategy is grounded in scientific research and assessments provided by EU institutions like the European Environment Agency (EEA) and the JRC. As such, a project that is jointly led by the Directorate-General for Climate Action of the European Commission and the EEA, the EUCRA (EEA, 2024) aims to provide a comprehensive assessment of current and future climate change impacts and risks relating to the environment, economy and wider society in Europe. Climate change is one of the biggest threats for humanity, seriously affecting people and nature. The PESETA IV[2] study initiated by the European Commission aims to better understand the effects of climate change on Europe and how these effects could be avoided with mitigation and adaptation policies.

The JRC embodies the principles of Science for Policy with its functions as the European Commission's science and knowledge service, and its primary mission is to provide independent scientific advice and support to EU policy.

With its new work program that aims at addressing the key EU priorities and the needs of different policy

1 Strategy for climate adaptation https://climate.ec.europa.eu/eu-action/adaptation-climate-change/eu-adaptation-strategy_en
2 JRC PESETA IV, JRC study https://joint-research-centre.ec.europa.eu/peseta-projects/jrc-peseta-iv_en

DGs, the JRC is focusing on various portfolios that examine the interplay of various factors such as demography, climate change, technology, and globalization, to identify and comprehend the potential risks that lie ahead. By delving into these risks in a holistic way, the JRC aims to deepen its understanding of the complex dynamics and potential risks associated with these interconnected domains.

Through extensive research, data analysis, and modelling, the JRC strives to provide valuable insights and evidence-based solutions to policymakers and stakeholders to mitigate the adverse impacts of demographic changes, health challenges, and climate change risks in the future.

Two main portfolios leverage multi-disciplinary perspective to increase resilience to disaster and future risks (Remáč et al., 2023):

Integrated situational awareness for crisis management (Portfolio #25): interoperable early warning systems anticipating up to six months ahead; integration of earth observation, media monitoring and in-situ measurements; cross-sectoral analysis of impacts.

Understanding and acting on risks of the future (Portfolio #26): connecting modelling frameworks across disciplines, such as climate and hazard models, economic and financial models, agricultural and energy models, epidemiological models; foresight for future crises; pooling data in the Risk Data Hub (RDH).

Several of the risks addressed in this report are a result of research conducted in the context of those two main portfolios.

The cross-disciplinary approach of the JRC to the provision of scientific advice will allow a more comprehensive approach to risk assessment, a clearer idea of the gaps in our research, and a holistic view on data needs and policies. To exploit the products which emerge from this view, the EU must be able to process and act on them. The same kind of silos which the JRC is trying to break down, may also exist at policy level. There are numerous examples of events causing impacts across multiple sectors, **requiring an integrated policy response.** Such a response requires the different crisis management, preparedness and response structures of the union to work together.

This is even more important for prevention and adaptation measures, which require investments and planning over long periods, coordinated with many stakeholders, often accompanied by societal changes with resistance from vested interests. A risk-based approach rooted in a shared understanding of the risks and independent scientific data can **facilitate trade-offs in policy choices.**

The purpose of this report is to identify the risks with cross-border implications and the emerging challenges that Europe will confront in the years ahead. It is also crucial to consider the ripple effects of disasters and how to analyse these risks, as well as to evaluate the available tools and additional knowledge needed. The report aims to illuminate the root causes and potential impacts of these risks, enabling policymakers to devise more effective strategies for governance and resilience-building. It also illustrates how science-based policy research can aid in detecting early warning signs and developing innovative solutions to mitigate the impact of cross-border and emerging risks, ensuring the safety and security of the EU and its citizens in the face of complex and interconnected challenges.

3.

CROSS-BORDER RISKS IN EUROPE

3 Cross-border risks in Europe

Most natural and man-made disasters present cross-border risks due to their geographical nature. With this context in mind, this chapter presents a cross-border overview disaster risks frequently identified by the Member States in their article 6 reporting (European Commission, 2017; European Commission 2021). In terms of practical implementation, in the 2020 round of article 6 reporting, Member States and Participating States in general focused on preparedness measures, while fewer reported on prevention measures. However, several cross-border measures were reported at various geographical levels (inter-regional and international) for several key risks, which is a sign of well-developed procedures that transcend national borders[1].

3 1 Defining cross-border risk

Defining cross-border impacts is not straightforward, given the complexity of today's interconnected systems and the diverse types of disruptions that can occur, including both direct and indirect, physical, and functional impacts.

The description of cross-border risks encompasses three dimensions: political boundaries, which can be horizontal (international borders) or vertical (escalation from local to national levels); functional crises that affect different policy areas, such as disasters impacting both transport and health sectors; and temporal aspects, as some disasters can transcend time boundaries, such as armed conflicts or terrorist attacks.

Furthermore, the definition of cross-border risks can have several meanings directly related to risk assessments, including hazard-based, impact-based, and systemic vulnerabilities (Menoni et al., 2023). Hazard-based definitions encompass hazards with regional impact, such as trans-boundary flooding, extreme weather, forest wildfires, and major industrial accidents. One of the challenges in the context of hazard-based cross-border risks is the coherent utilization of early warning systems on both sides of the border.

Impact-based cross-border risks refer to the potential for an affected asset in one country to impact the same system in other countries, as seen in critical infrastructures, where the loss of electricity, water supply, communication, etc., in one country can result from a disaster in a neighbouring country. It also considers the systemic vulnerabilities arising from the interconnections and interdependency between different systems, leading to increased complexity and variable geographies.

The consideration of multi-hazard events, combining various hazards and vulnerabilities, is increasing in academia and practice due to the growing realisation of the interdependency and complexity of risks. The severe cross-border implications of such events pose challenges, including the lack of common assessment methodologies between countries and the need for improvements in agreed arrangements for standardised communication.

1 SWD(2024) 130 final

3 2 Overview of main cross-border risks in Europe

Cross-border risks and cooperation are of great importance in the European Union since 37.5% of the EU population live in border areas along 38 internal borders made up by both geographic and linguistic barriers[2]. Most natural and man-made disasters present cross-border risks due to their geographical nature, for flooding around 70% of the European continent's fresh water bodies form at least part of a trans-boundary river basin.

Cross-border risks also extend beyond the borders of the EU, particularly for countries in the Southern and Eastern Neighbourhoods, and globally. The systemic and cascading consequences of natural disasters call for careful attention to cross-border concerns in national disaster risk assessment and management. Transboundary considerations – bilaterally or multilaterally – may be incorporated in a variety of forms such as joint risk assessment, contingency planning and exercises, financing and risk pooling arrangements, and technical cooperation.

3 2 1 Wildfires

Approximately 40% (182 million hectares) of the EU territory is covered by forests and other wooded land. European forests and human activities in the vicinity are regularly threatened by fires[3] which burn on average approximately 0.4 million hectares of the natural landscape on an annual basis, with broad variability between different years (see Figure 1, statistics for 2006-2023). In addition to the economic and environmental damage, wildfires are the cause of human casualties. For example, between the period of 2017 and 2018, Europe experienced the most devastating wildfires of the decade, which killed more than 200 people and injured over a thousand (San-Miguel-Ayanz et al. 2019). The 2018 Attica fire in Greece took the lives of more than 100 people and is the deadliest single wildfire recorded in Europe. Following the above, 2021, 2022 and 2023 have been among the most devastating wildfire seasons in the European territory, with 550,000 ha,800,000 ha, and over 500.000 ha burnt in the European Union, respectively. Most years, a large percentage of the burnt area occurs in Natura 2000 sites[4] – home to Europe's most valuable species and habitats. The environmental impacts of wildfires include the loss of biodiversity, damage to ecosystems and destruction of soil. Areas affected by wildfires are often prone to other ecosystem damages such as soil erosion, landslides and desertification. The economic damages caused by wildfires were estimated at around 10 billion euros in 2017 and 2.5 billion Euros in an average year (San-Miguel-Ayanz et al. 2018). In the first half of 2024, the number of fires mapped in the European Forest Fires Information System (EFFIS[5]) was higher than that of the previous seasons in the period 2006-2023, while the burnt areas were around average **(Figure 1** and **Figure 2)**.

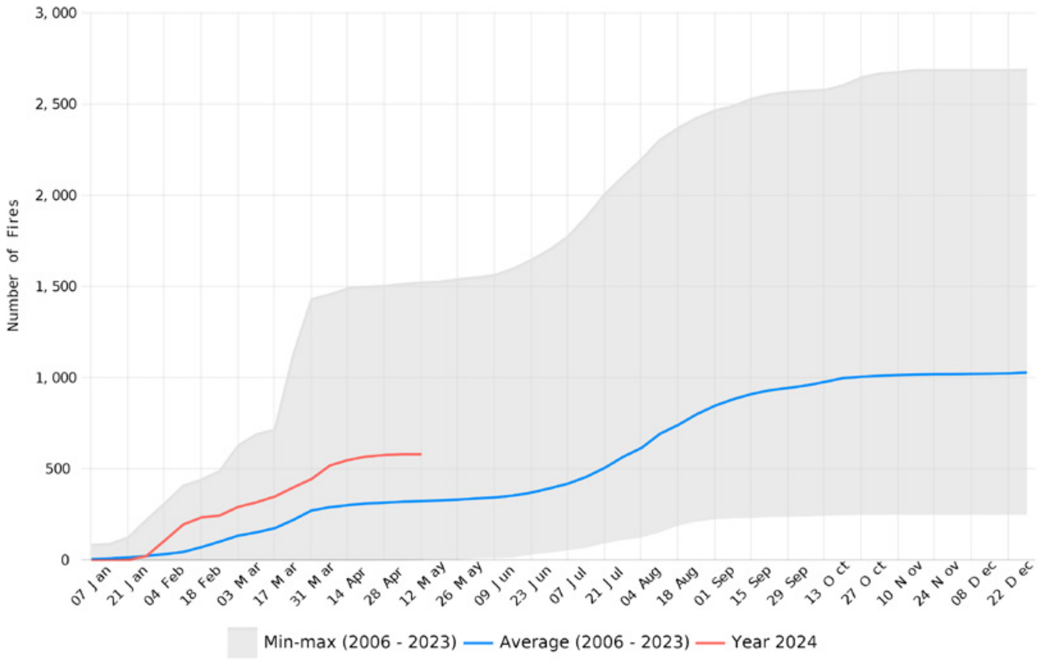
2 Interreg A – Cross-border cooperation: https://ec.europa.eu/regional_policy/policy/cooperation/european-territorial/cross-border_en

3 There are many terms used for fire in the landscape. The term used in the European Forest Fire Information System (EFFIS) is "wildfires", many of the fires in Europe occur in non-forested areas and are included in the EFFIS statistics.

4 Natura 2000 sites, https://environment.ec.europa.eu/topics/nature-and-biodiversity/natura-2000_en

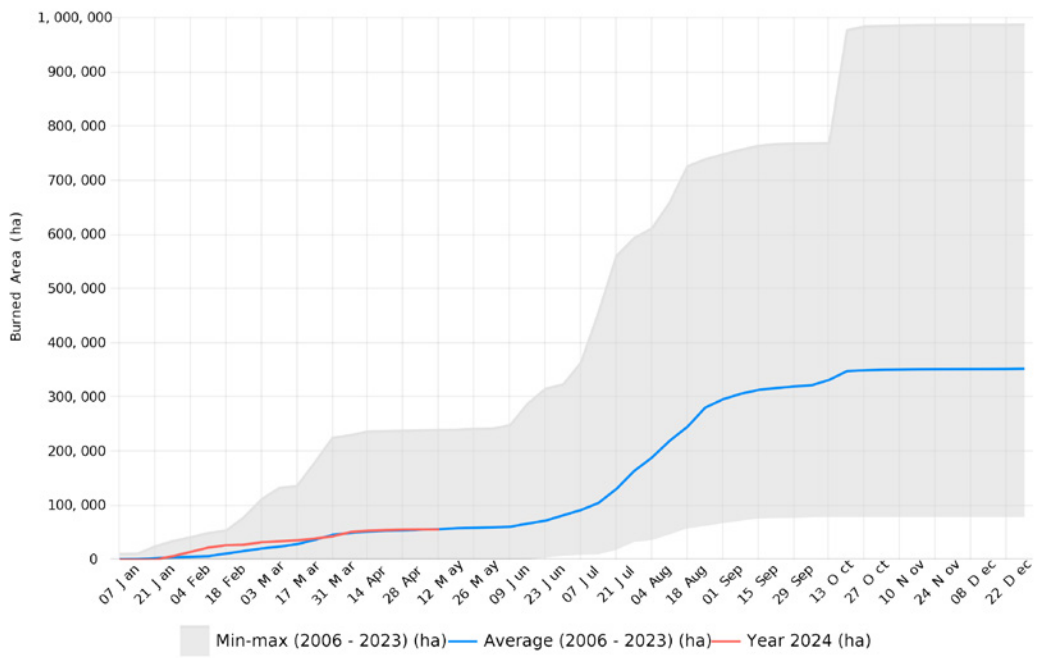
5 European Forest Fires Information System (EFFIS) http://effis.jrc.ec.europa.eu/

Figure 1: Trends in the average burnt area in Europe 2006-2024



Source: EC, JRC, EFFIS, 31 Mar. 2024

Figure 2: Trends in the average number of fires in Europe 2006-2024

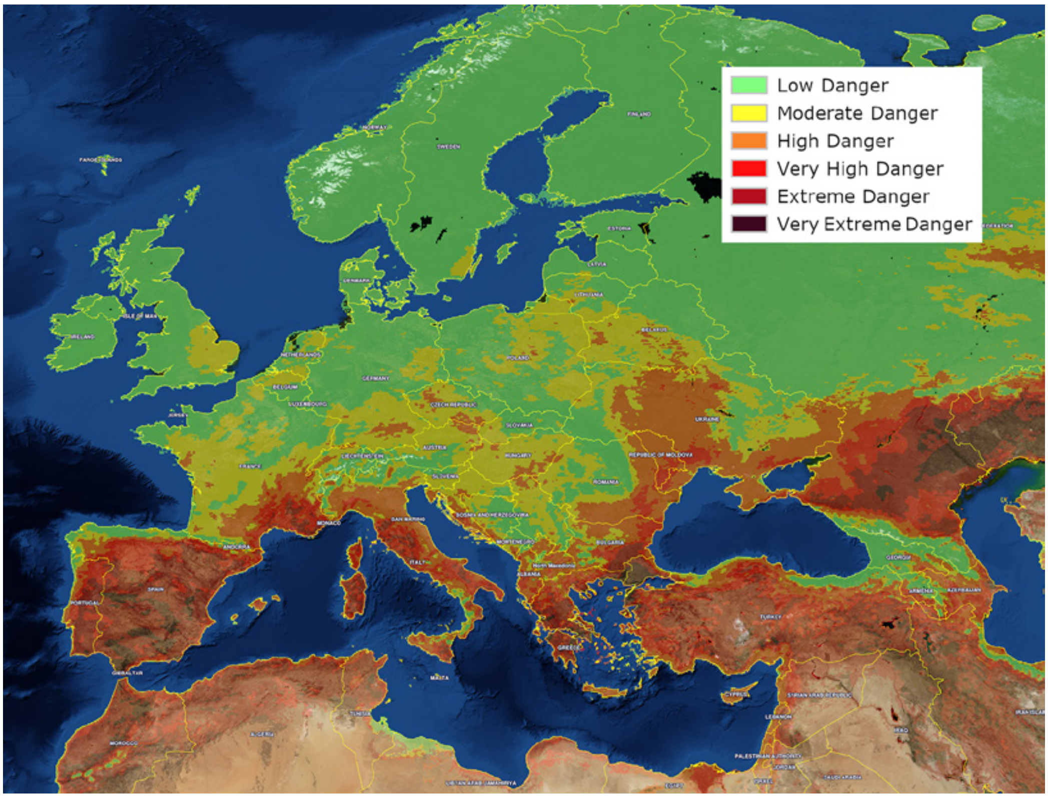


Source: EC, JRC, EFFIS, 31 Mar. 2024

While the Mediterranean region is the most affected by wildfires, wildfire risk exists in other regions of the EU. Recent years have shown that extreme wildfire events are becoming a reality in new locations, such as in Northern Europe. The 2018 wildfire season was the worst on record in Sweden. Other parts of Scandinavia, the Ireland, Latvia and Germany also witnessed higher than usual fire activity and this trend has persisted in recent years such as during 2021, 2022 and 2023. **Figure 3** shows fire danger conditions on 20 July 2023, when many wildfires were raging across Europe, including the largest wildfire ever recorded in Europe, in Alexandroupolis, Greece, which burnt over 95,000 ha.

Another trend observed in the last few years is that wildfire seasons starting earlier than usual and lasting longer. Moreover, the scale and intensity of fires have increased, triggering discussions on the phenomenon of “mega-fires, (European Commission, 2018).

Figure 3: Fire danger in Europe on 20 July 2023



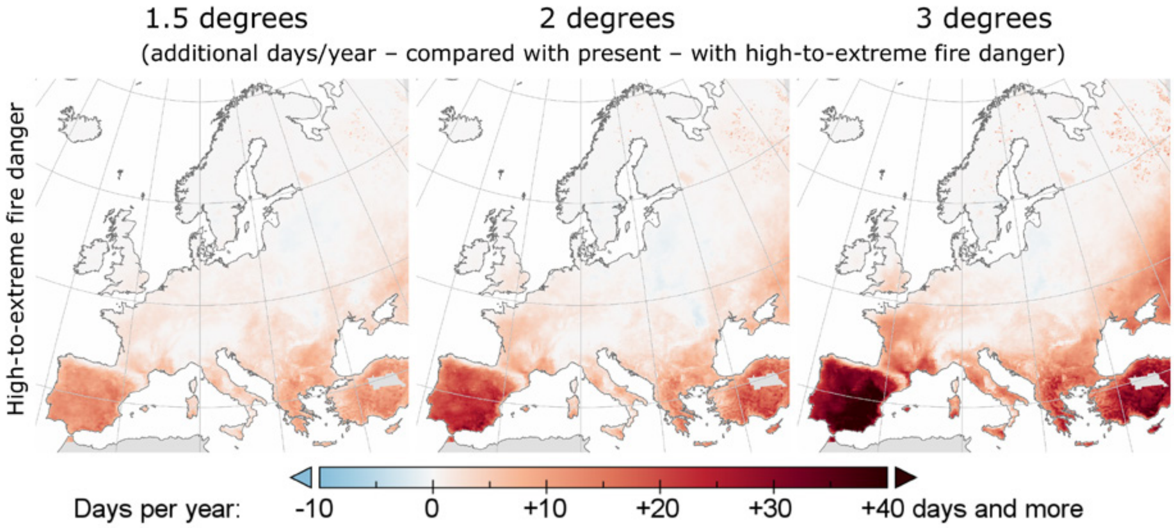
Source: EC, JRC, EFFIS

Drivers of wildfire risk

The likelihood of a fire to ignite and spread depends on the type of fuel on the ground and the weather conditions. Its impact depends on the amount of fuel that is available to burn, the weather conditions that determine the fire spread and intensity, and the assets that may be subject to damage, i.e. the proximity of population or infrastructure (Oom et al., 2022)

Climate change is one of the drivers of increasing wildfire risk. It is projected that warmer temperatures, heat waves and longer periods without rain will facilitate faire ignition and propagation, leading to more frequent and intense fires. In Southern Europe, the wildfire season will start earlier and last longer. Modelling work suggests that the burnt area in the South could increase by nearly 50% for a 2 °C scenario over the 21st century (de Rigo et al., 2017). The increase in temperatures is also expected to trigger the expansion of fire prone areas northwards and to higher mountain areas. In future, central and northern Europe area likely to become a new fire-prone area (Costa et al., 2020) (**Figure 4**).

Figure 4: Additional number of days per year with high-to-extreme fire danger (daily Fire Weather Index >= 30) for different levels of global warming compared to present (1980-2010) (Costa et al., 2020).



Source: EC, JRC, Costa et al. 2020

While climatic conditions play an important role in defining the fire hazard, human action is key for the risk to materialise. In Europe, approximately 96% of wildfires are caused by people. Socio-economic developments in the wildland urban interface and lack of forest management practices can also aggravate the situation. The depopulation of rural areas and changes in the land use have led to the accumulation of large amounts of fuel and it increased the fire-proneness of forests. At the same time, the expansion of urban areas in Europe contributes to more frequent and dangerous disasters in the wildland-urban interface (European Commission, 2018).

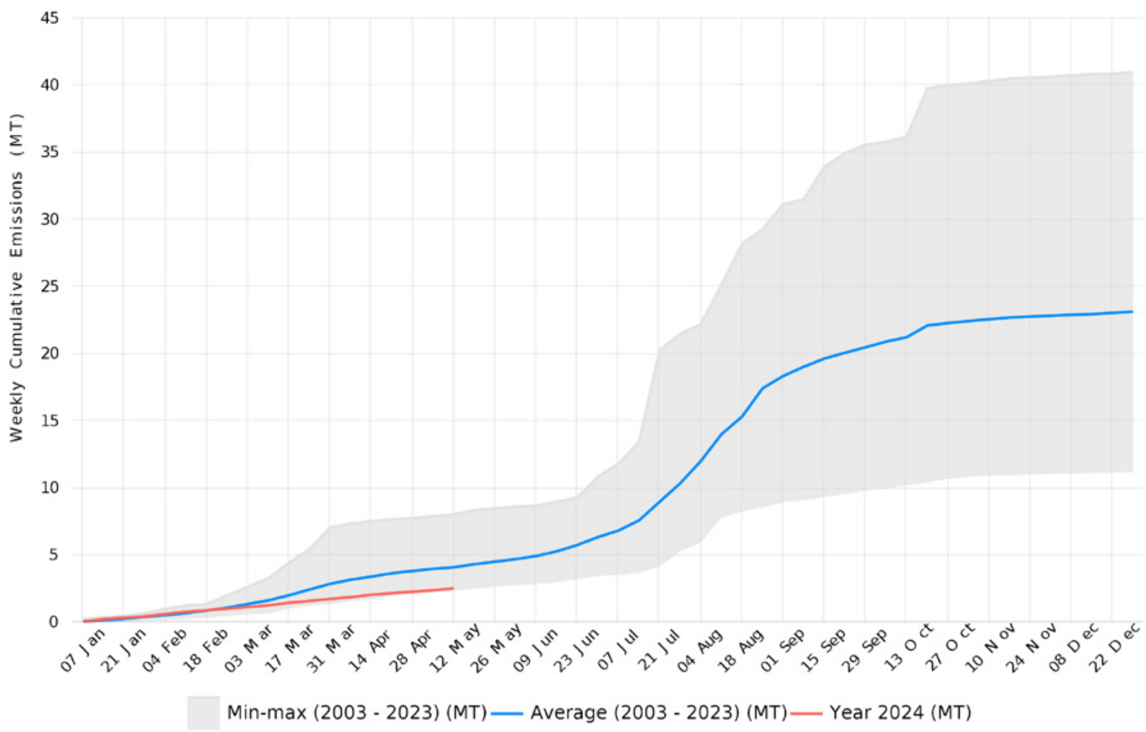
In a vicious cycle, wildfires themselves contribute to climate change through greenhouse gas emissions from burning forests and due to resulting deforestation (**Figure 5**).

Addressing the risk: EU actions 2017-2019

The EU Forest Strategy[6] of 2013 remains the main framework guiding the EU and Member States actions in sustainable forest management which is key for prevention of wildfires. Adaptation of forests to a changing climate is one of the eight priority areas of the Strategy. Guidance document has been developed to facilitate fire prevention-oriented management of forested landscapes (European Commission, 2021).

6 COM(2013) 659

Figure 5: CO_2 emissions in 2022 compared to the average in the period 2003-2021 (tonnes)



Source: EC, JRC, EFFIS Statistic portal

Monitoring and assessment of the wildfire risk at European level is supported by EFFIS that is continuously being upgraded to provide the most up-to-date and reliable data on wildfires. One of the recent elements added to EFFIS is the decision support system –containing information on the relative severity and potential threat of each wildfire. Also, a new module of wildfire risk assessment was included to the system[7]. This will facilitate informed decision-making on prevention, management and suppression priorities for wildfires. This activity follows from a previous initiative of the European Commission aiming at establishing a harmonized assessment of wildfire risk at the pan-European level, which will support decision making and international collaboration in fire management among countries (San-Miguel-Ayanz et al., 2019).

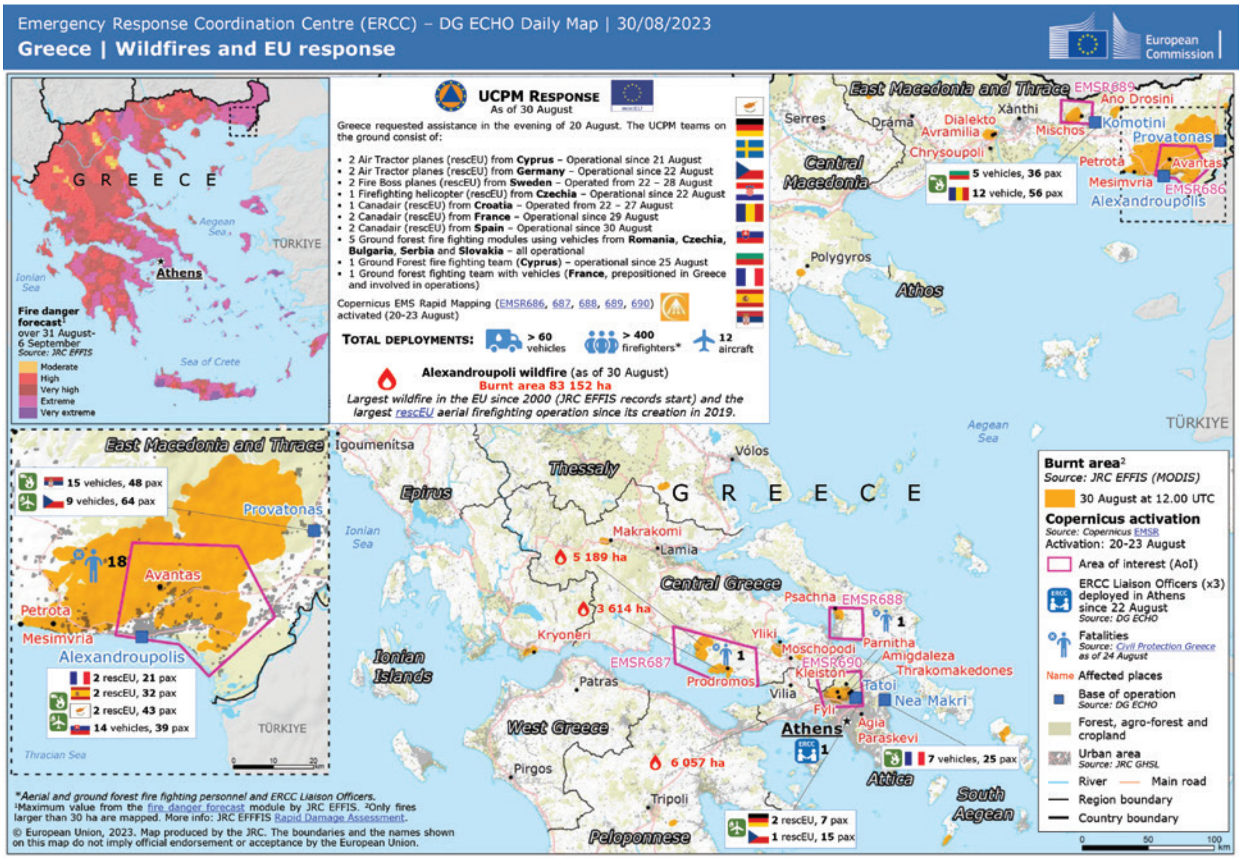
When a fire gets too big for a country to fight on its own, assistance can be requested through the UCPM, which following such a request mobilises assistance and expertise through the Emergency Response Coordination Centre (ERCC)[8]. In general, wildfires are the main emergency events inside the EU triggering requests for international assistance. During the 2017-2022 period, support in fighting wildfires was requested many times by Member States[9], both from the South and the North of Europe. Assistance provided to Sweden in fighting wildfires in summer 2018 was the largest European civil protection operation for wildfires in the last decade until 2023, when major operations took place in Greece (**Figure 6**).

7 EFFIS risk viewer https://effis.jrc.ec.europa.eu/apps/fire.risk.viewer/

8 The ERCC (https://erccportal.jrc.ec.europa.eu/#/echo-flash-items/latest) ensures rapid deployment of emergency support through a direct link with national civil protection authorities. Specialised teams and equipment, such as firefighting planes, search and rescue and medical teams, can be mobilised at short notice for deployments inside and outside of Europe.

9 France, Greece, Italy, Latvia, Portugal, Sweden

Figure 6: Greece, Wildfires – EU response



Source: ERCC portal[10], DG ECHO map

The extreme wildfire seasons of 2017, 2021, 2022 and 2023 revealed the limits of the UCPM in responding to multiple emergency situations, in particular when they were taking place simultaneously. It was one of the key reasons that prompted the revision of the UCPM legislation[11]. As a result of this revision, the European Civil Protection Pool was strengthened and new European response capacities – rescEU – were introduced and will serve as a safety net. Aerial firefighting means were identified as the first priority to be addressed when developing the rescEU pool. The rescEU means were largely increased after 2022 with the objective of doubling the UCPM firefighting capacity by 2023. In addition, the EU is currently implementing a fire prevention action plan in collaboration with Member States, experts and research organizations.

Additionally, the EU contributes to better preparedness for wildfires through regular exercises involving several Member States.

The European Structural and Investment Funds provide significant resources for investments in wildfire risk prevention and management in Member States, based on their specific needs and priorities. As a result of these investments made over the period 2014-2019, more than 18 million Europeans will be better protected from wildfires.[12] The EU Solidarity Fund (EUSF) provides financial aid for emergency and post-disaster reconstruction operations. In the period 2017-2019, the fund has supported two Member States[13] allocating 54 million euros to recover damages inflicted by wildfires.

10 ERCC portal, DG ECHO map https://erccportal.jrc.ec.europa.eu/ECHO-Products/Maps#/maps/4621

11 Decision No 1313/2013/EU of the European Parliament and of the Council of 17 December 2013 on a UCPM, amended by Decision (EU) 2019/420 of the European Parliament and of the Council of 13 March 2019

12 https://cohesiondata.ec.europa.eu/themes/5# (data retrieved on 31/05/2019)

13 Portugal and Spain, both in reference to the forest fires of 2017

The EU has been funding research in the field of wildfires over the last two decades through its Framework Programmes and other funding instruments. Some 60 research projects received a total EU contribution of more than 100 million euros (EC, DG RTD, 2018).

Managing the wildfire risk and building resilience: a way forward

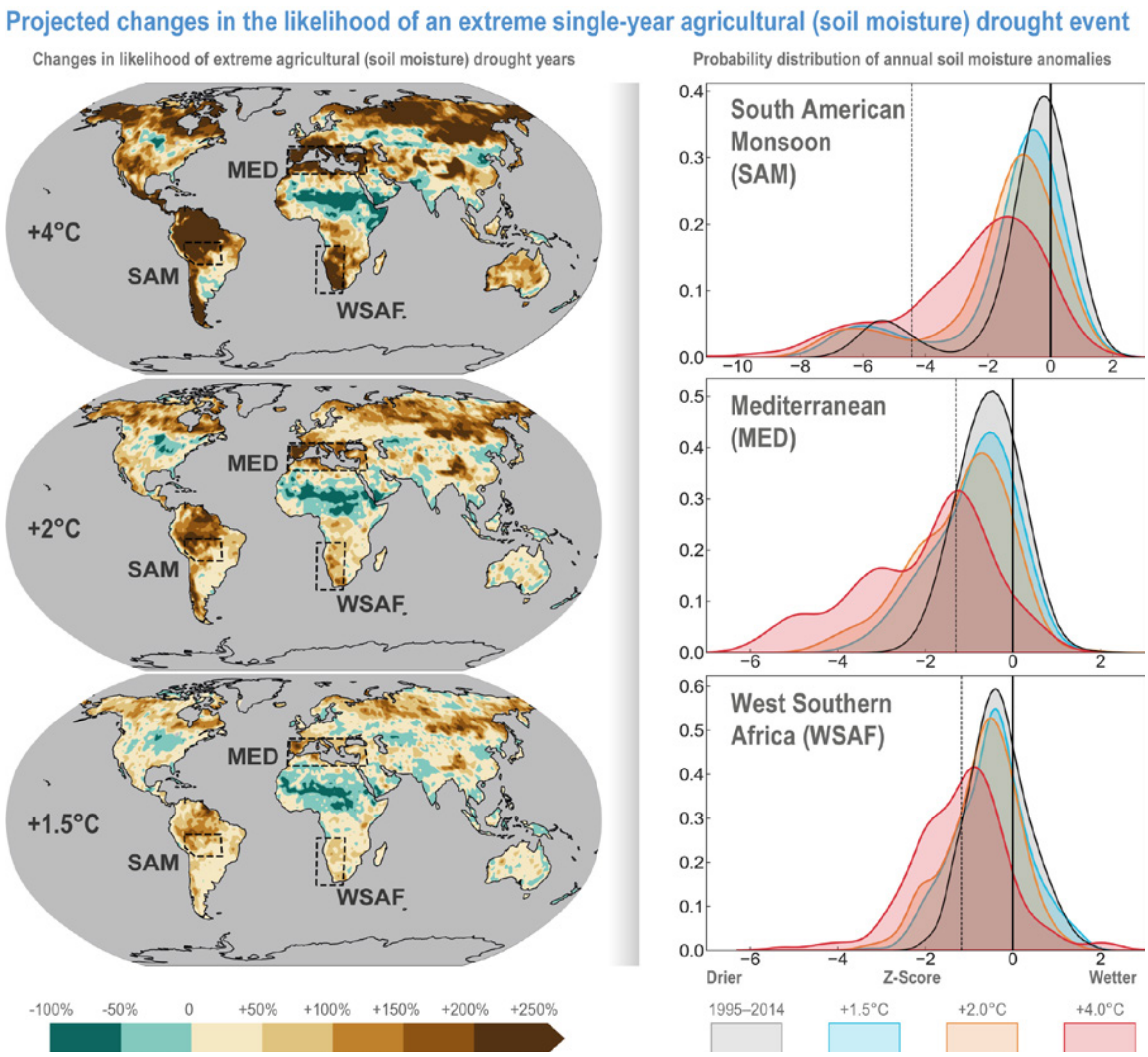
In order to improve the knowledge of wildfire risk and put forward evidence-based policy recommendations for a more effective risk management, the Commission took the initiative to review the EU-funded research on wildfires. The report (European Commission, 2018) concludes that the changing context of wildfires in Europe requires a shift towards a more holistic fire management approach – the one that addresses the climatic, environmental and socioeconomic roots of fires. The basis for action should be sustainable landscape management strategies that integrate prevention, climate change adaptation, risk communication, preparedness, suppression and restoration considerations. Reinforced and longer-term efforts in prevention and investment are crucial. Fire preparedness and resilience of local populations need to be strengthened. As regards the suppression, we will have to build up the capacity to fight more extreme fires, during a longer season. New knowledge is required on the impact of climate change on fires within and beyond fire prone areas to be better prepared for the future (San-Miguel-Ayanz et al. 2018).

Most European countries are vulnerable to wildfires, particularly during the summer period. Wildfires present a cross-border risk both in that they can progress and spread across many national borders in Europe, but also due to the fact that often extreme fire danger conditions cause fires all over a larger region even when the individual fires may geographically confined to one country. For instance cross-border fires are frequent across Portugal and Spain, or Spain and France, or Greece and Bulgaria. In 2017, in Portugal, 500 fires were reported in the central and northern regions in October 2017, at the same time more than 90 fires were reported in the northern parts of Spain. The damages were significantly higher in Portugal but the EUSF was applied for and approved for both countries.

3 2 2 Droughts

Drought is a systemic natural hazard with important repercussions in almost all sectors of natural and socio-economic systems. For instance, recent estimates of drought impact over Europe are in the order of 9 billion Euros per year, with climate change projections indicating that, in the absence of climate action (4°C in 2100 and no adaptation), annual drought losses in the EU + UK are projected to rise to more than 65 billion Euros per year (Naumann et al. 2021). Yet, drought is not only a source of economic concerns; droughts can also lead to impacts on ecosystems and societies, as for instance by decreasing food security, a major source of concern particularly in the most vulnerable countries (Barbosa et al. 2021). The projected changes in the likelihood of extreme single-year drought (by means of soil moisture) in different areas around the globe is showed in **Figure 7**.

Figure 7: Projected changes in the likelihood of drought events (soil moisture).



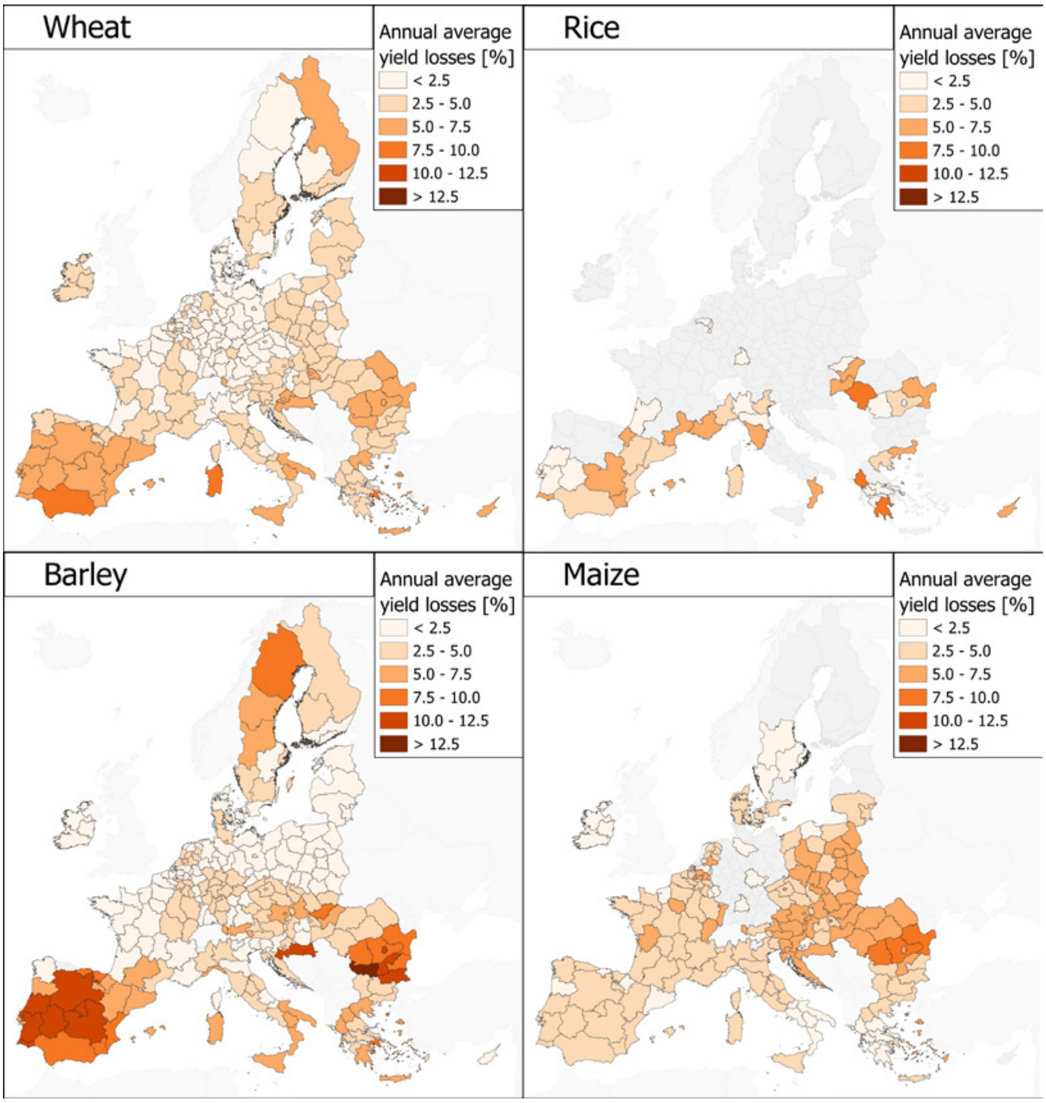
Source: Caretta et al. 2022, IPCC WG2 – AR6.

To increase the preparedness to drought events and to better manage drought risks, drought hazard information needs to be consistently provided, and drought risk assessments need to be implemented in order to support policy makers and water managers in developing scientifically-sound adaptation strategies and drought management plans. Indeed, the current lack of knowledge on the mechanisms that control droughts' onset, evolution and recovering, hampers the capability of making predictions (Wood et al. 2015, Hao et al. 2018), thus limiting the ability to understand how major drought hazard will evolve in space and in time, let alone drought exposure and vulnerability. Moreover, due to the wide-ranging direct and indirect (and often cascading) impacts from droughts, drought risk assessments need to include information tailored to specific sectors and oriented to the needs of specific users.

Drought risk can be defined as the likelihood to incur impacts, damages and/or economic losses during and after a drought and depends on the interactions between hazard, exposure and vulnerability.

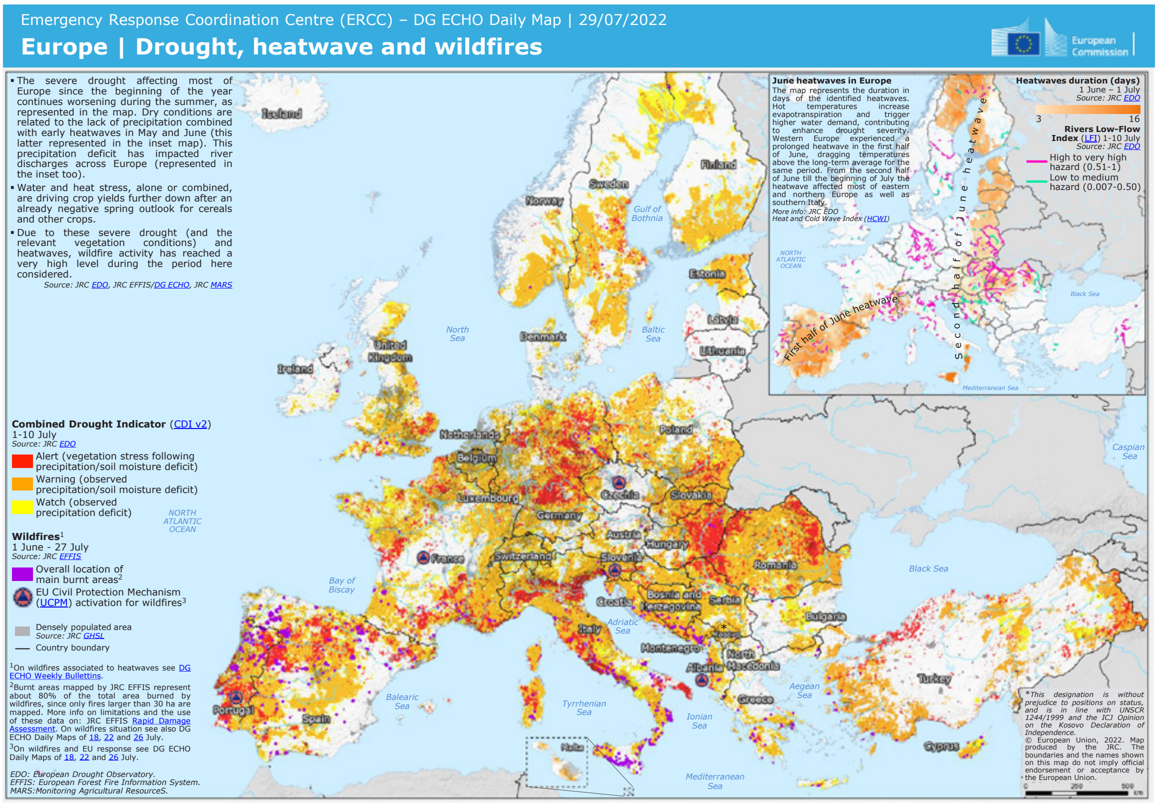
As shown in **Figure 7**, negative soil moisture anomalies are expected to become more common under different climate warming scenarios in Europe. Indeed, the severity and frequency of droughts appear to have increased already in parts of Europe, in particular in Southern Europe, while minimum river flows will also decrease significantly in many other parts of the EU, especially during summer. This is particularly worrying as Southern Europe has been identified in the European Drought Risk Atlas as a drought hot-spot (Rossi et al., 2023) (**Figure 8**). For instance, the 2022 spring and summer drought in Europe (**Figure 9**) has been characterized by dry conditions and a persistent lack of precipitation combined with a sequence of heatwaves and localized wildfires in the Iberian Peninsula and the Mediterranean areas. The severe precipitation deficit has affected river discharges widely across Europe, particularly in Northern Italy and Central Europe. Reduced stored water volume has had severe impacts on the energy sector for both hydropower generation and cooling systems of other power plants. Water and heat stresses have substantially reduced summer crops' yields, and the most affected crops were grain maize, rice, soybeans, and sunflowers.

Figure 8: Drought risk for agriculture in Europe (annual average yield losses, %)



Source: Adopted from the European Drought Risk Atlas, (Rossi et al., 2023)

Figure 9: Drought, heatwave and wildfires in Europe during the summer of 2022



Source: ERCC portal, DG ECHO Map[14]

Results of future projections done in the frame of the EU PESETA III[15] and IV projects concluded that rising temperatures can result in reductions in labour productivity, in shifts in flower/plant blooming, growing season and changes in soil water content, ultimately affecting agriculture productivity and ecosystem services provision. Some uncertainties on future crop yields still remain due to factors such as agro-management strategies (including changes in varieties) and the CO_2 fertilization effects on crop growth. Energy demand for heating will decrease, yet energy requirements for cooling spaces will rise rapidly with warming. Reduced water availability due to changes in precipitation may disrupt energy provision that depends on cooling with surface water and lower the potential of hydropower production. Southern parts of Europe may face increasing water shortage, but water related risks will affect the entire Europe.

Many impacts on society and the environment will be connected to changes in climate extremes, due to their disproportionate rise compared to the corresponding change in climatological averages. River flood risk is projected to increase in many regions of Europe. Coastal floods, especially in the second half of this century with accelerating sea level rise will show a dramatic increase along most European coastlines. Transport and other critical infrastructures in river flood plains and close to the sea will be increasingly at risk of damage and disruption by inundation. More frequent and severe drying of soils and vegetation, mainly in Southern Europe will increase the risk of wildfires. There will be a strong rise in human mortality from heat, not taking adaptation into account.

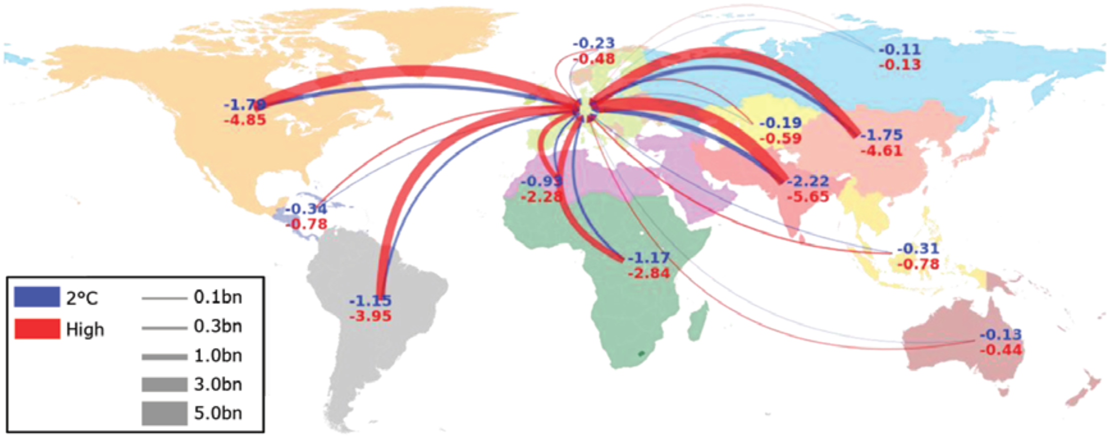
At the same time, there will be additional welfare impact in the EU associated to changes in trade flows due to climate impacts occurring in third countries related to four impact areas (residential energy demand, river flooding, labour productivity and agriculture). The transboundary effect is estimated to increase the EU welfare loss by 20%.

14 ERCC portal, DG ECHO MAP https://erccportal.jrc.ec.europa.eu/ECHO-Products/Maps#/maps/4156

15 PESETA III https://joint-research-centre.ec.europa.eu/peseta-projects/peseta-iii_en

As shown in **Figure 10**, Europe is an integral part of an intricately interconnected global system comprising various networks such as international trade, travel, and telecommunications. Consequently, the increased likelihood of extreme weather events and the impacts of climate change can extend far beyond the regions or nations directly affected. These cross-border consequences of climate-related impacts, often termed as indirect effects, transboundary effects, or spill-over effects, hold significant importance for European adaptation policies. The cross-border consequences of climate-related impacts can substantially influence the vulnerability to climate change and the associated risks faced by different regions, sectors, and populations. One notable impact manifest in the intricate and expansive value and supply chains of European products, often extending and linked to distant geographical regions (as, for instance, the regions illustrated in **Figure 10**). These interconnected chains inevitably result in repercussions within Europe (Burke et al. 2015), rendering essential to accurately characterize the three components of drought risk under a global perspective and with consistent tools and metric with the aim at facilitating efficient DRM and the successful implementation of adaptation strategies. The preparation of Drought Management Plans should be linked to an agreed conceptual framework for drought management and based on clear drought definitions (Vogt et al. 2018). JRC is actively working on each of the components of drought risk to provide scientifically-sound and robust information for supporting decision- and policy-makers in better dealing with drought risks.

Figure 10: Geography of global transboundary effects (due to climate impacts in the rest of the world, via international trade) in Gross domestic product (GDP) terms (bn €).



Source: Szewczyk et al., 2020

In terms of drought hazard characterization, JRC has developed an innovative event-oriented drought tracking algorithm and a related database of droughts in Europe based on spatio-temporal clustering approach (Cammalleri et al. 2023 and 2022). By adopting a flexible clustering algorithm that can adjust to different drought definitions, and tuning the clustering algorithm on a reference dataset specifically built for meteorological and agricultural droughts, the developed methodology overcomes several limitations in identifying and characterizing drought events, such as the lack of treating droughts as an event-oriented phenomenon. Indeed, the definition of a clear methodology capable of identifying and tracking drought events in both space and time offers huge benefits for operational monitoring systems and early warning systems (WMO, 2006).

In general, droughts are multi-faceted events that can impact one or several socio-economic sectors, including but not limited to agriculture, energy, water supply, and water quality. As such, drought events can broadly be categorized as meteorological, agricultural and hydrological droughts.

Agricultural droughts are particularly relevant for Europe, and are usually characterized according to the affected variables of the hydrological cycle. In this context and aiming at providing actionable information for supporting drought risk management, JRC has recently revised the Combined Drought Indicator (CDI; Sepulcre et al. 2012), a drought-related indicator specifically designed to detect areas affected by agricultural drought and estimate their potential severity. The revised CDI identifies areas where vegetation and crops are at risk or are already affected by drought conditions. The CDI is based on the cause-effect relationship for agricultural drought, whereby a shortage of precipitation leads to a soil moisture deficit, which in turn results in a reduction of vegetation productivity. The indicator is computed by combining anomalies of precipitation, soil moisture and satellite-measured plant photo-synthetically activity - as measured by, respectively, the Standardized Precipitation Index, Soil Moisture Anomaly and fAPAR Anomaly[16]. As such, the CDI allows for classifying droughts in five levels (corresponding to the different stages of the cause-effect relationship for agricultural drought). The three primary drought classes are: (1) “Watch”, indicating that precipitation is less than normal; (2) “Warning”, indicating that soil moisture is in deficit; and (3) “Alert”, indicating that vegetation and crops show signs of stress. An example of the application of the CDI is shown in **Figure 11**. The main benefit of the revised CDI is the provision of an integrated approach that allows for a convergence of indicators and therefore evidence of drought, ultimately supporting policy-makers in effective risk management and decision-making.

While the JRC is providing robust information related to the management of drought risk, the characterization of drought risk by means of the three dimensions (i.e. hazard, exposure and vulnerability) and the representation of their interactions over different socio-economic sectors pose several challenges. Indeed, changes in precipitation, combined with rising temperatures, will significantly worsen existing stresses on the quality and quantity of freshwater resources. Economic development, human health and ecosystems are inseparably linked to sufficient availability of freshwater. The European Green Deal and its initiatives now provide the necessary framework and momentum to move forward with an ambitious agenda on water quantity management, along with an increasing awareness and the application of new water-related actions. Some factors that could be included into drought risk assessments are listed below:

- Dependency on agriculture for livelihoods,
- Energy use,
- Farmers with crop/livestock insurance,
- Market fragility,
- Adult literacy rate,
- Availability of functioning early warning systems,
- Volume of water storage in a safe and sustainable reservoir,
- Population without access to high-quality water,
- Institutional capacity and government effectiveness

In this context and in line with the adoption of the new EU Strategy on Adaptation to Climate Change in 2021, the EC (DG ENV and JRC) launched the European Drought Observatory (EDO) for Resilience and Adaptation project (EDORA)[17], aiming to improve drought resilience and adaptation throughout the EU. An example of the impact chain of drought risk as considered in EDORA is shown in **Figure 12**.

Amongst its outputs, the main outcomes of the EDORA project includes a drought impact database that compiles and structures information on drought impacts over the last 40 years across the EU, and a

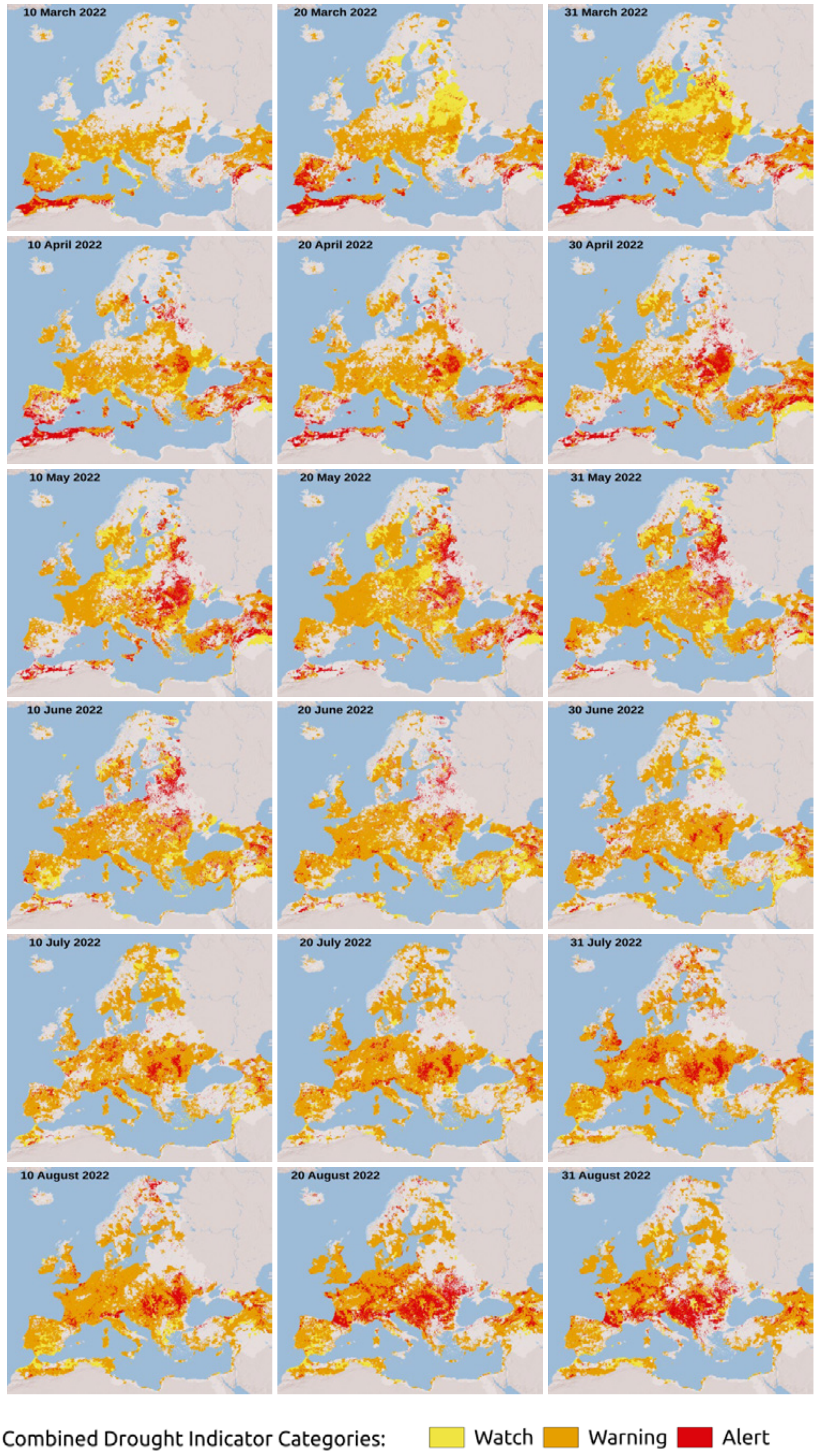
16 https://drought.emergency.copernicus.eu/documents/factsheets/factsheet_fapar.pdf
17 EDORA https://drought.emergency.copernicus.eu/edora/php/index.php?id=201

drought risk atlas, identifying the current baseline of drought risks as well as future risks under different climate change scenarios. Both products encompass multiple sectors affected by drought across the EU (agriculture, energy, public water supply, ecosystems, inland navigation, tourism, and human health).

EDORA also aims to increase the connections between existing drought observatories in the EU Member States, and, where lacking, to promote the development of new ones. The project is improving both coordination and geographical coverage of drought monitoring in the EU, as key to tackle current and future challenges related to drought. At the same time, it supports the ad-hoc Task Group on Water Scarcity and Drought that has also carried out a review of drought management plans in the EU Member States.

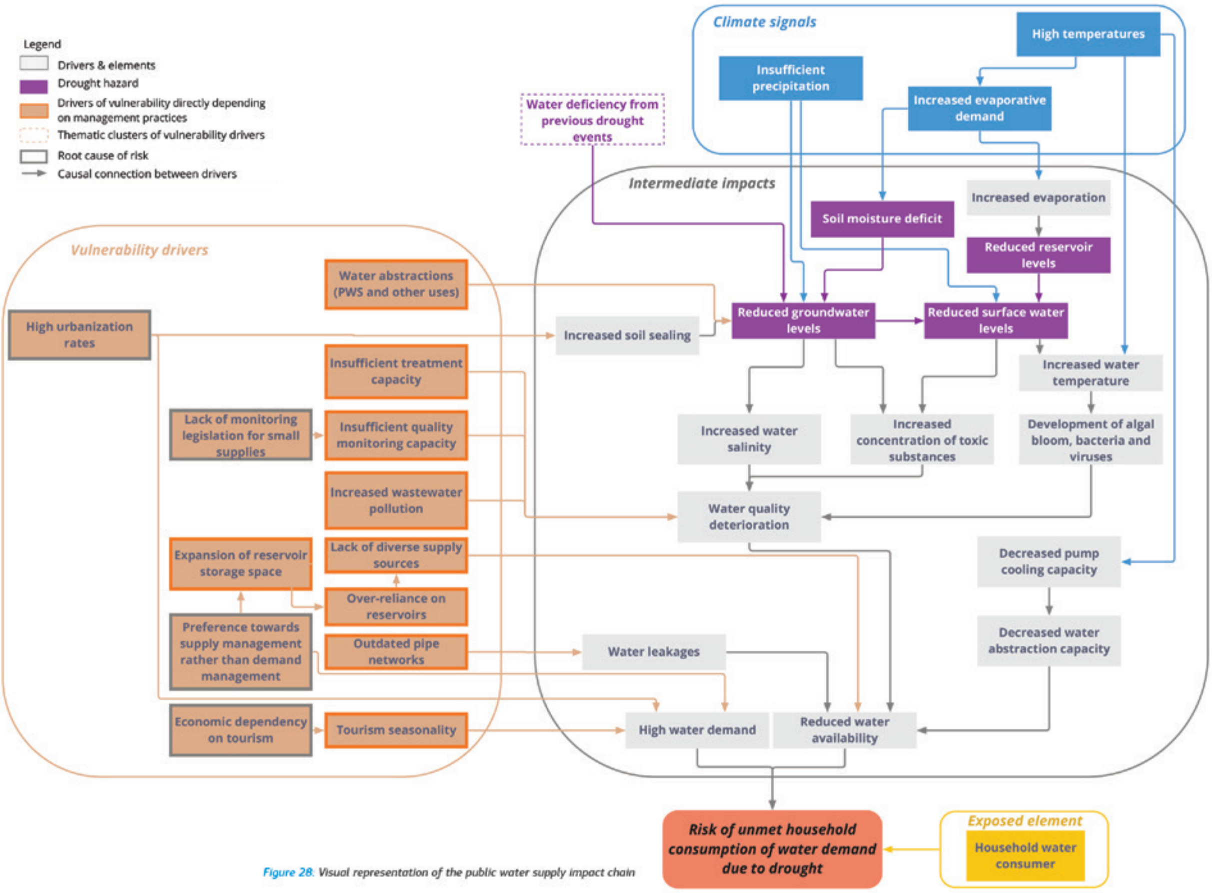
In summary, drought is a complex phenomenon that requires a multidisciplinary approach to holistically assess its risks, including the potential transboundary effects in the EU and elsewhere. A good example of currently available tools that can foster drought risk management can be found in the National Drought Management Policy Guidelines published by the Integrated Drought Management Programme (IDMP) (WMO and GWP 2014) and adapted to regional circumstances by the Global Water Partnership for Central and Eastern Europe (GWP-CEE 2015). As presented in EC (2007) two basic approaches for drought risk management are currently applied. Their related legal and institutional tools can be divided into reactive and proactive actions. The proactive approach is linked with plans to prevent or minimize drought impacts in advance; these are mainly long-term actions, aimed at to make the territory and the economy more robust to cope with droughts. The reactive approach includes actions after a drought event has started and is linked to short-term actions that can be executed during an emergency.

Figure 11: Temporal evolution of the severe spring drought in northern Europe in 2022, as shown by maps of the European Drought Observatory (EDO)'s CDI, computed for every 10-day period from March to August 2022



Source: EC, JRC, Copernicus EDO

Figure 12: Impact chain of drought risk for public water supply in EU27



Source: EC, JRC, EDORA project

3 2 3 Floods

According to the 6th Intergovernmental Panel on Climate Change (IPCC) assessment report (IPCC, 2023)[18] the frequency and intensity of heavy precipitation events have likely increased in Europe. This has led to an increased number of riverine floods in Europe for the last three decades (Blöschl et al., 2020) and to high reported economic flood damages. According to the PESETA IV[19] Project assessment economic damages caused by floods are expected to rise further suggesting that the EU economy would face 6 times the present losses of €7.8 billion annually and nearly half a million people would be affected, if exposed to a 3°C rise in global temperatures above pre-industrial levels (Feyen et al., 2020).

In 2007, the EU Floods Directive[20] entered into force with the aim to reduce "potential adverse consequences of flooding for human health, the environment, cultural heritage and economic activity". The directive requires a river basin-wide approach where Member States need to develop flood risk management plans including, where river basins are transnational, the incorporation of cross-border flood risk management. Prior to the development of flood risk management plans, Member States are required to carry out a preliminary flood risk assessment to identify the areas within national and transboundary river basins prone to flooding and to develop flood hazard and risk maps on the basis of this assessment.

There are well over 40 international river basins in Europe (SWD(2019) 33 final[21]). Despite the fact that there is currently a lack of detailed information on the impacts of transboundary floods, it is clear that international cooperation on flood risk management is not only necessary, but also beneficial in order to reduce the consequences of flooding (e.g. Danube Flood Risk Management Plan[22]). Moreover, such collaboration contributes to the enhancement of knowledge and information resources and expands available strategies, thus strengthening the overall effectiveness of flood risk management efforts.

While an increasing trend in reported economic damages of riverine floods is observable in Europe, the normalized economic damages (by wealth or GDP) as well as the number of fatalities from floods is decreasing (Paprotny et al., 2018). This suggests that better preparedness and risk management for floods through, e.g. early warning systems, flood risk maps, etc. have increased awareness about floods also for transboundary rivers. There is also evidence that the Floods Directive has increased resilience to floods in transboundary river basins in some countries and regions (e.g. Priest et al. 2016) but it is currently not possible to quantify the impact of the effectiveness of the EU Floods Directive with regards to improvements in cross-border flood risk at the European scale.

Major flood events in the last three years

Eastern Spain and southernmost France were hit by a severe storm with high winds and heavy rainfall in January 2020, causing floods and requesting prompted evacuations. In total across Spain, 14 people were killed while 3 more remain missing. Severe river flooding and landslides resulted in the evacuation of 2,000 homes across southern France.

In July 2021, several Member States were affected by severe floods, causing deaths and widespread damage. Floods occurred in several river basins across Europe including Austria, Belgium, Croatia, Germany, Italy, Luxembourg, the Netherlands, Romania and Switzerland. At least 243 people died in the floods, including 196 in Germany, 43 in Belgium, two in Romania, one in Italy and one in Austria. Germany and Belgium were the most affected countries, with recovery costs exceeding 30 and 5 billion euros, respectively.

18 IPCC https://www.ipcc.ch/assessment-report/ar6/
19 PESETA IV https://joint-research-centre.ec.europa.eu/peseta-projects/jrc-peseta-iv/river-floods_en
20 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:32007L0060
21 https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=SWD:2019:0033:FIN:EN:PDF
22 https://www.icpdr.org/tasks-topics/tasks/flood-risk-management/danube-flood-risk-management-plan-2021

The Limburg Province in the Netherlands experienced severe flooding with damages amounting to over 1 billion euros. Austria and Luxembourg suffered less severe impacts but still incurred damages of 83 and 189 million euros, respectively.

In Italy two major events occurred recently. Due to intense rainfall in September 2022, Marche region experienced fluvial and flash flood events resulting in an extensive economic loss of 668 million, 12 fatalities and one person is still missing. In May 2023, Emilia-Romagna region was affected by heavy rainfall causing the overflow of twenty-three rivers across the region and flooding 37 municipalities. At least 16 deaths were recorded, several people are still thought to be missing and thousands have been evacuated.

Cross-border flood risk management is particularly challenging requiring a high degree of coordination and cooperation between Member States. Nearly all Member States which share flood risk areas with neighbouring Member States report that coordination took place during the identification of flood risk areas. However, common transboundary flood risk areas were hardly identified. While in most basins medium probabilities refer to a return period of ≥100 years as requested in the Directive, for the scenarios addressing low and high probability flooding huge differences among transboundary basins can be found (SWD(2019) 33 final).

The level of detail provided regarding climate change varies for the different international river basin districts. While there has been a clear effort to take climate change into account for some of the international river basins, in others it will be considered in the future. In general, it can be said that consideration of climate change is more developed in those basins where an international body has been established (SWD (2019) 33 final).

Joint management objectives have been mainly developed in those basins where an international body has been established. However even if such objectives exist the measures taken to manage flooding are mostly developed and coordinated on Member States level with sometimes limited attention to the international level. This is reflected in the fact that in no international basin a cost benefit assessment as proposed by the Directive has been carried out in order to assess where measures could be best situated (SWD(2019) 33 final).

Main challenges for cross-border flood risk management

Several critical aspects contribute to the complexity and challenges associated with transboundary flood risk management.

1. International cooperation among all countries sharing the same river basin is needed. This includes bilateral as well as multilateral agreements between the relevant countries. River basin commissions play a key role here.
2. A coordination between the national governance systems is required to effectively communicate and share information and data.
3. Good transboundary communication is essential for cooperation. Joint problem definition and a common understanding of interests among all riparian countries are important for stimulating and improving transboundary cooperation.
4. Efficient data sharing needs to be established

Overall, as pointed out also in Priest et al. 2016, the lack of adoption of common definitions pertaining to the Floods Directive (e.g. return periods for low and high probability events) and concepts (definition of common transboundary flood risk areas, climate change integration) by riparian Member States, may hamper successful transboundary flood management. Insufficient coordination reduces synergies because it makes it difficult to assess which combination of flood strategies may work best within the whole river basin. Nevertheless, also good examples and practices of cross-border flood risk management exist (and the lessons learnt from the implementation of the Floods Directive in transboundary river basins during the first cycle should be addressed in subsequent implementation cycles. It should be noted that at the time of writing of this chapter the second implementation cycle has been finalised but an updated assessment on cross-border flood risk management has not yet been performed.

Good practices of cross-border flood risk assessment and management

In the Danube River Basin, the determination of transboundary areas of potential significant flood risk was coordinated. Transboundary risk areas were defined by the Flood Protection Expert Group as any area (in the transboundary reach of a river) that has been assigned as a transboundary risk area by at least one country. The assignment was further discussed at the bilateral level. If the transboundary character of a risk area is regarded as not yet agreed by one country, this is shown on the map. For a river crossing a border, the area of common interest is assigned as a transboundary risk area. The extent of this area of common interest has to be agreed by the neighbouring countries. The International Commission for the Protection of the Danube River agreed that two scenarios (medium and low probability) are relevant for the level of the international River Basin district. Only fluvial flooding was considered.

In Bulgaria, floor hazard risk management (FHRMs) were prepared for all risk areas shared with other Member States in transboundary units of management. The development of the FHRMs for these two transboundary flood risk areas was coordinated and based on mutually agreed methodologies within the international Danube river basin, and with Greece. The Danube flood risk management plan (FRMP) explains that the FHRMs for the Bulgarian area of the Danube were prepared as part of the project Danube Floodrisk, which included all countries from the ICPDR as partners to the project. As part of the project all national methodologies were coordinated and a common database with all necessary data was set up. The preparation of the FHRMs for the transboundary area with Romania was bilaterally coordinated at each step of the preparation. The preparation of the FHRMs for the transboundary areas of potential significant flood risk (APSFR) shared with Greece was coordinated by the technical sub-group to the joint expert group under the Joint Declaration for Cooperation in the Area of Water Management with Greece. At its meetings, the methodologies of the two countries were discussed, a common methodology (e.g. concerning the scenarios to include) for the development of the FHRMs in the transboundary areas was agreed and necessary data exchanged.

In Finland, the only international unit of management analysed in detail for this assessment is Tornionjoki (FIVHA6), shared with Sweden, with an APSFR shared on both sides of the border. In this catchment, flood maps were elaborated in co-operation with Swedish authorities. In the FRMP summary, it is indicated that the Finnish-Swedish Transboundary River Commission and the Swedish authority MSB (Swedish Civil Contingencies Agency) gave their written opinions on the designation of the APSFR. Moreover, in the FRMP it is explained that a joint Interreg IV A project, “Detailed inundation planning in the lower part of Tornio River”[23], carried out from 2009-2012, estimated flood risk. A specific coordination body was not formed for the FRMP; rather, coordination work was carried out by the authorities of both regions and via the Finnish-Swedish Transboundary River Commission. The corresponding Swedish FRMP also refers to the Interreg IV A project, but provides fewer further details.

Recommendations and the way forward

Lessons learned from recent flood events and from implementing the Floods Directive point to the following recommendations:

23 https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=SWD:2019:0070:FIN:EN:PDF

- While for medium probabilities in most basins a 100-year return period is applied, low and high probabilities vary widely. For those who have not used the 100-year time return for medium probability this should be done in subsequent cycles. Wherever possible, low and high probabilities should be streamlined to have one common understanding on the risks;
- More information should be made available regarding numbers on the potential adverse consequences of flooding harmonised at the basin level (e.g. households potentially impacted) to enable the quantification of the impact of the implementation of the Floods Directive also for transboundary rivers;
- In the second cycle, climate change considerations should be integrated in the setting of objectives and in the prioritisation of measures for cross-border flood risk management;
- The full extent of a risk area's area of influence (upstream and downstream) should be considered with a view to identifying risk areas with a transboundary dimension; this aspect is also relevant in deciding on measures with cross-border effect.

3 2 4 Earthquakes

Introduction and setting stage

Seismic risk refers to the potential for damage, loss, or harm to people, buildings, infrastructure, and the environment due to the occurrence of earthquakes. It encompasses the likelihood of an earthquake of a certain magnitude occurring in a specific area (i.e. seismic hazard), as well as the vulnerability of the built environment and population exposed to the effects of the earthquake (i.e. exposure).

The seismic hazard in broad terms indicates everything related with an earthquake that may affect the normal activities of people. This includes surface faulting, ground shaking, landslide, liquefaction, tectonic deformation, tsunamis, and seiches (USGS, Earthquake Hazard Program). The activities most directly caused by an earthquake are known as primary earthquake hazards (subsidence/uplift, liquefaction, surface rupture including cracks, landslides, and ground shaking). Moreover the effects brought on by primary hazards are named secondary e.g. ground gases, flooding, fire, tsunami (Pacific Northwest Seismic Network, PNSN). In a specific meaning seismic hazard is the probability of the occurrence of specified intensity earthquake in a specific time of interest and area (Thenhaus et al 2003).

Seismic vulnerability refers to the susceptibility of buildings, infrastructure, and populations to damage and harm resulting from the effects of an earthquake.

Seismic exposure refers to the elements or assets that are at risk of being affected by the impact of an earthquake. This can include buildings, infrastructures, critical facilities, natural resources, and human populations located in areas prone to seismic activity.

The impact of the earthquake depends on several factors of the hazard such as magnitude, depth at which the earthquake struck and geology. Earthquakes of magnitude 7.0 and above may cause widespread, intense ground shaking in addition to other primary and secondary hazards; earthquakes of magnitudes 6.0 to 6.9 tend to cause local damages, while smaller earthquakes can cause damage to vulnerable structures at near-source distances (UNDRR, 2021). . The impact is also depending on the vulnerability and exposure e.g. severe impact in areas with high people density, fragile vulnerable building structures, or localized soil conditions that amplify ground shaking.

Seismic impact in Europe

In Europe earthquake is among the most common hazards assessed in the national risk assessments prepared in 2015 and 2018 by the member states participating at the UCPM[24]. This hazard is bringing attention to the infrastructures and buildings primarily built before the current building rules, making residents there especially vulnerable (UNDRR, 2022)[25].

Earthquakes have an impact on the national incomes and capacity to support the local economy. In contrast to poor households, wealthy households may have access to a wider range of nonfinancial and financial coping mechanisms that might lessen the severity of disaster shocks. The length of the ensuing recovery and reconstruction activities is ultimately impacted by these differences in socioeconomic level.

In many European cities, the impact of seismic risk on multifamily residential housing poses a serious concern. Multifamily buildings are frequently located in or close to urban areas, and many of the residents of these homes are susceptible to additional level of risk mainly related, among other factors, to the density of urban areas, and structural flaws brought on by the buildings' age.

In order to gain a better understanding of the behaviour and possible losses of multifamily buildings built

24 (Poljanšek et al, 2021)
25 GAR 2022 - https://www.undrr.org/gar/gar2022-our-world-risk-gar

before 2000 in 27 cities spanning 20 countries in Europe and Central Asia during earthquakes, World Bank examined the seismic risk of these buildings[26]. According to the report, most multifamily residential buildings built before 2000 housed half of the population on average in the cities under study. These buildings are primarily classified as either reinforced concrete frame buildings or unreinforced masonry buildings. Old unreinforced masonry buildings are particularly vulnerable to earthquakes and account for a sizable amount of the direct monetary losses, fatalities, and number of people who will be permanently relocated in case of a strong earthquake.

Table 1 and **Figure 13** the list of important earthquakes that occurred in Europe during the last two decades is shown. It included the events which affected whole regions and caused significant losses reaching billions of euros and for which the EUSF was granted following the request of assistance to the EC. For each request of assistance JRC performs a plausibility check based on the declared impact and using advanced models and detailed data available, including post-disaster remote sensing data (mostly from CEMS satellite, aerial, and drone acquisitions) as well as in-situ data.

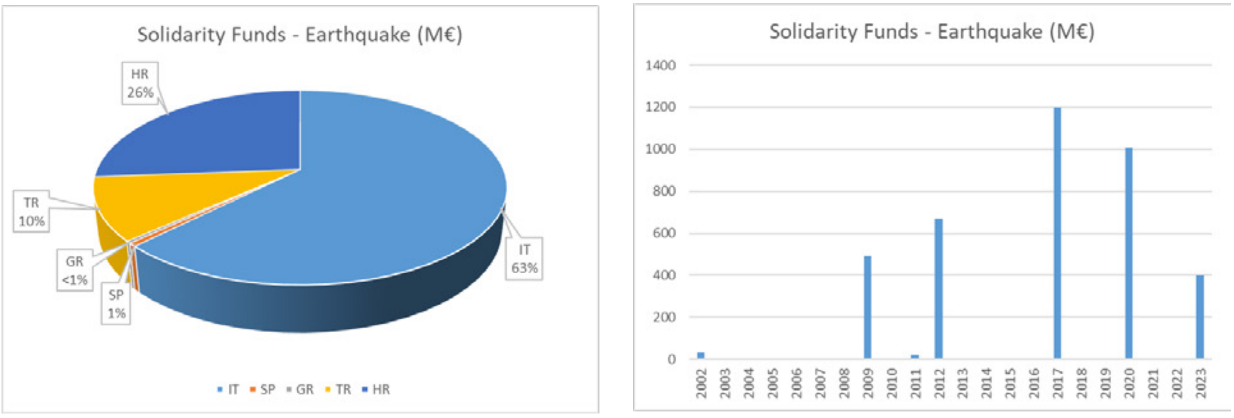
Table 1 Earthquakes in Europe since 2002, for which the EUSF was requested and granted

Location	Year	Type	Damage (M€)	Granted (M€)
Molise, Italy	2002	regional	1,558	30.8
L'Aquila, Italy	2009	major	10,212	493.8
Lorca, Spain	2011	regional	843	21.1
Emilia Romagna, Italy	2012	major	13,274	670.2
Kefalonia, Greece	2014	regional	147	3.7
Lefkada, Greece	2015	regional	66	1.6
Central Italy	2016-2017	major	21,879	1196.2
Lesvos, Greece	2017	regional	54	1.4
Kos, Greece	2017	regional	101	2.5
Zagreb, Croatia	2020 Mar	major	11,572	683.7
Samos, Greece	2020	regional	101.2	2.5
Petrinja, Croatia	2020 Dec	major	5,508.7	319.2
Crete, Greece	2021	regional	143	1.3
Southern Türkiye	2023	major	n.a.	400

Source: EU, EUSF[27]

26 WORLD BANK https://documents1.worldbank.org/curated/en/873811622437677342/pdf/Summary-Report.pdf
27 EUSF OVERVIEW https://cohesiondata.ec.europa.eu/stories/s/An-overview-of-the-EU-Solidarity-Fund-2002-2022/qpif-qzyn/

Figure 13 EUSF granted for earthquake events: percentage by Country (left) and overall amount per Year (right)



Source: EU, EUSF[28]

Between 1994 and 2013, the combined death toll from earthquakes and related primary and secondary effects was close to 750,000 globally, more than from all other natural hazard events (CRED, 2015).

Seismic Risk Reduction

It is possible to reduce the risk through seismic retrofitting of already-existing structures, better adherence to seismic safety building standards, e.g. the Eurocodes, and guidelines, and avoiding the construction of new structures on unfavourable locations, e.g. adjacent to active faults. For this scope, within the pilot project 'Integrated techniques for the seismic strengthening and energy efficiency of existing buildings', a simplified method for assessing the benefit of combined renovation was proposed and applied to representative buildings. An integrated framework was developed for regional impact analysis. Seismic risk, energy performance and socioeconomic aspects were assessed throughout Europe to identify priority regions and investigate renovation scenarios (Gkatzogias et al., 2022)..

Cross-border risks

Challenges

Given the wide-ranging destructive consequences of earthquake events, and the cross-border character of the major ones, it is essential to invest in effective international/global tools for the earthquake risk assessment and management. This requires in-depth knowledge but also a big coordination effort, among the multiple knowledge communities and response mechanisms, at national, international, regional and global level.

Strong earthquake events can trigger other hazards and their consequences invest all aspects of the society, therefore a multi-hazard, cross-sectoral approach cannot be avoided to achieve relevant and long-lasting results in all phases of the management for this type of risk (preparedness, response, recovery, prevention and mitigation).

28 EUSF (earthquake) https://ec.europa.eu/regional_policy/funding/solidarity-fund_en

Solutions/tools

The following list presents a non-exhaustive selection of existing models, services, tools and approaches, available for informing the process of a cross-border earthquake risk assessment and management:

- Global Disaster Alert and Coordination System (GDACS) and DG ECHO related products
- European Macroseismic Scale, EMS-98
- Copernicus Emergency Management Services (CEMS)
- Eurocodes
- Global Earthquake Model Foundation's tools
- 2020 European Seismic Hazard Model (ESHM20)

The above-mentioned tools have European/Global coverage. These solutions are built on a variety of data sources (e.g. satellite imagery, geographical and ancillary data, statistical repositories), to produce analytical products that depict the spatial distribution of the earthquake hazard, vulnerabilities, exposures, risk, as well as capacities in coping with it. Below the description of these tools/methods.

GDACS and DG ECHO related products

GDACS[29] is a collaborative platform used to provide real-time alerts and information about natural disasters around the world. GDACS is managed by the UN Office for the Coordination of Humanitarian Affairs (UN-OCHA) and the EC (DG JRC and DG ECHO). It aims to improve the preparedness, early action, operational coordination and communication for disaster response efforts. The system monitors and analyses data from various sources to provide timely and accurate information on disasters such as earthquakes, tsunamis, tropical cyclones, and floods.

The rapid impact estimations of GDACS are especially relevant for the international humanitarian community, to inform their decision making on if/when/how to mobilise itself in support to the countries requesting for international support. Moreover, the GDACS rapid impact analyses become relevant also in the situation where an earthquake impact on multiple countries: despite each one of them may have better impact estimations for their national territories, not necessarily they have the same for areas outside their borders. Therefore, having a rough knowledge of what might have happened in the neighbouring affected countries, helps to facilitate coordination at cross boarder level.

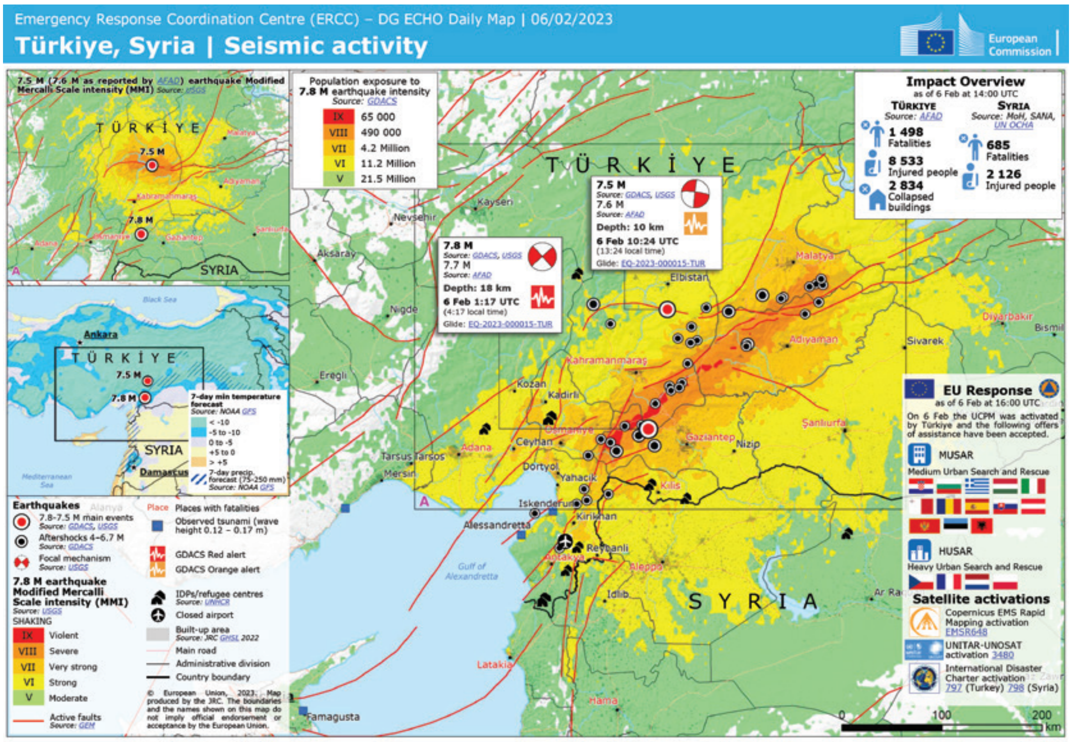
GDACS is the basis for the regular/ad-hoc monitoring products and scientific analyses co-designed by the European Crisis Management Laboratory (ECML)[30] of the JRC and ERCC of DG ECHO for earthquakes events of relevance for the UCPM. In particular, the daily situational awareness reports and maps (ECHO Daily Flash and ECHO Daily Maps **Figure 14**: Situation map on the Türkiye and Syria earthquake started of 6 February 2023 and on-demand products (ECHO Situation Maps/Infographics) depict the spatial distribution of hazards (including earthquakes), vulnerabilities, as well as capacities in coping with them. The mentioned products are publicly available in the ERCC portal[31].

Besides contributing to identifying high-risk areas, helping in prioritize interventions and facilitate the communication with stakeholders, these products represent an important tool used by the ERCC for its daily activity of monitoring global disasters. Beyond its value added as an operational tool, for retrieving rapid impact estimations of earthquakes (with possible triggered tsunami) and volcanic activities everywhere at global level, GDACS is also a source of data and information on these types of events

29 GDACS https://www.gdacs.org/
30 ECML https://joint-research-centre.ec.europa.eu/laboratories-and-facilities/european-crisis-management-laboratory_en
31 ERCC PORTAL https://erccportal.jrc.ec.europa.eu/

occurred in the last 20 years, as it provides access to all such types of event occurred globally since 2004, together with all related impact estimations at the time, as well as information on the operational response activities performed at international level.

Figure 14: Situation map on the Türkiye and Syria earthquake started of 6 February 2023



Source: ERCC portal, DG ECHO map [32]

European Macroseismic scale, EMS-98

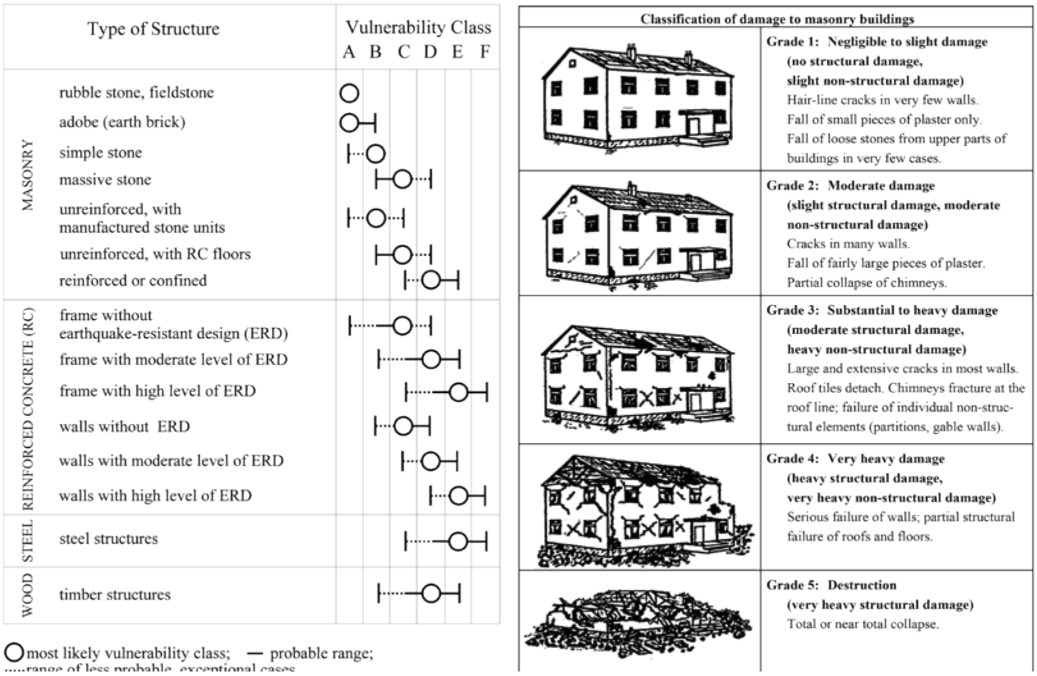
The EMS[33], which is also utilized in several non-European nations, serves for assessing seismic intensity. EMS-98 is the scale that was released in 1998 as an update to the 1992 test version.

The EMS is the first intensity scale intended to promote collaboration between engineers and seismologists rather than being used only by seismologists.

When referring to the EMS-98, the term “macroseismic intensity” refers to a classification of the degree of ground shaking based on site-effects (i.e. recorded in a small region). The EMS-98 intensity scale indicates the degree to which an earthquake impacts a particular location, as opposed to the Richter magnitude scale, which indicates the seismic energy delivered by an earthquake. A comprehensive handbook with instructions, pictures, and application examples is included with it. The EMS defines also the vulnerability classes for different building types and damage grades for building types **Figure 15**.

32 ERCC portal, DG ECHO map https://erccportal.jrc.ec.europa.eu/ECHO-Products/Maps#/maps/4393
33 EMS https://www.gfz-potsdam.de/en/section/seismic-hazard-and-risk-dynamics/data-products-services/ems-98-european-macroseismic-scale

Figure 15: The EMS defines vulnerability classes for different building types (left) as well as damage grades for building types, including masonry buildings (right)



Source: Grünthal G., 1998

Copernicus Emergency Management Services

CEMS[34] provides information for disaster risk management and emergency response in relation to different types of disasters. The service provides all actors involved in the management of risk, natural disasters, man-made emergency situations, and humanitarian crises with timely and accurate geo-spatial information derived from satellite remote sensing and completed by available in situ, aerial or open data sources.

The CEMS consists of two components:

- a mapping component;
- an early warning component

The mapping component has a worldwide coverage and provides the key actors (mainly Civil Protection Authorities and Humanitarian Aid Agencies) with maps based on satellite imagery. The service has been fully operational since 1st April 2012 and it is technically managed by the DG JRC. The CEMS analytical products can support all phases of the emergency management cycle. For earthquake risk management, the CEMS can be activated in two modes:

- **Rapid Mapping,** provides geospatial information within hours or days of a service request in order to support emergency management activities in the immediate aftermath of a disaster
- **Risk & Recovery Mapping** supplies geospatial information in support of Disaster Management activities including prevention, preparedness, risk reduction and recovery phases.

A crucial data source for post-event impact assessment is the recent introduction of the Aerial Component to Improve CEMS Mapping Products. This component improves the quality of the damage detection

34 CEMS https://emergency.copernicus.eu/

on the buildings, hardly visible from satellite, in particular if the roof is slight damaged. The imagery offers a spatial resolution ranging from 5 to 20 centimetres per pixel, allowing for a more detailed analysis of the terrain, infrastructure, and features on the ground. The unmanned component (drones) also produces 3D point clouds and DSM data while the manned component (planes) can produce LiDAR (Light Detection and Ranging) acquisitions up to 8-10 points per square meter. This new transversal component complements satellite data, improving the overall accuracy of Rapid Mapping and Risk and Recovery Mapping products.

The recently added **CEMS exposure mapping component** provides highly accurate and continuously updated information on the presence of human settlements and population with the Global Human Settlement Layer (GHSL)[35] at global level, i.e. another fundamental element for earthquake impact estimations:

- Population grids are effective datasets to assess the amount of resident population at fine spatial resolution. Population counts per grid cell quantify the amount of people exposed to hazards.
- Built-up surface grids are essential information to map human settlements and their characteristics (like land use and density). The amount of built-up surface per grid cell is useful to estimate settlement typologies and is used as covariate for population disaggregation.

Eurocodes

Implementing design and construction rules with provisions for earthquake safety is the most efficient way to reduce the risk of earthquakes. A resource on seismic building codes is the US Federal Emergency Management Agency's (FEMA, 2020) website.[36]

The Eurocodes[37] standard set serves as the European benchmark. The EN Eurocodes are a series of 10 European Standards, EN 1990 - EN 1999, to provide a common approach for the structural design of buildings including geotechnical and seismic related aspects. For the design of special construction works (e.g. nuclear installations, dams, etc.) other provisions than those in the EN Eurocodes might be necessary.

EN 1998 Eurocode 8 (CEN, 2004) applies to the design and construction of buildings and other civil engineering works in seismic regions. Its purpose is to ensure that in the event of earthquakes human lives are protected, damage is limited, and structures important for civil protection remain operational.

Global Earthquake Model Foundation's tools

Global Earthquake Model (GEM)[38] produced a series of Seismic Hazard and Risk Models and Datasets, freely available for public good, non-commercial use, even though they may have different license restrictions. A selection of them is quickly listed below, as described in the GEM webpage.

The **Global Seismic Hazard Map** consists of openly accessible global datasets and plots for peak ground acceleration with a return period of 475 years on rock. It depicts the geographic distribution of the Peak Ground Acceleration (PGA) with a 10% probability of being exceeded in 50 years, computed for reference rock conditions (shear wave velocity, Vs30, of 760-800 m/s), (Johnson et al. 2023)

The collection of **Country/Territory Seismic Risk Profiles** (Silva et al. 2023) summarizes key metrics of seismic risk, to provide stakeholders in risk management an overview of the risk in a region at a glance.

35 GHSL: https://ghsl.jrc.ec.europa.eu/
36 FEMA https://www.fema.gov/emergency-managers/risk-management/earthquake/seismic-building-codes
37 EUROCODES https://eurocodes.jrc.ec.europa.eu/
38 GEM https://www.globalquakemodel.org/

The risk results are the results of an event-based risk analysis, where 100,000 years of earthquakes are simulated. Three lines of business are considered: residential, commercial, and industrial. Therefore, value or earthquake losses to other building occupancies (e.g., schools, healthcare) and infrastructure are not included.

The **Open Quake Engine** (Silva et al. 2014) is an open-source software for seismic hazard and risk assessment which comprises a set of calculators capable of computing human or economic losses for a collection of assets, caused by a given scenario event, or by considering the probability of all possible events that might happen within a region within a certain time span. Since its initial release in 2013, the OpenQuake engine has become the benchmark software for seismic hazard and risk calculations worldwide.

The **Global Vulnerability Model** (Martins et al. 2023) consists of a set of functions that estimate the consequences of earthquakes of a given intensity to different building typologies. This model includes curves to assess economic losses, divided into structural, non-structural and content losses, as well as estimates of fatalities.

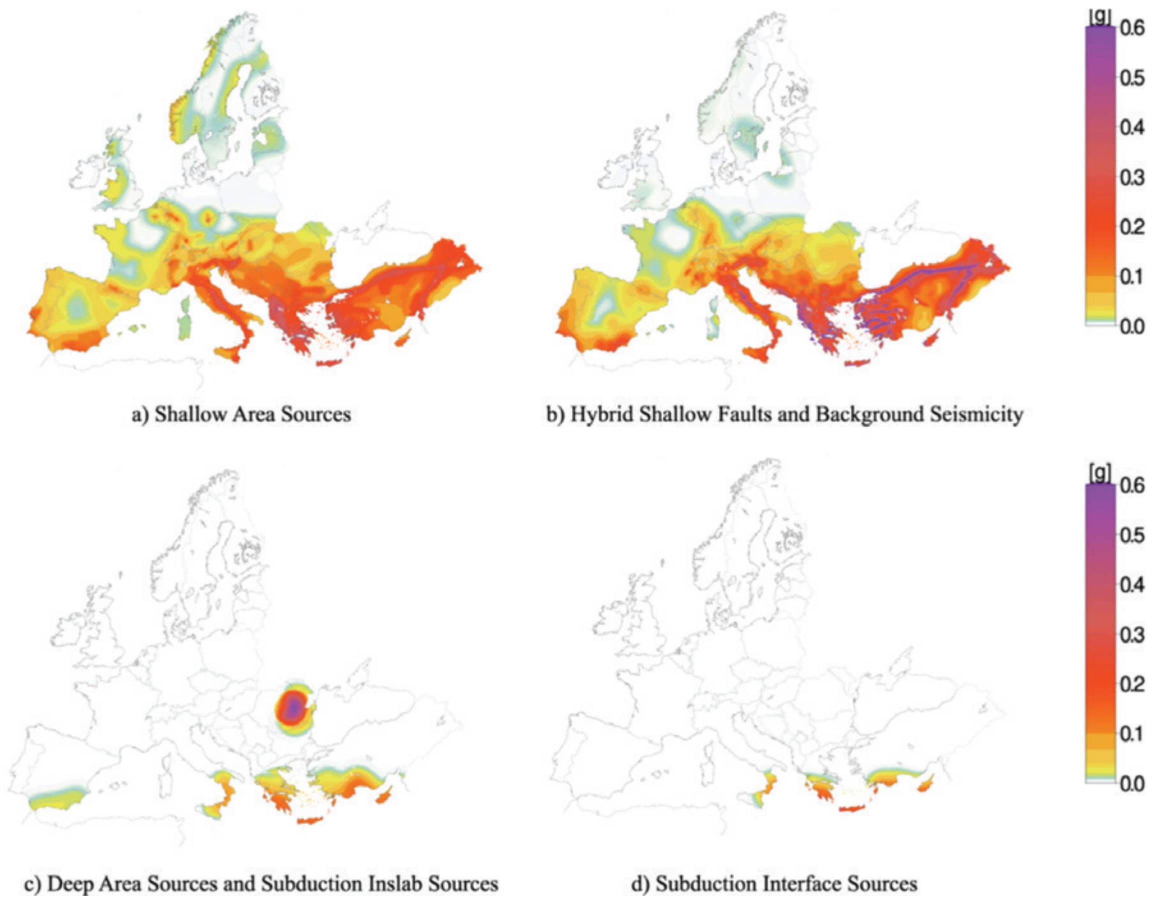
The database is separated by region-country/territory and considers functions for over 3500 building typologies identified in the **Global Exposure Model** (Yepes-Estrada et al. 2023) developed, curated and maintained by the GEM Foundation. The fragility functions are derived analytically, using non-linear time-history analyses on equivalent single-degree-of-freedom oscillators and a large set of ground motion records representing several tectonic environments. The entire database is available for direct download under a CC BY-NC-SA license for risk modellers, analysts and researchers to perform seismic risk assessment on their portfolios.

2020 European Seismic Hazard Model (ESHM20)

The European Seismic Hazard Model (ESHM20)[39] model (Danciu et al. 2024), **Figure 16**, provides the earthquake hazard assessment of the Euro-Mediterranean region and was built upon recently compiled datasets (i.e. earthquake catalogues, active faults, ground shaking recordings), information (tectonic and geological) and models (seismogenic sources, ground shaking). A fully probabilistic framework was adopted in the hazard model implementation and all datasets and inputs are fully cross-border harmonized.

39 ESHM20 https://gitlab.seismo.ethz.ch/efehr/eshm20/-/blob/master/documentation/EFEHR_TR001_ESHM20.pdf

Figure 16: Ground shaking hazard maps for PGA [g] mean (a), median(b), 16% quantiles (c) and 84% quantiles (d)



Source : Danciu et al. 2024

Scenarios

Creating a variety of scenarios to illustrate the effects of disasters is one method to frame risk. Article 10 of Decision No 1313/2013/EU, amended by the Regulation (EU) 2021/836 of the European Parliament and of the Council of 20 May 2021, calls the European Commission and Member States to work together to improve cross-sectoral disaster risk management planning at Union level, both for natural and man-made disasters which cause or are capable of causing multi-country transboundary effects. That planning shall include scenario-building at Union level for disaster prevention, preparedness and response. Some of the key objectives of these scenarios is to identify gaps and needs of the UCPM and to support the quantification of the foreseen Disaster Resilience Goals.

The Commission developed a series of scenarios, involving MS and PS experts, which include –among others- an earthquake-related one. One of the key purposes of the scenario-building initiative is to challenge the UCPM and to identify possible solutions for these challenges. The process is ongoing and the representatives of MS and PS are fully involved in the identification of findings with respect to each of the Union Disaster Resilience Goals (i.e. anticipate, prepare, alert, respond, secure).

Economics for Disaster Prevention and Preparedness

Underwritten by the UCPM Annual Work Programme 2020, the World Bank provided technical assistance for a project coordinated with the European Commission's Directorate-General for European Civil

Protection and Humanitarian Aid Operations (DG ECHO). The study "Economics for Disaster Prevention and Preparedness, Investment in Disaster Risk Management in Europe Makes Economic Sense" aims to give UCPM members and EU Member States/Participating States (MS/PS) a comprehensive analysis and information on the financial benefits of funding disaster and climate preparedness and prevention. The analysis can be used to: (i) show the net benefits of investing in prevention and preparedness for various hazards; (ii) highlight best practices in prevention investing for different MS/PS and UCPM members as well as at a regional scale; and (iii) provide guidance on methodological approaches to estimate the net benefits of interventions, including soft investments.

Risk communication

The Sendai Framework calls for risk reduction strategies to become more people-centred by emphasizing communication and interaction with a variety of stakeholders, particularly the public that is at risk. Implementing dialogic approaches is challenging due to the large number of parties. The public, business, academic, and civil society sectors must all contribute to risk management, resulting in a web of multi-stakeholder interactions that is prone to misunderstandings (Basher, 2006).

The socio-demographics of populations at risk are diverse and dynamic among the general public, especially in cities where social and economic conditions are diversifying and migration is increasing. Conventional risk communication is strained by this.

An example of systematic risk communication campaign in Europe is the "I don't take risks" one, implemented in Italy since 2011. It is a public communication campaign about appropriate civil protection behaviours and practices that leverages the collaboration of science, volunteers, and institutions to provide everyone with easily recognizable messages that inspire action every day of the year. Basic information on the earthquake, volcanic activities and tsunami hazard and suitable self-protection behaviours are provided in clear and concise information materials. Trained civil protection volunteers from the community also systematically distribute and illustrate these materials in public spaces.

Way forward

Besides the need for harmonised, good-quality data on exposure and observed damage, it is important to advance also on the mitigation phase. Indeed, seismic risk mitigation is a sound financial investment that reduces losses, casualties, disruption of services, costs for response operations, and time to recover from a disaster. Ongoing and future plans for energy renovation and adaptation to climate change provide a unique opportunity to create a safe, sustainable and resilient built environment. Lastly, seismic risk analysis should extend beyond residential buildings and cover also industrial and commercial buildings, critical facilities and networks, e.g. the ageing transport infrastructure in Europe. Prioritisation and impact analysis are key to inform bespoke renovation plans.

3 2 5 Chemical industrial risks

The EU is one of the most highly industrialised regions of the world. According to International Monetary Fund statistics published in the World Economic Outlook Database[40] in 2022, the European Union's GDP is around $16.6 trillion (nominal), representing around one sixth of the global economy. Highly industrialised economies, like that of the EU, are by nature intense users of all kinds of chemicals and therefore, have a significant exposure to chemical accident risk. Some of the most versatile substances for industrial use are hazardous substances, such as chlorine, ammonia and hydrogen fluoride. Substances that are considered high hazard are mainly those that are flammable, explosive, toxic to humans, or toxic to the environment, and several substances belong to more than one of those categories. Although, there may be a reduction in carbon-based fuels in future, toxic and flammable petrochemicals such as ethylene, benzene and toluene are likely to continue be essential to the modern economy unless suitable replacements are found.

A small subset of cross-boundary industrial accidents may also be from other sources than chemical hazards, such as storage and warehouses of products that decompose into hazardous substances when exposed to thermal radiation. For purposes of this discussion, cross-boundary industrial risks are considered to be mainly chemical accident risks. Chemical accident risks are considered to represent the vast majority of sources of cross-boundary industrial risk in the EU. In any case, much of the information is equally applicable to other hazard sources.

Notably, most chemical accidents in the EU and the world also occur on fixed sites. Hence, most of our knowledge comes from this domain and the vast majority of legislation and data are associated with fixed hazards, rather than transport, pipelines, and offshore exploration. For this reason, this section is largely centred on what is known about the potential for cross-boundary industrial accidents on hazardous sites. When referring to all potential sources, it will the use term "hazardous activity" rather than "hazardous site" or similar wording. Nonetheless, transport and distribution of dangerous goods as well as pipelines are also potential sources of such incidents. Indeed, there have been cross-border industrial incidents in pipelines, for example, on the border between Turkey and Iran in 2020[41], but thus far none of had far-reaching affects other than shutting down the distribution system temporarily.

The section will first provide a general description of chemical accident risk in the EU, including accident history and what industries are involved. It will then focus on factors that can be used to prioritise certain types of hazardous activities over others in a cross-boundary industrial risk management strategy. This discussion will include examples of past cross-boundary industrial disasters as well as potential factors that may increase the risk in some parts of the EU in future.

Chemical accident risk in the EU

The EU Seveso Directive (2012/18/EU) establishes requirements for controlling major hazards at industrial sites that produce, handle, or store dangerous substances greater than a certain threshold quantity. Sectors associated with chemical, oil and gas sectors, including manufacture (or refining), handling and storage make up around 50% of establishments covered by the Directive. Power plants metal and mining industries, and waste management sectors also are significantly represented among Seveso sites. Not surprisingly, the majority of the EU's major accidents on Seveso sites occur in these sectors.

Numerous other downstream industries, i.e., users of the chemical, petrochemical, fuels, and metal prod-

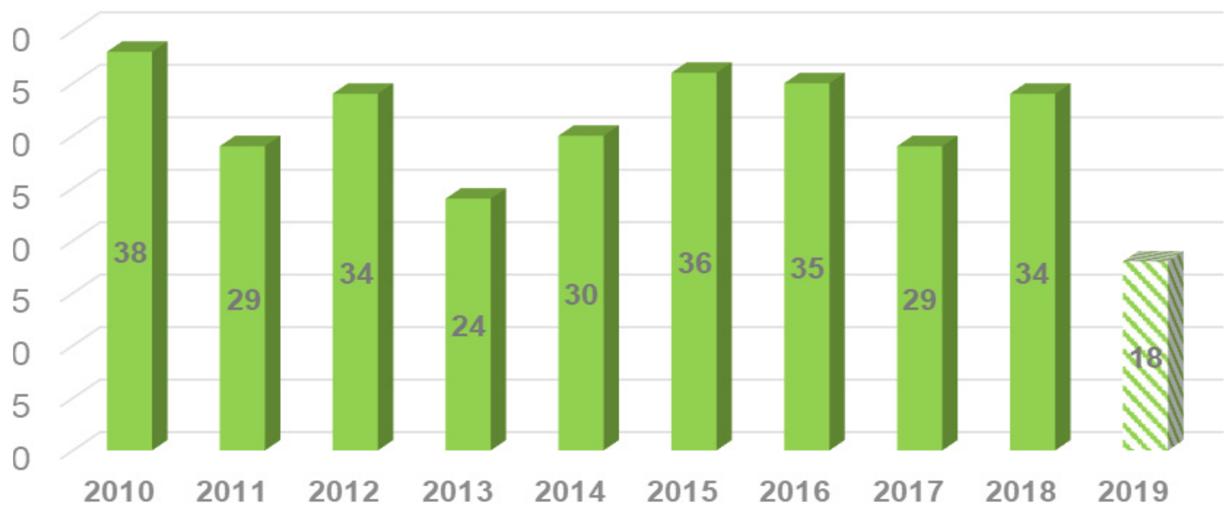
40 WORLD ECONOMIC OUTLOOK DATABASE https://www.imf.org/en/Publications/WEO/weo-database/2022/October/weo-report?a=1&c=998,&s=NGDPD,PPPGDP,PPPPC,&sy=2021&ey=2022&ssm=0&scsm=0&scc=0&ssd=1&ssc=0&sic=0&sort=country&ds=.&br=1

41 https://www.dailysabah.com/turkey/blast-hits-natural-gas-pipeline-on-turkish-iranian-border/news

ucts produced in the top 75%, because they also handle hazardous substances in high volumes. These sites belong to all parts of the industrial and commercial marketplace, including car manufacturing, furniture making, and even large and sports and leisure complexes (mainly due to chemicals used to maintain clean swimming pools), In addition, so-called lower hazard sites (not covered by Seveso because they do not handle dangerous goods in sufficient quantities) still pose also chemical risks.

For more than two decades, the EU has averaged around 30 major chemical accidents per year on Seveso sites (**Figure 17** shows data for the last ten years), according the EU's eMARS database.[42] However, an analysis of JRC's GMI-CHEM data for 2019 indicated that Seveso sites are responsible for about 50% of serious chemical incidents in the EU annually with the remainder occurring mainly on non-Seveso in establishments or in transport. In fact, the number of Industrial and commercial sites that represent a moderate chemical hazard in the EU is far greater than the number of high hazard sites. This situation is well-captured by the number of industrial installations covered by, the EU's Industrial Emissions Directive (IED)[43]. In 2022, around 520,000 industrial installations responsible for emissions of various toxic substances and heavy metals were regulated under IED[44]. Notably, only a small portion of IED installations are also classified as Seveso establishments since the vast majority of Seveso sites qualify for Seveso Directive coverage due to flammable and explosive risks rather than emissions to the environment.

Figure 17: Seveso number of major accidents (y-axis) reported to the EU's eMARS system from 2010 to 2019



Source: EC, JRC, 2022

EU exposure to cross-boundary chemical accident risks

Cross-boundary chemical accident risks became increasingly recognised as an important type of disaster that required attention at international level. Two disasters in particular, the Chernobyl nuclear disaster occurring in Ukraine, Soviet Union, in April 1986, and the Sandoz chemical spill in Schweizerhalle, Switzerland that occurred just over 6 months later. While Chernobyl was a nuclear accident, it brought into focus the inadequacy of domestic law for protecting the global environment.

42 Since 1984, under the Seveso Directive, among other obligations, Member States are required to report major accidents, as defined in Annex VI of the Directive, to the EU's eMARS database, managed by the JRC's Major Accident Hazards Bureau.

43 As covered under the current Directive, 2010/75/EU. This Directive is currently undergoing revision.

44 Although not covered by the EU Seveso Directive, IED installations permit conditions include appropriate measures to prevent leaks, spills, incidents or accidents occurring during the operation. Member States have national progammes that establish controls, including permitting and other measures, for overseeing risk in these installations. Transport of dangerous goods is regulated under the UN dangerous goods transport conventions under associated EU Directives.

Establishment of regional legal framework for cross-boundary industrial accidents

A fire at the Sandoz agrochemical warehouse in the Schweizerhalle industrial complex in Basel-Landschaft, Switzerland, on 1 November 1986. The entire warehouse was destroyed, spilled thousands of tons of chemicals, including highly toxic pesticides and mercury, into the Rhine River, an impact that was greatly exacerbated by the additional release of the firefighting water into the adjacent water body. The high concentration of these pollutants turned the Rhine River red and killed nearly all plant and animal life for nearly 200 kilometres downstream, closing down all downstream drinking water treatment facilities in Switzerland, West Germany, France and the Netherlands. Sandoz is considered to be one of the greatest environmental disasters in Europe of the 20th century.

Together with the UN Water Convention, the United Nations Economic Commission for Europe (UNECE) Convention on Transboundary Effects of Industrial Accidents (TEIA) was signed in Helsinki in 1992. The UNECE TEIA Convention was largely modelled after the Seveso Directive and has been revised accordingly, subsequent to every revision of the Seveso Directive. By late January 2000, 15 countries and the European Union had ratified the Convention. The Seveso Directive has also incorporated UNECE TEIA obligations in its requirements, including notification and coordination with competent authorities of bordering countries where accident scenarios have been identified that might affect them.

On 30 January, 2000, a cyanide spill in the Tisza River originating in a gold mine in Baia Mare, Romania, brought renewed attention to cross-boundary industrial risks. Following unusually high winter temperatures, a high volume of water in the mine tailings dam of the Baia Mara Aural gold mine caused it to burst and release 100,000 cubic meters of waste water, heavily contaminated with cyanide, into the Lapus and Somes tributaries of the river Tisza, one of the biggest in Hungary. The spill caused massive reductions in populations of fish, benthos (bottom fauna) and plankton, particularly in the upper part of the Tisza River in Hungary, where the contamination effects were estimated to be the most severe (World Wildlife Fund, 2002).

Currently, the European Union and 41 European and Asian countries who have ratified the UNECE TEIA Convention and 38 countries (plus the EU) have ratified the UN Water Convention. In 2003 the Protocol on Civil Liability for Damage and Compensation for Damage Caused by Transboundary Effects of Industrial Accidents on Transboundary Waters, was adopted at a conference held in Ukraine. The Protocol is a joint instrument to the Convention on the Transboundary Effects of Industrial Accidents and to the Convention on the Protection and Use of Transboundary Watercourses and International Lakes.

Future outlook: Risk indicators to consider

A number of events and studies in the past two decades confirm that the EU remains at risk from potential cross-boundary events. As noted in the prior section, the industrial economy of the EU remains strong and therefore, vulnerable to chemical accidents including those with potential cross-boundary impacts. Moreover, the EU is also surrounded by neighbours, with industrial economies of varying size and composition, where industrial accidents may also occur and generate impacts beyond their borders. Indeed, there are hundreds, potentially even thousands of accident scenarios that could become the next cross-boundary incident affecting the EU. Most or all of them are likely to be low probability events, yet cross-national strategies are necessary for prevention, preparedness and response, should one of these unlikely suddenly become a reality.

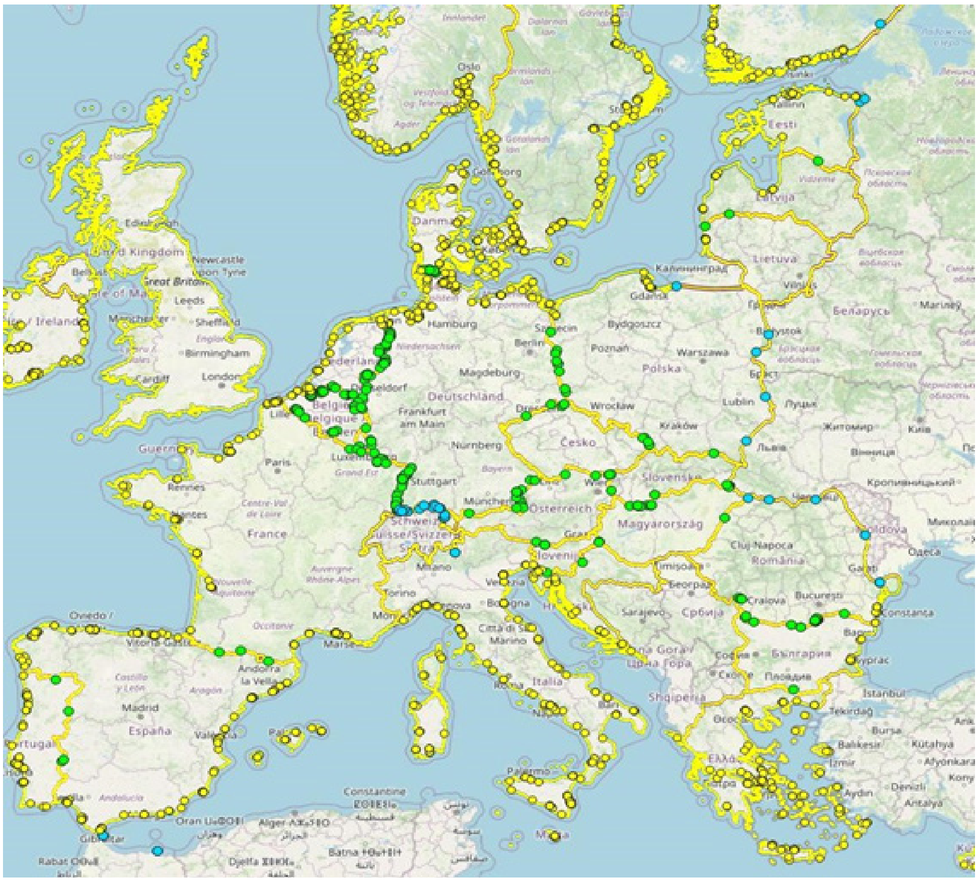
Such a strategy could be focused on priorities shaped by existing knowledge about hazardous sites in the EU and in bordering countries, past cross-boundary events, and other elements of the economic and social context that could have some influence. The following paragraphs discuss data and facts that can be used to shape these priorities. At national level, most EU Member States will likely have already considered these issues in their national strategies, especially driven by requirements of the Seveso Directive and as Parties to the UNECE TEIA Convention.

Location and types of cross-boundary industrial risks in the EU and on its borders

Both the EU and the UNECE have knowledge bases that can contribute to the assessment of cross-boundary risk in the EU region. The eSPIRS database of Seveso establishments, managed by the JRC, allows mapping of all such establishments in the EU. A 2024 analysis of the eSPIRS data, using ArcGis as a tool for further analysis, generated the map shown in **Figure 18** of Seveso plants that might be capable of having an incident with transboundary effects. As the map shows, at the time there were nearly 2,300 Seveso plants within 5 kilometres of another country's border. A similar analysis of IED installations would likely indicate that there are several thousand more sites that plausibly represent industrial accident risks with cross-border implications.

The UNECE also has a number of publications that can assist in assessment of cross-border risk. For example, it has supported and published the results of the project aimed at risk reduction and crisis management in the Delta Danube region, including a map showing where relevant hazards were located in Moldova, Ukraine and Hungary (Savov et al., 2016). In particular, it has given focus to particular types of sites that tend to be at higher risk for cross-border incidents, notably mine tailing dams, oil terminals in port locations, and pipelines.

Figure 18: Detail of Seveso Plants within 5 kilometres of a border (green: internal EU border, blue: external EU border and yellow: sea border).

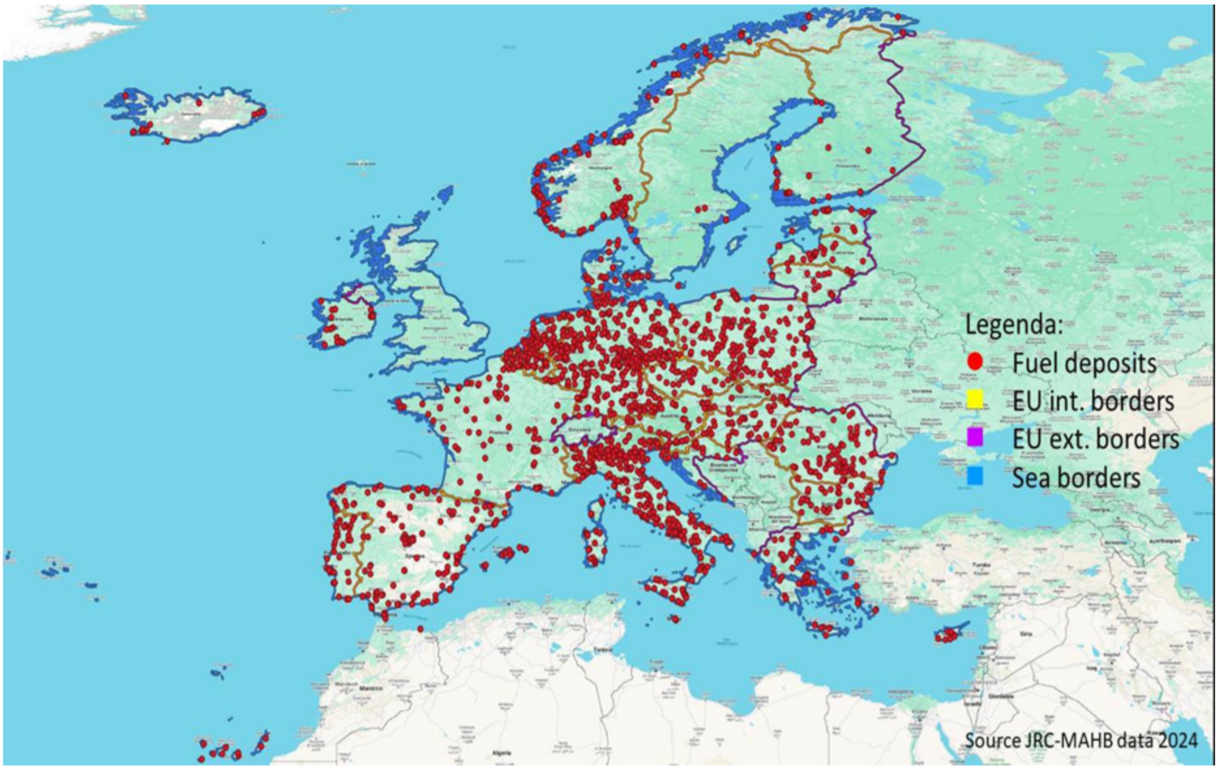


Source: EC, JRC, 2022

This work highlights features of these sites that can make them higher risks for cross-boundary industrial accidents. Mine tailing dams are particularly vulnerable because they are open basins of mining waste, including cyanide and other extraction chemicals, located in the upstream portion of important watersheds. They are vulnerable to flooding and consequent overflow into the water body, particularly in cases of extreme weather conditions, such as heavy rains or sudden thaws, or poorly maintained, ageing facilities (UNECE, 2014).[45] As recently, as July 2021, a rupture of a tailings dam at a diamond mine in Angola caused the death of twelve people over the border in Angola, and injured 4,400 others. The contaminated waters travelled for over 1,400 kilometres from the mine to finally dissipate into the high-discharge Congo River twenty days later.

Oil terminals in river and sea port locations store large amounts of oil and petroleum products, and at higher risk for spills and tank overflows due to frequent activity surrounding the loading of these substances for transport and distribution (via water, road, rail, or pipeline) (UNECE, 2015a).[46] **Figure 19** shows a map of Seveso fuel storage sites in the EU from the analysis of the eSPIRS database in 2024. Pipelines throughout the UNECE region transport large volumes of hazardous substances, crossing borders, and can be a source of a cross-border industrial accident if not properly constructed, monitored, operated and maintained (UNECE 2015b).[47]

Figure 19: Seveso fuel storage sites in the EU



Source: EC, JRC, JRC-MAHB data, 2024

Past cross-boundary accidents

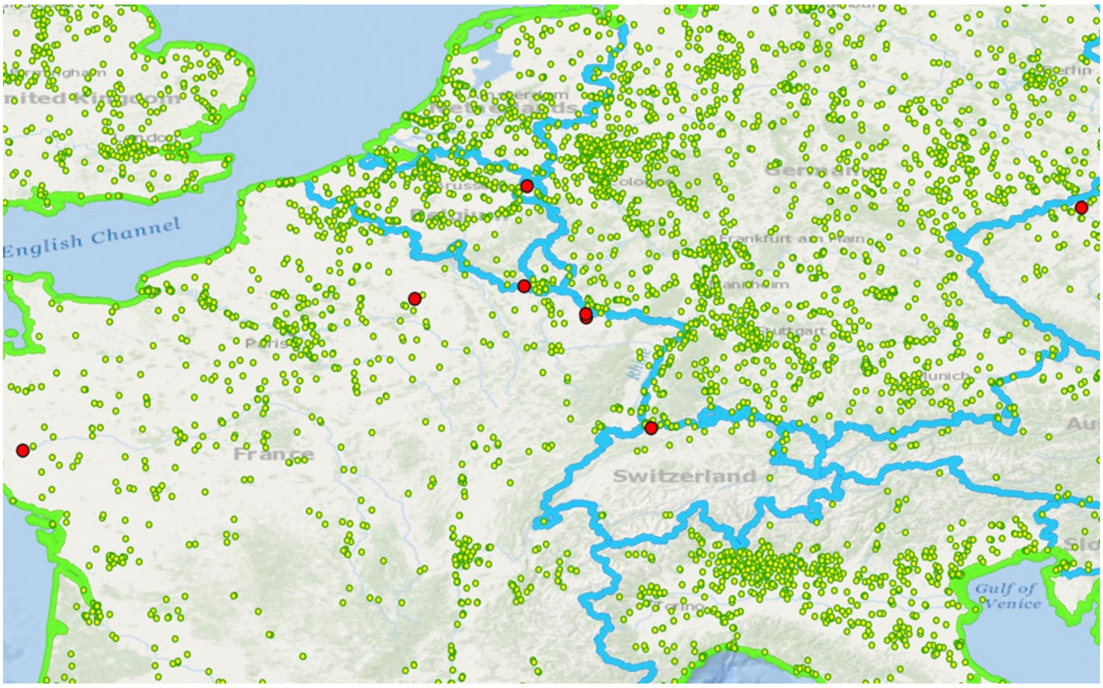
There have been relatively few cross-border industrial accidents in the last four decades. The map in **Figure 20** indicates only 8 incidents in the eMARS database, six of them on Seveso sites, and the other two represent the Schweizerhalle and Baia Mare disasters (that were both outside the EU at the time). In 2019, another cross-border industrial accident was reported in relation to the conflagration a chemical production and storage complex in Rouen, France, involving a Seveso establishment. Notably, none of the Seveso incidents reported to the eMARS database thus far have had serious cross-boundary impacts.

45 UNECE 2014, https://unece.org/environment-policy/publications/safety-guidelines-and-good-practices-tailings-management-facilities
46 UNECE 2015, https://unece.org/info/Environment-Policy/Industrial-accidents/pub/21638
47 UNECE 2015, https://unece.org/info/Environment-Policy/Industrial-accidents/pub/21639

However, there have been two significant incidents that had cross-boundary implications since 2000. In October 2010, a reservoir containing waste product at the aluminium plant Ajkai Timfoldgyar Zrt in western Hungary ruptured sending 700,000 cubic meters of toxic red sludge onto the villages of Kolontár, Devecser and Somlóvásárhely. At the time of the incident, there was a credible fear that the chemicals from the red sludge would seep into streams and tributaries of the Danube, sending the sludge downstream into Croatia, Serbia, Romania, Bulgaria, Ukraine and Moldova, and eventually, the Black Sea. Fortunately, even though high sludge concentrations did reach the Danube River, harmful concentrations were no longer detected by the time the contaminated waters reached Budapest and thus, there was no longer a threat to downstream countries.

During August 2022 massive fish kills were noted on the Oder river and eventually resulted in the death of approximately 360 tonnes of fish and had an ecological impact along 500 km of the river. This is now considered one of the largest ecological disasters in recent European river history. It is almost certain that their deaths were caused by a substantial toxic algal bloom that happened at this time. The causal species was identified as Prymnesium parvum, a species adapted to brackish salinities. A key factor that enabled the proliferation of this species was the high salinity of the Oder river during this time, probably due, at least partly to discharges of industrial wastewater (some of them possibly IED installations) with a high salt content e.g. from mining activities. While there was no one cause of this disaster, the report recommended several improvements that could prevent such an incident in future, including a complete investigation of discharges in the catchment in order to explain the increase in salt load that played a key role in bloom development (Free et al., 2023).

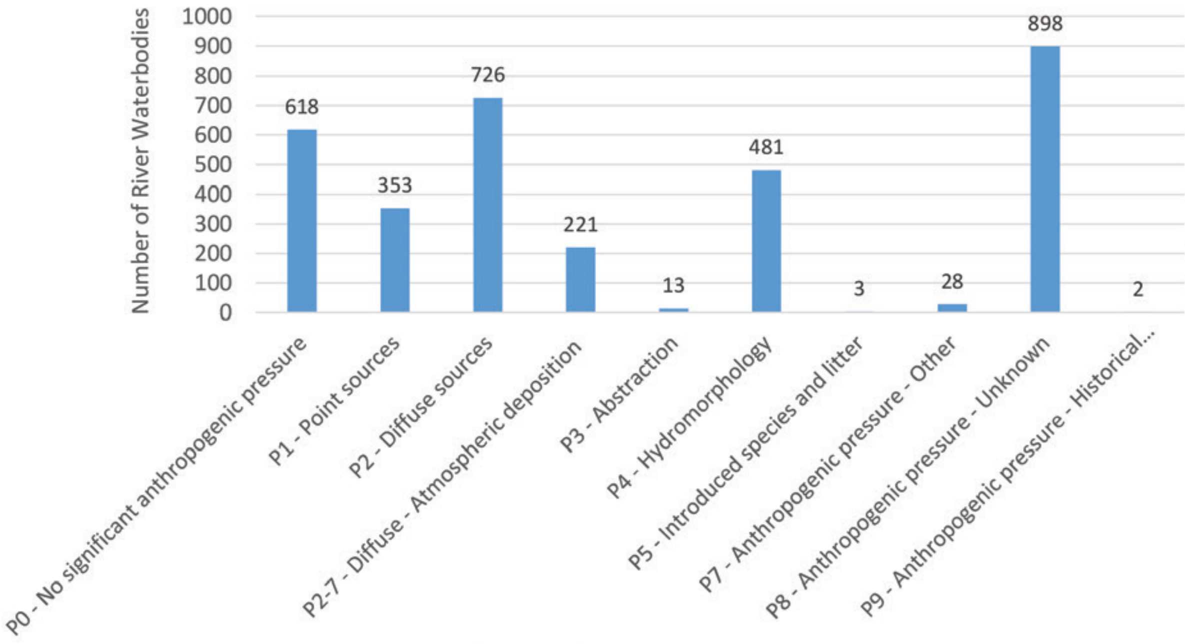
Figure 20: Major accidents reported to eMARS with cross-boundary impacts



Source: EC, JRC, 2013

Figure 21 represents the Polish and German inputs on environmental pressures in the Oder River Basin District provided to the EEA in the 2nd river basin management plan, made available through the EEA dashboards (Free et al., 2023).

Figure 21: Environmental pressures on the Oder River basin



Source: EEA, 2023

Knowledge about factors and conditions that can increase the risk of a cross-boundary industrial accident

Knowledge of chemical accidents also helps to provide a basis for considering what factors are most likely to drive towards the occurrence of a serious cross-border industrial accident. In the first incidence, the level of hazard associated with an activity and its location are primary considerations in assessing the risk that a cross-boundary incident could occur. In particular, all past cross-border industrial disasters of the last 50 years have originated from large amounts of hazardous chemicals released into the nearby waterbody. Moreover, even without these examples, science already has confirmed that water can be a very efficient delivery mechanism of pollution concentrations. In addition, it is very common for production facilities to be situated in the proximity of a large water body due to the easy availability of water for processing and waste management and/or as a cheap mode of receiving supplies or shipping finished products. There are often industrial sites along water bodies that have many hazardous sites increasing the risk of a domino effect where not just one hazardous activity, but several, release pollutants into the nearby water body. Furthermore, more upstream locations have more possibility of generating incidents with downstream impacts.

Location can be a less important factor considering cross-boundary impacts of airborne releases. The potential for such incidents to travel across borders is dependent on a number of factors that are almost as important as location, including the type and volume of substance(s) released, terrain and weather conditions. While these incidents are possible, and are considered as an important subset of cross-boundary accident scenarios, there are likely to be far fewer activities with accident scenarios of this nature compared to those that are associated with cross-boundary impacts from water-borne releases. There have been virtually no incidents in the last several decades, other than Chernobyl, which was a nuclear accident, that have caused significant and widespread transboundary effects via an airborne release which affected multiple countries. In any case, the Seveso Directive requires sites to assess their risks and identify typical potential accident scenarios. In this way, risk of cross-boundary impacts due to airborne releases from major hazard sites located internally in a country can usually be identified, thereby helping in preparing a coordinated and effective response help to minimize the potential impact of such events should they occur.

After taking account of location, the level of risk of a cross-border incident is also affected by existing safety conditions and risk management measures associated with the activity. A lack of awareness of the risks, inadequate control measures, poor maintenance, ageing infrastructure, lack of preparedness, as well as any number of other recognised chemical safety vulnerabilities can add significantly to the risk of a serious accident originating in an activity already in a vulnerable location relative to cross-boundary industrial risk. For example, the combination of concerns about the upstream location and aging conditions of mine tailing dams in the UNECE region led UNECE to spearhead a project to generate awareness of the potential risks and publish good practice recommendations for reducing the potential that a serious transboundary accident would be triggered on one of these sites.

Local conditions, particularly extreme climate conditions, social unrest, war and terrorism, also can significantly raise the possibility that a cross-boundary industrial incident will occur in particular locations. The war launched by Russia against Ukraine in 2022 is a tragic example of how quickly risk of a cross-boundary incident can be elevated. From the beginning of the assault in February until the end of May 2022, the JRC"s GMI-CHEM recorded 31 industrial incidents from military attacks reported in the media. Of these, 10 originated on sites in the chemical industries, many of them that potentially stored ammonia, a toxic substance that under certain conditions can travel in relatively strong concentrations for an estimated 5-10 kilometres. Most of these sites were on the eastern side of Ukraine distant from EU borders. However, one attack in Odessa nearly missed a large chemical plan in the port of Odessa and the consequences of such an incident could possibly have been devastating for the Baltic Sea. The destruction in June 2023 of a critical infrastructure such as the Kakhovka dam is the latest stark reminder of how disaster can spiral out of control into a crisis with long-term effects. It also highlighted the importance of disaster preparedness and recovery and critical infrastructure resilience maintenance.

Moreover, in October 2022, UN Environment Programme (UNEP) published an in-depth report on potential environmental and health impacts of the war in Ukraine (UNEP, 2022).[48] In **Table 2**, UNEP has catalogued the incidents caused by military operations and formally registered by the Ukraine State Environmental Inspectorate. Fortunately, all of the releases were naturally diluted or contained by the emergency services, preventing serious health impacts in the surrounding community. In addition to releases from chemical installations, the report lists several other pollution sources including overwhelmed waste management systems, military vehicle use and waste, and munition debris. The report also emphasises that in addition to direct hits on industrial operations, military actors often clear vegetation or otherwise disrupt ecosystems, to remove cover for enemy combatants, or make areas uninhabitable and force local populations to leave. These methods, along with the collapse of governing institutions, can have major impacts on the land, water as well as the flora and fauna, such that there are fewer barriers preventing the transmission of contaminated air and water across borders. Up until now, the impacts on bordering countries have not been sufficient to raise any alarms but the risk of cross-border pollution from the Ukraine conflict remains.

48 UNEP 2022 https://wedocs.unep.org/bitstream/handle/20.500.11822/40746/environmental_impact_Ukraine_conflict.pdf?sequence=3&isAllowed=y UN Environment Programme (UNEP), 2022, The Environmental Impact of the Conflict in Ukraine: A Preliminary Review

Table 2 Registered incidents of release of Toxic Industrial Chemicals according to the operational headquarters of the State Environmental Inspectorate of Ukraine.

Industrial Site	Location	Date	Description of the Incident
Coke Plant	Avdiivka	March 13, 2022	Large fire caused by shelling.
Sumy Khimprom	Sumy	March 21, 2022	Release of ammonia; the gas cloud covered and area of 2.5 km^2.
SOE Khimprom	Chernihiv	March 23, 2022	Depressurising of a tank with liquid ammonia (12 tons), followed by a fire in the working premises.
Scientific-Industrial Enterprise Zorya	Rubezhne, Luhansk oblast	April 5, 2022	Release of 80 tons of nitric acid caused by the hit of storing tank. The radius of the affected area reached 3.5 km.
Severodonetsk Azot	Severodonetsk	May 5, 2022	Heavy shelling in one of the largest ammonia producers in Ukraine.
Azovstal	Mariupol	May 29, 2022	Release of liquid ammonia due to the damage of pumping station. The radius of the affected area reached 2.5 km.
Ammonium pipeline Tolyatti - Odessa	Nearby town of Bakhmut in Donetsk oblast	May 30, 2022	Release of technical (low pressure) ammonium from a non-operational by-pass pipe. At least six communities were under threat of chemical pollution.

Source: UNEP, 2022

In summary, as a highly industrialised region, the EU will always have a somewhat elevated exposure to cross-boundary industrial risk compared to less developed regions. The majority of risk sources are within the EU itself, represented by major hazard (Seveso) sites as well as moderate hazard sites and other hazardous activities associated with the transport and distribution of hazardous goods. The Seveso Directive and the UNECE TEIA Convention are both mechanisms that have raised awareness of these risks as well as stimulated Member States to be proactive in directing prevention and preparedness strategies to contain them.

The EU is also vulnerable to potential chemical incidents originating in neighbouring countries. Ukraine in particular at this moment has potential for chemical releases that spill over onto EU territory. With its healthy industrial economy, Ukraine is also exposed to industrial risk and even before the war, the EU strongly supported its efforts to strengthen chemical incident risk management. Notably, the DG ECHO and DG JRC have provided substantial assistance to Ukraine in building capacity for the implementing the Seveso Directive within the framework of the DG ECHO and DG JRC project on Seveso Capacity Building in Neighbourhood Countries (2014-2020) and the DG JRC Enlargement and Integration Action (2021-2022).

In the future, it is likely that cross-border industrial risk, as it affects EU Member States, will remain at current levels or increase, but it is unlikely to decrease. The EU should continue to monitor existing sources and be vigilant about technological and social change that could change the nature or level of this risk. With UNECE, the EU Member States regularly participate in emergency response exercises to prepare and test their coordinated responses to potential cross-boundary industrial incidents. Additionally, capacity building efforts conducted by UNECE as well as the DG JRC and DG INTPA in the frame of the Chemical, Biological, Radiological and Nuclear (CBRN) Centres of Excellence project can contribute immensely to preventing transboundary risks emanating from neighbouring countries.

3 2 6 Nuclear and radiological accidents

Introduction

A nuclear accident can be defined as any event challenging nuclear safety provisions.

Following a nuclear accident, radioactive materials can be released into the atmosphere and can settle and contaminate people, buildings, food, water, and livestock. The main exposure pathways are inhalation and exposure to the traveling plume and deposited material, which poses a significant health risk that should be anticipated in order to provide with adequate protective measures to decrease the risk of occurrence and mitigate the consequences through appropriate countermeasures.

In order to protect the public, the workers and the environment, nuclear emergency preparedness and response studies are carried out to determine appropriate measures (preparedness phase) and implementation of suitable actions (response phase) to protect the public from the effects of radiation exposure.

State of art

The state of the art of nuclear and radiological accidents includes the possibility to evaluate the dynamic of the radionuclide emitted (i.e. Source Term), the knowledge of the radionuclides dispersion in space and time (i.e. Atmospheric Dispersion), health radiation effects, operational intervention levels and generic criteria triggering actions in case of emergency. The study of accident and dispersion dynamic are performed with dedicated computational tools whose results are affected by uncertainties regarding the accident evolution, the physical and chemical models, the atmospheric dispersion models and the weather conditions.

In the field of preparedness and response to nuclear emergencies, accident analytical simulations using computational software tools for the prediction of spatial and temporal radionuclide concentrations is key. Within the field of accident simulation and radioactive release calculation of so-called severe accidents (**Figure 22**), i.e. nuclear accidents with partial or total fuel melting, ASTEC (Accident Source Term Evaluation Code)[49], MAAP (Modular Accident Analysis Program)[50] and MELCOR (Methods for Estimation of Leakages and Consequences of Releases) are among the most widespread software tools worldwide.

ASTEC is developed by the French Technical Safety Organization “Institut de Radioprotection et de Sûreté Nucléaire”. It aims to model the entire accident sequence developing in a nuclear power plant, from the initiating event until the release of nuclear material in the environment, including the accident management response. It has been developed initially to represent the pressurized light water reactors and has been enriched gradually to cope with other designs such as boiling water reactors, to some extents pressurized heavy water reactors and experimental facilities, including International Thermonuclear Experimental Reactor fusion facility (Chailan et al. 2019).

MAAP is a computer software owned and licensed by Electric Power Research Institute. It is a fast-running computer code that simulates the response of light water and heavy water moderated nuclear power plants for both current and Advanced Light Water Reactor designs. It can simulate Loss-Of-Coolant Accident (LOCA) and non-LOCA transients for Probabilistic Risk Analysis (PRA) applications as well as severe accident sequences, including actions taken as part of the Severe Accident Management Guidelines (SAMGs). There are several parallel versions of MAAP for Boiling Water Reactors (BWRs), Pressurized Water Reactors (PWRs), Canada deuterium uranium (CANDU) reactors, FUGEN design and pressurized-water Russian Water-Water Energy (VVER) reactors.

49 https://www.maison-joliot-curie.eu/fr/events/15/accident-source-term-evaluation-code-astec-tackling-new-nuclear-safety-challenges-in-europe-through-innovative-collaboration
50 https://www.fauske.com/maap-modular-accident-analysis-program

MELCOR is a fully integrated, engineering-level computer code developed by U.S. Sandia National Laboratories and used by the U.S. Nuclear Regulatory Commission. Its primary purpose is to model the progression of accidents in light water reactor nuclear power plants. The code treats a broad spectrum of severe accident phenomena in both BWRs and PWRs in a unified framework. MELCOR current uses include estimation of source terms and their sensitivities and uncertainties in a variety of applications (Humphries et al 2023).

In the field of support to decision-making on the implementation of protective measures to mitigate public radiation exposure, ARGOS (Accident Reporting and Guidance Operational System), MACCS (MELCOR Accident Consequence Code System) and JRODOS (Java based Real-time On-line DecisiOn Support) are among the most widespread software tools worldwide.

ARGOS is a decision support system for crisis and emergency management for incidents with chemical, biological, radiological and nuclear release. It make the best possible decisions in case of incidents involving atmospheric dispersion of hazardous CBRN-materials on the basis of evaluation coming from long-range atmospheric dispersion, airborne gamma spectrum monitoring data, and calculation regarding dose saved, cost, worker dose and amount of waste produced. It also includes a database containing information for accidents in nuclear ships and submarines and the capability to display trajectories output from both long- and short-range models[51].

MACCS was developed by Sandia National Laboratories for U.S. Nuclear Regulation Commission (NRC) to estimate the offsite consequences of potential severe accidents at nuclear power plants. The code is used to perform probabilistic health and economic consequence assessment of hypothetical releases of radioactive material. Atmospheric dispersion and transport, wet and dry deposition, probabilistic treatment of meteorology, environmental transfer, countermeasure strategies, dosimetry, health effects, and economic impacts are addressed in the code (Leute et al. 2023).

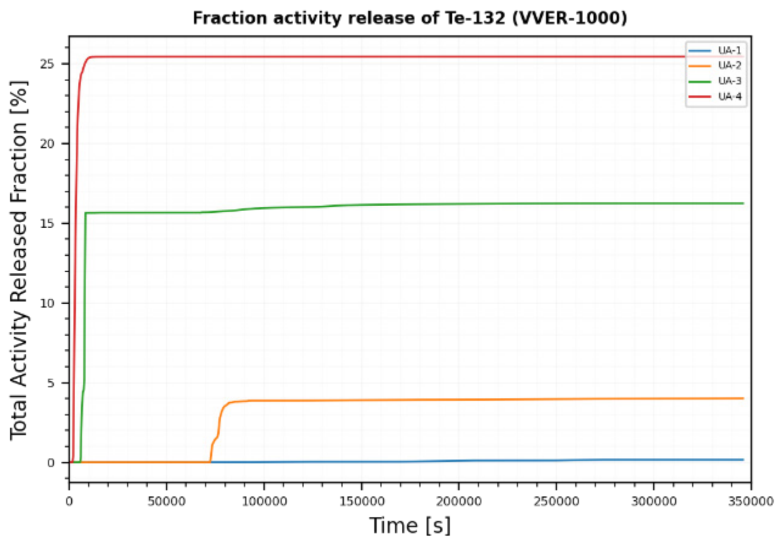
JRODOS (Java based Real-time On-line DecisiOn Support System) was developed and maintained by the Karlsruhe Institute of Technology for operational use in emergency response centres of European countries since about 1990. Its main purpose is to provide all the information required to decide on measures to protect the population quickly, continuously, consistently and comprehensively. The code is able to reach these tasks because contains different models for radionuclides atmospheric dispersion (i.e., Gaussian, Lagrangian, Eulerian) and for prediction and analysing the resulting contamination, health and economic consequences[52,53].

51 ARGOS for Nuclear Incidents https://www.pdc-argos.com/nuclear.html

52 JRODOS - Decision Support Systems https://www.ites.kit.edu/english/294.php

53 JRodos: - report https://resy5.ites.kit.edu/JRODOS/documents/JRodos_Report_forHomepage.pdf

Figure 22: Example of Source Term dynamics - MAAP code (Te-132, VVER-1000)



Source: MAAP

State of play

The state of the play involves the improving of the coordination among EU Member States and the system and procedure in case of major accident.

In the improving coordination field, transboundary and coordinated response among EU Member States against the effects of ionising radiation is fundamental given that the source term can spread beyond several hundred kilometres from the source point.

With this aim, Head of European Radiological Protection competent Authorities (HERCA) was established in 2007 as an initiative of the French Nuclear Safety Authority (ASN) to promote the exchange of knowledge and experiences and facilitate practical and harmonized solutions to important regulatory issues in the field of radiation protection.

HERCA has promoted and followed the implementation of documents[54] into national emergency preparedness and response arrangements. However, results from international exercises continue to show inconsistencies in how neighbouring countries respond.

The Association of Regulators of Western Europe (WENRA)[55], established in 1999, is the association of nuclear regulatory, agencies of nuclear countries in Western Europe (EU MSs plus United Kingdom, Switzerland, Canada, Japan). WENRA aims at improving nuclear safety but it also collaborates with HERCA towards a better cross-border coordination in case of nuclear emergency.

Within this scope, the European Commission DG ENER commissioned a work to carry out the review and analysis of the "Implementation of nuclear and radiological emergency preparedness and response requirements in EU Member States and neighbouring countries[56]. One of the main object of this project is the review and evaluation of the practical implementation of national emergency preparedness and response arrangements including cross-border cooperation and coordination aspects and public confidence.

54 HERCA https://www.herca.org/activity/emergency-preparedness-and-response
55 WENRA https://www.wenra.eu/node/165
56 HERCA-WENRA report https://www.wenra.eu/sites/default/files/news_material/herca-wenra_approach_for_better_cross-border_coordination_of_protective_actions_during_the_early_phase_of_a_nuclear_accident.pdf

The results showed that HERCA-WERNA approach (HWA) for a better cross-border coordination of protective action during the early phase of a nuclear accident has been implemented in full by only one-third of the participant, while 60% have been implemented the HWA only in part.

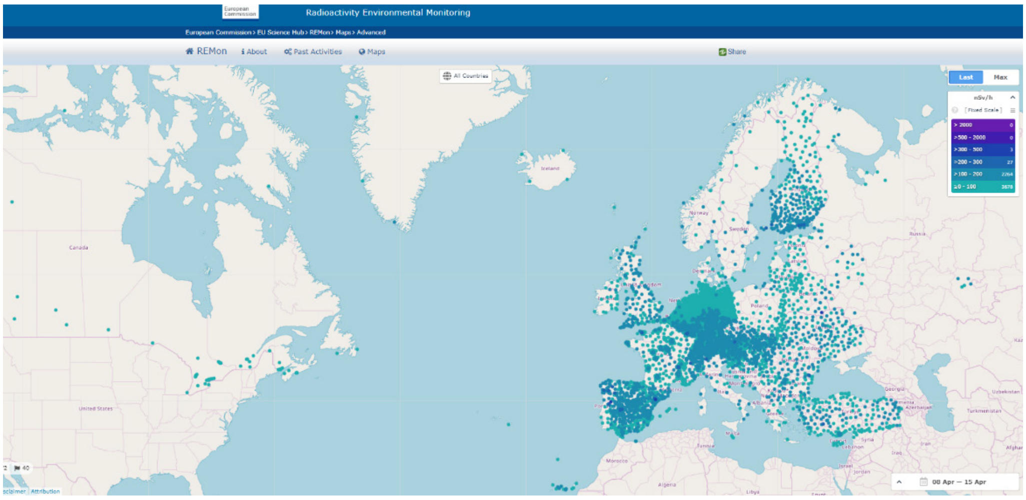
In the field of improving system and procedure, In accordance with Council Decision 87/600, the European Commission continues to improve its systems and procedures for a rapid exchange of information and data in case of a major accident, working 24/7. During the early phase of a large-scale accident with release of radioactivity to the atmosphere, it is mandatory for EU as well as for MSs to notify and inform competent authorities as early and extensively as possible.

JRC Exchange information Tools

To be able to provide rapid exchange information and data in case of a major accident, the JRC has developed the European Community Urgent Radiological Information Exchange (ECURIE)[57] which is the official notification system of the European Commission through which EU member states are obliged to notify and send relevant information in case of radiological/nuclear accident. To facilitate this exchange of information, the JRC conceives and develops the necessary IT tools and provides the testing and training, in close collaboration with the national contact points in the EU.

Complementary to such analytical capabilities, the EURDEP network of radioactive environmental monitoring, mainly gamma dose rates, among EU Member States and other countries (neighbouring countries, Hong Kong, Canada, etc.) (**Figure 23**) would play a significant role in the event of a crisis via the automatic European Radiological Data Exchange Platform[58].

Figure 23: JRC Radioactivity Environmental Monitoring Map (EURDEP)



Source: EURDEP

As a direct implementation of Council Decision 87/600, the JRC (together with DG ENER) has accumulated more than 20 years of expertise in networking the national nuclear emergency authorities by conceiving, developing, testing and operating EC information exchange systems.

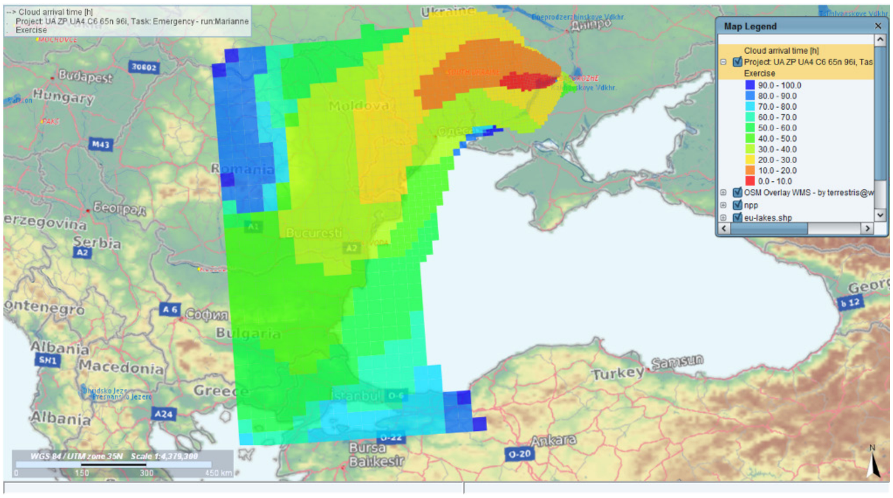
The JRC has accumulated a significant expertise in this filed and provides assistance and technical support to EC' several Directorates, the International Atomic Energy Agency and national competent authorities ensuring that users from EU member states and other European countries have the necessary inter-communication tools and access to information.

57 European Community Urgent Radiological Information Exchange (ECURIE) https://ecurie.jrc.ec.europa.eu/
58 EUropean Radiological Data Exchange Platform (EURDEP) https://remon.jrc.ec.europa.eu/About/Rad-Data-Exchange

JRC tools and methodology

The JRC works on accident modelling and radiological consequences evaluations using dedicated software simulation tools. It also provides and support the exchange of environmental radioactivity data and early sharing of information in case of nuclear or radiological accident among EU Member States. To this end, nuclear accident modelling and emergency preparedness and response capabilities are streamlined via the development and application of the DAPHNE (Diagnosis And Prognosis of Hazards in Nuclear Emergencies) methodology, that allows the identification of accident scenarios, source term characterization, dose projection and radiological risk maps. **Figure 24** shows a typical output such as the estimated cloud arrival time following a hypothetical accident at the Zaporižžja nuclear power plant.

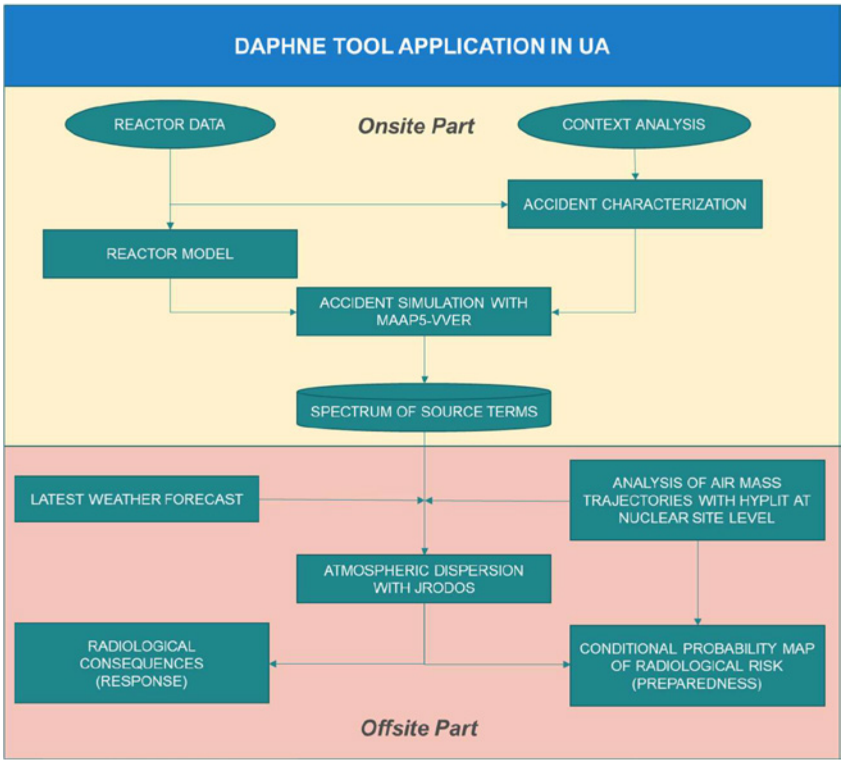
Figure 24: Map representing cloud arrival time (h) – Scenario 4 – Air mass trajectory Cluster 6



Source: DAPHNE

Figure 25 shows a schematic representation of the DAPHNE methodology flowchart aimed at providing a fast and accurate nuclear diagnosis and radiological consequence assessment in case of accident and the technical basis for the justification of adoption of emergency protective measures. The DAPHNE approach involves the evaluation of a source term spectrum and corresponding radiological consequences together with the calculation of radiological risk maps at geographical location.

Figure 25: Structure of the DAPHNE methodology



Source: DAPHNE, 2024

Way forward

JRC is committed to improving its emergency preparedness capabilities by further developing the DAPHNE methodology. To reach this goal, a source term database is planned to be updated and its scope extended to all NPPs models within the EU borders and neighbouring countries; the preparedness phase is also planned to be extended by performing conditional probability maps of radiological risk to the entire EU NPPs site for both safety and security events.

A methodology that provides a reliable awareness alert level due to natural hazard events potentially affecting nuclear facilities supporting GDACS[59] is under development, and it will be the object of a proposal within an exploratory research program.

59 GDACS https://www.gdacs.org/About/overview.aspx

3 2 7 Natech events

Soaring industrialization and human development increasingly put natural and technological hazards on a collision course. When natural hazards, such as earthquakes, floods, storms, etc., impact industrial activities that process, storage or transport hazardous substances, the resulting damage to facilities and equipment can cause releases of toxic chemicals, fires or explosions. The consequences of such natural-hazard triggered accidents can be significant, with potentially long-term social, environmental and economic effects. Also, natural hazards can cause multiple releases of hazardous substances at the same time, destroy safety barriers, and down lifelines needed for accident prevention and mitigation. This type of risk is called Natech risk and it is expected to increase with climate change which is bound to affect the frequency and severity of hydro-meteorological accident triggers (Krausmann et al., 2017).

Analyses of industrial accident databases showed that 2-6% of accident records were caused by natural hazards (Suarez Paba et al., 2020). Considering that there is a reporting bias towards severe accidents, it is very likely that the real number of Natech accidents is higher. Also, a study on pipeline Natech accidents suggests that the consequences of such accidents may be more severe in monetary terms that those of accidents triggered by non-natural causes (Girgin and Krausmann, 2016).

In the past few years a number of major Natech accidents made the headlines, for example the Fukushima nuclear power plant meltdown in the wake of the Great East Japan earthquake and tsunami in 2011, the chemical releases and oil spills due to Hurricane Harvey in the USA in 2017, and the fires at an oil storage terminal in Cuba due to lightning in 2022. But also; Europe suffered its share of Natech accidents, some of which with major consequences. One of these, the Baia Mare tailings dam accident, also highlighted the potential for disastrous cross-border impacts.

Case study – The Baia Mare tailings dam disaster

On 30 January 2000, a tailings pond at a gold-mining operation in Baia Mare, Romania, breached and released about 100,000 m^3 of tailings waste with a 126 mg/l cyanide load, copper and other heavy metals (EC, 2000)[60]. The breach was caused by bad weather, resulting in heavy rain, and unexpected levels of snowmelt which led to an increase in water levels in the pond. Design deficiencies were also indicated as having contributed to the disaster. Emergency preparedness and response plans were inadequate, considering the large amounts of hazardous substances stored in close proximity to the population and to the Somes River. The cyanide spill entered several rivers (including the Tisza and Danube) before reaching the Black Sea, affecting some 2,000 km of the Danube's water catchment area in Romania, Hungary, and former Yugoslavia (UNEP/OCHA, 2000). As a consequence, major fish kills occurred (**Figure 26**), and although there were no immediate health impacts on the population as alternative water sources were provided to villagers near the accident site, chronic health effects from the heavy metal contamination were considered possible (EC, 2000).

Natech risk management in the EU: state of play

Natech risk is a technological risk and as such has a risk owner responsible for managing it. The main legislation for Natech risk governance in the EU is the Seveso III Directive on the control of major accident hazards involving dangerous substances (EU, 2012)[61] which aims to achieve a high level of industrial

60 EC (2000) Communication from the Commission – Safe operation of mining activities: a follow-up to recent mining accidents, COM(2000)664 final, 23 October 2000, Brussels

61 EU (2012) Directive of the European Parliament and of the Council of 4 July 2012 on the control of major-accident hazards involving dangerous substances, amending and subsequently repealing Council Directive 96/82/EC, Official Journal of the European Union L197/1.

safety and includes actions on operators and authorities to ensure effective accident prevention and consequence mitigation. Following the Baia Mare disaster and two other accidents, the Directive was amended to, inter alia, explicitly require that the natural hazards of concern to Seveso sites be identified and considered in the safety document of that site. The Directive also includes a provision for reporting to the European Commission in case of accidents involving cross-border consequences in the EU.

Similarly, the UNECE Convention on the Transboundary Effects of Industrial Accidents (UNECE, 2017) helps Parties to the Convention to prevent industrial accidents that can have transboundary effects and to prepare for, and respond to, accidents if they occur. Recognising natural hazards as an important industrial accident initiator, the Conference of the Parties to the Convention adopted a decision to strengthen Natech risk management in the UNECE region and beyond with measures for Parties to, inter alia, integrate Natech risk in industrial safety, disaster risk reduction and climate adaptation policies (UNECE, 2022a). At the same time, a Roadmap for action to strengthen mine tailings safety within and beyond the UNECE region was endorsed which includes a chapter with specific actions to prevent Natech accidents and adapt to climate change (UNECE, 2022b). All EU Member States are Party to the Convention.

Figure 26: In the Hungarian part of the Tisza River, an estimated 1240 tonnes of fish were killed after the Baia Mare tailings dam breach.

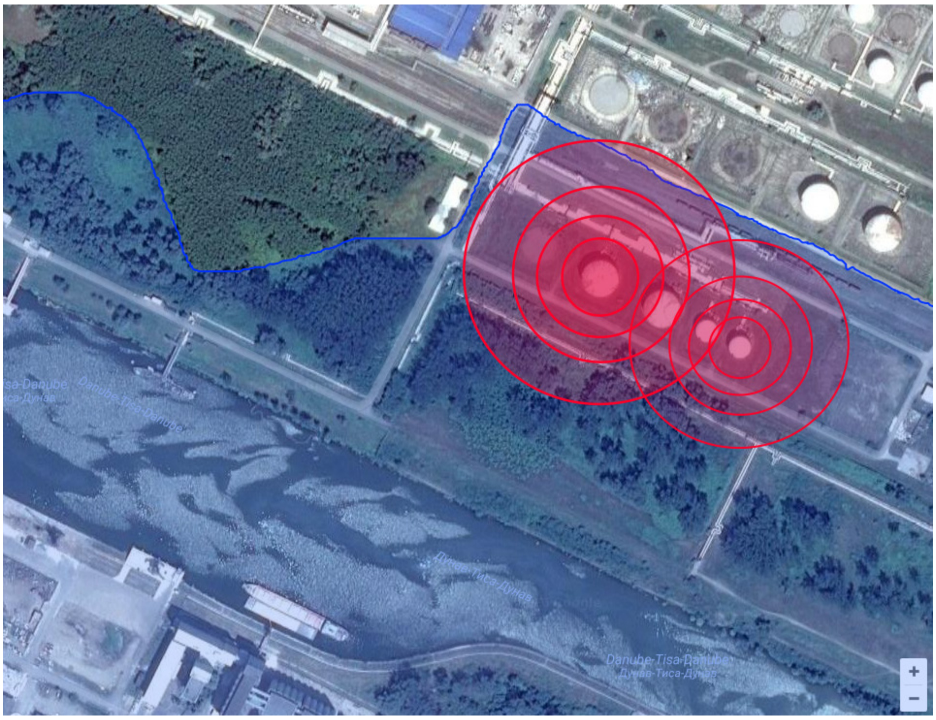
Source: Photo by Délmagyarország/Karnok Csaba, CC BY-SA 3.0

Awareness of Natech risk has been increasing in the EU and globally over the past decade, strongly supported by international organisations that have picked up on the topic (e.g. OECD, 2022; 2023, UNDRR 2019, UNECE, 2022a). Methodologies and tools needed for helping industry operators and authorities to manage Natech risks have been developed more slowly due to the complexity of modelling multi-hazard cascading risks. The JRC has developed the RAPID-N system for rapid Natech risk analysis and mapping which is available free of charge to all. RAPID-N is a web-based decision-support system and unites natural-hazard analysis, industrial damage estimation and chemical-accident consequence analysis in one tool (Girgin and Necci, 2018; Necci and Krausmann, 2022a). **Figure 27** shows an example output of RAPID-N in which a flood impact at a storage tank farm was simulated which resulted in releases and fires.

Similarly, the JRC has developed and maintains the eNATECH database which is a public and free repository of Natech accidents globally. Having recognised the limitations of conventional industrial accident databases in terms of data quality and completeness that render their use for meaningful Natech lesson learning studies difficult, the eNATECH structure reflects the advanced accident representation needed to capture the characteristics of Natech events (Necci and Krausmann, 2022b).

In past surveys, industry and authorities highlighted the lack of guidance for Natech risk management as an important gap that hampers the effective prevention of, preparedness for and response to Natech accidents. The JRC recently released a tool that aims to close this gap by providing step-by-step guidance on how to identify, analyse and treat Natech risks at hazardous industrial sites (Necci and Krausmann, 2022c). The guidance focuses on the development of specific scenarios for Natech risk analysis, a topic that has been indicated as particularly in need of clarification by industry and government stakeholders. Addressing Natech risk management from a technical perspective and being valid for all types of natural hazards, the JRC guidance complements other guidance documents for Natech risk management that either provide a high-level discussion of the topic to raise awareness or are specific to one natural hazard only (e.g., DSB, 2022[62], INERIS, 2014[63], TRAS 310, 2022 and TRAS 320, 2022[64]).

Figure 27: Example output of RAPID-N showing the fire scenario endpoint distances due to a flood-triggered hazardous substance release.



Source EC, JRC, 2018

Future outlook

Although significant progress in Natech risk management has been made globally over the past decade, gaps persist that require continued action from authorities, industry and academia. Challenges pertain mainly to awareness raising, risk governance and communication, and knowledge creation.

For example, industry needs to be aware that their vulnerability to natural hazards can also be linked to the unavailability of safety barriers and utilities, such as power or water, during natural-hazard impact.

62 DSB 2022 https://www.dsb.no/globalassets/dokumenter/veiledere-handboker-og-informasjonsmateriell/veiledere/veileder_om_vurdering_av_naturfarer_som_kan_gi_risiko_for_kjemikalieulykker_natech.pdf

63 INERIS 2014 https://www.ineris.fr/sites/ineris.fr/files/contribution/Documents/dra-14-141515-03596a-1406203884.pdf

64 TRAS 310 (2023) https://www.kas-bmu.de/tras-endgueltige-version.html and TRAS 320 (2022) https://www.kas-bmu.de/tras-endgueltige-version.html

In addition, design-basis assumptions can prove to be insufficient if a natural hazard exceeds the intensity the design basis is built on, e.g. due to climate change. Similarly, stakeholders need to recognise that while natural hazards may be unforeseeable, their impacts on industry are predictable and can be planned for (Krausmann and Necci, 2021).

From a risk governance perspective, the existing legal frameworks in the EU are effective in managing Natech risks at site level. However, industrial installations cannot be viewed in isolation from their surroundings, and Suarez Paba et al. (2020) contend that addressing Natech risks requires a territorial approach to risk governance that incorporates physical (e.g. industrial facilities, lifelines, building stock), organisational and socio-economic factors into the risk analysis. This means that good cooperation between industry and authorities at local, regional and cross-border level – where necessary – is essential, and risk communication among all stakeholders needs to be enhanced.

From the scientific side the improvement of Natech risk analysis methodologies and tools needs to be ramped up, in particular with respect to developing better natural-hazard equipment damage functions, and including economic and environmental impacts in the analysis. This is closely linked with the necessity for better information sharing on industrial risks, accidents and near misses which is currently suffering from a reporting bias towards high-consequence events and possible confidentiality concerns.

3 2 8 Cross-border impacts on networks due to natural hazards

Incidents involving networks delivering essential services to society across two or more countries are witnessed in the everyday life of citizens whenever exceptional conditions disrupt transport, power or telecommunication systems. Yet compiling a list of major transboundary incidents informed by official and reliable sources is not a straightforward task, such as accounting for governance arrangements providing joint assistance to population, businesses, and services across borders in Europe.

The current chapter, regarding cross-border implications of potential failures of networks providing essential services due to natural hazards, is an extract of a study initially carried out in mid-2019 and lately enhanced in a more comprehensive work published by the JRC (Menoni et al., 2023). Essential networks considered here are covered by recent EU level legislative developments discussed in the following paragraph, considering also the possible evolution foreseen in the work of Blagoeva et al. (2020). The pandemic made it clear that the globalization increases our systems vulnerabilities. Challenges have proven to be always more complex than expected, climate change also plays an important role (Tavares Da Costa et al., 2021 and 2023) and cross -border networks need to be more resilient in order to avoid disruptions and reduce losses.

Essential networks and related Policies

Policies at the EU level have witnessed a significant development along the few past years. The recently approved Directive on the Resilience of Critical Entities[65] (CER, (EU) 2022/2557) introduces the concept of critical entities intended as those responsible for essential services which, in case of an accident or a disruption, may significantly hamper the provision of such. Compared the previous Council Directive 2008/114/EC, the CER endorses the shift from protection to resilience, promoting a systemic approach, acknowledging potential cascading failures and domino effects (Pescaroli and Alexander, 2015; Boni et al., 2020; Barquet et al., 2024), across sectors and borders.

The term entity permits a better alignment with the Directive on Measures for a High Common Level of Cybersecurity across the Union, the so called NIS 2 Directive[66] that is addressing entities, public or private, responsible for essential and important services that rely on digitalization. The new NIS2 Directive, repealing the previous Directive (EU) 2016/1148 (NIS), is aimed at protecting data and information systems from risks, thus aiming also at the protection of the assets that make data transfer and management possible. Nonetheless, in this context where the two related directives focus on the protection of data and information as well as the physical assets of those entities, the EU telecom sector is increasingly concerned by natural extremes as reported in the European Union Agency for Cybersecurity ENISA[67] report of 2020. Even though natural extremes cause a smaller percentage of incidents, their impacts result to be significant due to the long duration of disruptions, in fact by analyzing ENISA numbers and figures natural hazards end up being the largest cause of impacts in terms of “total user hours lost”, obtained by multiplying the number of lost user connections by their duration.

In the Decision 1313/2013/EU on the Union Civil Protection Mechanism at article 6 it is stated that MS shall prepare and submit to the European Commission National Risk Assessments identifying, analysing an assessing risks and capacities to prevent and mitigate them. The DG JRC produced two reports providing Recommendations for National Risk Assessment for Disaster Risk Management in the EU, respectively in 2019 (Poljansek et al., 2019) and 2021 (Poljansek et al., 2021) devoting a specific chapter to CI disruptions. Both the 2017 and 2020 Reports highlight the limitations in providing information and assessments on the cross-border dimensions of CI disruptions.

65 Directive on the Resilience of Critical Entities https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32022L2557
66 Directive on Measures for a High Common Level of Cybersecurity across the Union EUR-Lex - 32022L2555 - EN - EUR-Lex (europa.eu)
67 ENISA report 2020 https://www.enisa.europa.eu/publications/telecom-annual-incident-reporting-2020

Finally, in the Communication on the Union Disaster resilience Goals issued on February 2023[68] "the complexity and interdependency of risks the EU faces" is addressed requiring therefore to "identifying vulnerabilities in critical sectors, anticipating hazards and threats and reinforcing collective action to better prevent and prepare for disasters".

Case studies of events with cross-boundary impacts on networks providing essential services

When attempting to list incidents on critical entities with transboundary impacts in the recent report by Menoni et al, 2023, the challenges faced were numerous. First of all, even though it may seem straightforward to define "cross-border impacts", this is not the case due to complexity of nowadays systems and the various types of disruptions, both direct and indirect, physical and functional, i.e. those related to the loss of service, that may occur. The study, which considers both direct and indirect impacts, that intersect borders between one jurisdiction and another, and especially between one country and another (or involving multiple countries at the same time), provides three criteria that are useful to identify potential cross-border impacts, namely hazard based, impact based and related to systemic vulnerabilities. The study produced a comprehensive table (see Annex II) organized as a matrix in which a number of case studies have been gathered together with relevant information such as the triggering hazard, the direct damage, the systemic failures as the damage triggered in other sectors and systems, and the type of intervention and recovery undertaken. An extract of the table is presented here (**Table 3**), with an example related to the impacts on critical infrastructures in Germany, the Netherlands, Belgium and Luxembourg due to the severe floods that occurred in July 2021.

For each case the infrastructures and the Member States involved are reported in the third and fourth column respectively. In the fifth column the initial hazard that may have triggered a sequence of events is identified, and its direct impact shown in the subsequent column. Column 7 is devoted to highlight the systemic damage and consequent unserviceability of one or more essential network, whilst column 8 describes the cross-sectoral impacts on industries, commercial and service providers due to the network disruption. In the last column the sources of data are shown. As can be seen in the comprehensive table in Annex II, most of sources are media or partial reports on the event.

The sources analysed vary from official reports made by public administration to declare the state of emergency or to account for the event and the damage it provoked, to press reports and in some cases research articles. Most information are nation based, in order to account for the transboundary consequences either sources from the two (or more) countries involved had to be consulted challenging the identification of cross-border impacts. In fact, there is no European database comprising information on transboundary events affecting critical entities. National databases reporting occurred damage are very limited or no publicly accessible, as the relevant example of the TNO Database in the Netherlands. As a consequence, the table resulting from the carried research can neither be considered exhaustive nor comprehensive. Nevertheless, it probably contains some of the most severe failures that occurred in recent times as they got enough coverage to be found in one of the open sources mentioned.

Despite the limitations, some interesting observations can be drawn from the mentioned table and from **Figure 28**. The latter shows at a glance some relevant facts provided in the table. Most reported cases relate to the energy and the transport sectors. Case studies seem to be clustered along the borders of Germany and in general in Central Europe, even though caution is needed in drawing conclusions given the pitfalls in the completeness of the provided information.

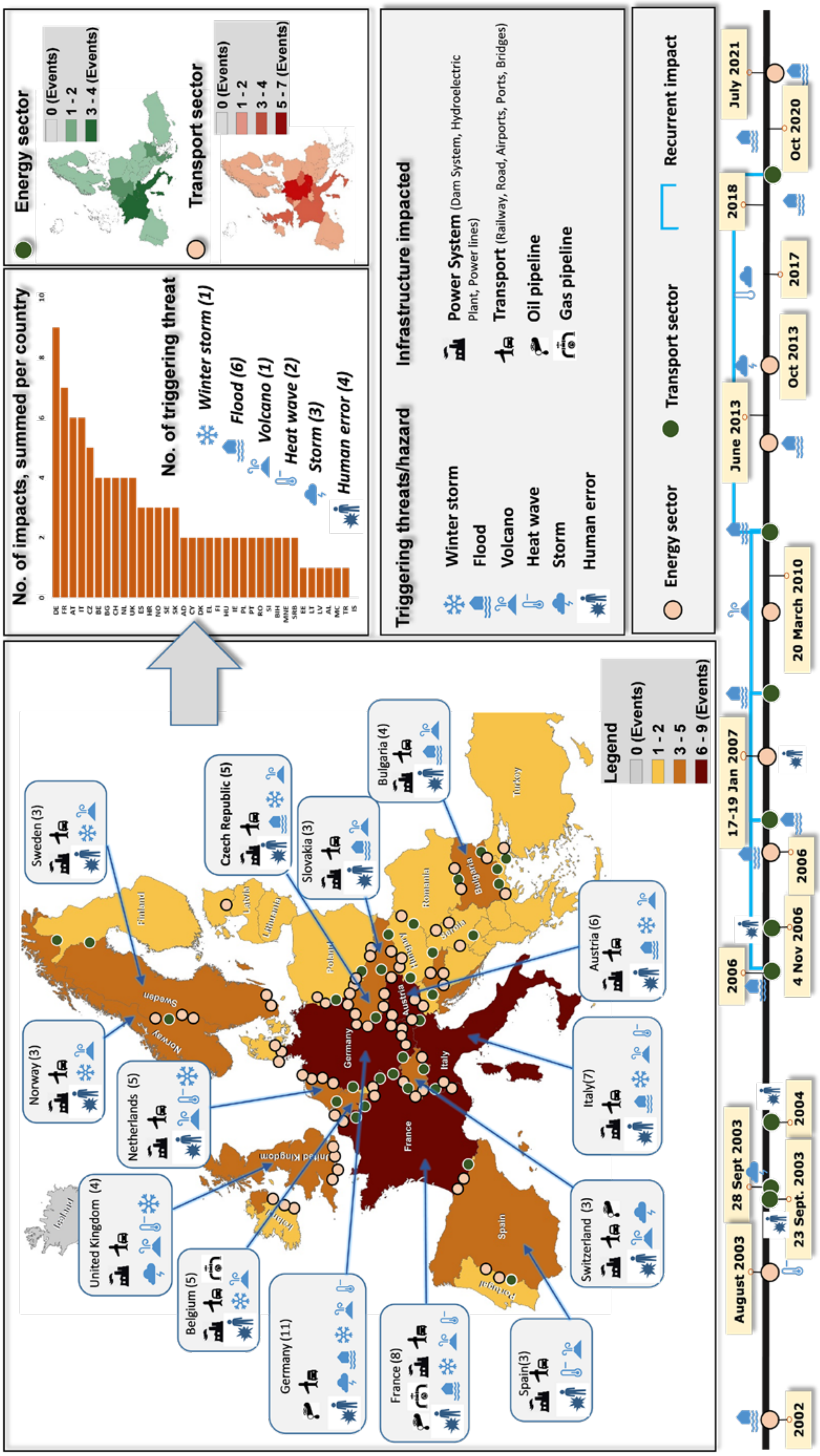
68 Communication on the Union Disaster resilience Goals https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX-:52023DC0061

Table 3: Extract from comprehensive table (Annex II) of an example related to the impacts on critical infrastructures in Germany, the Netherlands, Belgium and Luxembourg due to the severe floods that occurred in July 2021.

N.	Events	Infrastructure(s) involved	Countries involved	Initial triggering hazard/ threat and initial conditions	Direct damage and failure to CI	Systemic damage and failure	Second order damage to another CI (cascading)	Source of the case study and brief description of recovery intervention (when available)
18	July 2021	Transport system, power system, telecommunication and manufacturing	Western Europe (Belgium, Luxembourg, Germany, Netherlands, Austria, Switzerland)	Severe flooding caused by strong storms	At least 183 people have died. Entire villages were severely damaged. Dozens of highways and roads closed due to debris and floodwater.	Widespread disruption to logistics and manufacturing operations. Dozens of areas remained without power, telephone, or cell phone networks.	Manufacturing sector with delivery delays and supply shortages. Several companies in the most severely affected industrial areas have been inundated by floodwater that caused extensive damage to machinery, production facilities, and warehouses.	The EEA Report (2014) outlines a series of recommendations to support companies in identifying of sub-tier suppliers and alternative sources for the most critical components; investing in technological solutions to map out and providing better access to supplier networks.
Case studies – REFERENCES								
Case study 18	Koks E.E., Van Ginkel K.C.H., Van Marle, M.J.E., Lemnitzer A. (2022). Communication: Critical Infrastructure impacts of the 2021 mid-July western European flood event. NHESS, 22: 3831–3838; EEA Report 8 (2014) Adaptation of transport to climate change. Challenges and opportunities https://www.eea.europa.eu/publications/adaptation-of-transport-to-climate							

Source: Menoni et al, 2023

Figure 28: Map locating the various cross-border incidents described in Table 3



Source: Authors' elaboration

Practices for transboundary threats

Considering the complexity of networks and the environment in which they operate, the dynamicity of both threats and systemic vulnerability of those and of sectors that depend on them for their own functioning make essential the necessity to embrace resilience thinking. Because of such complexity and dynamicity not all threats, failures and impacts can be fully envisaged and anticipated. Therefore, avoiding catastrophic modes of failure, maintaining operations, and recovering in the smoothest possible way, which are, among other features, the essence of resilience defined in broader terms in the CER Directive as the capacity to prevent, resist, absorb and recover from disruptive incidents, become key; even more when considering the complexities of cross-border and transboundary infrastructures in terms not only of the assets themselves, but also of the communication capacities and data sharing processes and the governance and coordination between the different appointed organizations for each country. While there is the need to improve information sharing, to learn lessons jointly and to establish protocols for the merge of resources and means for repair, some good practices of cross-border cooperation exist. The USA and Canada collaboration[69] represents an international good example; such as at the EU level the Nordic collaboration model of Sweden, Norway, Denmark, Finland, Iceland regarding the cooperation on civil defence and the management of emergencies[70]. Other examples are represented by the Euregio Meuse-Rhine Incident Control and Crisis Management interservice collaboration and the cross-border collaboration between Italy and Switzerland (for more detail see Menoni et al., 2023).

In addition, there are some initiatives, as the (RDH)[71] of the DRMKC, which could display a significant added value in the matter. The RDH platform hosts disaster loss and risk data to support evidence-based disaster risk management activities in Europe. It enables reporting on, assessing and sharing disaster risk, damage, and loss data at the EU scale for different sectors or assets such as critical services. Within the RDH, critical services include railways, roads, public water supply. The analysis of losses data is performed at different scales and hence can provide insights into local and cross-border information on disruptions to critical entities. Such type of implementation could add value to critical entities research and disaster risk management enhancing sharing and communication among the different MS and the multiple actors involved.

Future pathways

Future directions of work foreseen can be distinguished between technical, methodological advancement and governance frameworks. All important to enhance the understanding and the capacity to intervene on cross-border impacts on networks due to natural hazards. Some challenges have to be acknowledged, some others can be overcome in pursuing such future research and practice pathway.

The chapter of the Recommendations for National Risk Assessments (2019) devoted to CI (Theocharidou et al., 2021) addresses the challenges that are still ahead for governments in not only listing their critical entities but also in developing appropriate forms of data collection and management, and in better assessing vulnerabilities due to increased interconnection and interdependencies. The case studies in Annex II, with an example in **Table 3**, show that often impacts are due to a combination of hazards rather than to individual occurrences. This is because some hazards entail a number of rather different phenomena that may affect exposed elements in many diverse ways. However, as shown by an in depth analysis conducted by Theocharidou and Giannopoulos (2015) of the methodologies, codes and tools developed insofar in EU funded projects, none is fully multi-hazard and multi-sector, as would be needed. Despite advancement in the conceptual understanding of systemic, cascading

69 Canda-US action plan for Critical Infrastructures https://www.cisa.gov/sites/default/files/publications/ip-canada-us-action-plan-2010-508.pdf

70 https://www.msb.se/en/about-msb/international-co-operation/nordic-co-operations/

71 EC, JRC DRMKC RISK DATA HUB https://drmkc.jrc.ec.europa.eu/risk-data-hub/

impacts in multi hazards environments (Barquet et al 2024) there are still gaps to fill in the capacity to assess such impacts across spatial levels and considering the interconnections among sectors. Simulations and modelling has advanced in the field of network and graph modelling (Pasini et al 2021), however not enough consideration has been given insofar to the role of governance aspects in enhancing or reducing the overall performance of assets and infrastructures in a multi hazard environment (Curt 2021). Following the results of the Matrix project funded by the EU, Scolobig et al (2017) address the need to clarify what are the responsibilities of administrations and stakeholders to conduct multi-hazard and multi-risk assessments as well as take action on the basis of the results. The ongoing Myriad[72] project on multi hazard risks is proposing an agenda for future enhanced multi-hazard risk assessment frameworks for a variety of sectors, including for example transportation (Ward et al 2021). Complexity of certain models and challenges in making governments prioritize resilience measures on essential networks and critical infrastructures more in general is a concern that has been raised (Phillips and Petit 2021) and solutions to downscale such complexity using for example index based methods have been proposed. Data availability is an important concern for any method that is adopted (Luiijf and Klaver 2021; Larsson and Große 2023). The lack of comparable data of minimal quality has been experienced collecting the case studies referred to in the study by Menoni et al, 2023 (**Table 3**, **Figure 28**, Annex II).

Multi-hazardous events cause multi-risk conditions as damage due to one hazardous event will sum up and combine potentially with cascading effects to the impact provoked by another event occurrence. However multi-risk conditions are created also by systemic vulnerabilities and by chains of impacts in interconnected systems (Menoni and Boni, 2020), even in case only one extreme natural phenomenon has occurred. In fact, parts of CI are not only exposed and vulnerable but may also turn into hazards themselves. This is often the case with floods, as contamination of water may occur as a consequence of toxic and hazardous materials present in inundated factories. Natech instances on critical infrastructures are illustrated in Krausmann et al (2019). Due to the rising societies' dependencies on complex systems, and due to the emerging challenges posed by climate change, focusing only on the interaction between hazards (multi-hazard approach) might lead to an underestimation of risks. A multi-risk approach, intended as the consideration of risk in a multi-hazard framework together with vulnerabilities interaction and dynamics (Zschau, 2017) would allow to better address current and future risks for safeguarding networks providing essential services.

In parallel, risk governance perspective, need to be enhanced, in this sense the recommendations of the OECD report 2019[73], on enhanced governance of CIs can be re-elaborated through the transboundary lenses. Finding good practices of cross-border cooperation is not an easy task. However, in order to be able to use them as a reference for MS, they should be more investigated and better reported. Projects should be developed to search intentionally for different forms of cooperation cross-border focusing on CI through for example Interreg projects, large scale surveys among organisations in charge of CIs and civil protection, safety organisations. The fragmentation and large number of actors delivering essential services represents an additional challenge. Once the provision of the latter in Europe was a fully public concern, but following the liberalization of the energy and communication markets in the Eighties and Nineties of the 20th Century the regime of management has been growing in complexity. Many CI have become private or semi-private and the management of the physical assets has been detached from the management of the service itself thus creating more layers that are concerned whenever a failure occurs.

However, future needs to enhance resilience of critical entities following the CER directive have beenrecently discussed during the CERIS workshop on Infrastructure Resilience[74] (November, 2023)

72 MYRIAD https://www.myriadproject.eu/

73 OECD https://www.oecd.org/gov/good-governance-for-critical-infrastructure-resilience-02f0e5a0-en.htm

74 CERI (Infrastructure Resilience) https://home-affairs.ec.europa.eu/news/ceris-workshop-infrastructure-resilience-addressing-cer-requirements-through-research-2023-12-12_en

highlighting the importance of implementing resilience and its assessment, the necessity create a more effective collaboration and the importance of shifting from critical infrastructure protection to critical entities resilience.

In this work cross-border has been intended as implying inherently a spatial aspect intertwined with the administrative, cultural, organisational factors that must be taken into consideration whenever two (or more) countries are involved. Not only direct damage to networks has been considered, but also functional, due to the systemic interconnections. Therefore, cross-sectoral, cascading, and escalating failures have been considered as they often characterize the second and higher order impacts that can be suffered cross-border and may actually make governance arrangements more difficult to establish. The main objective of the study from which this contribution has been retrieved was to analyse what is available on this specific topic from case studies to methods for assessing risks and resilience that can be applied and adapted to a transboundary context. The study highlighted that there are challenges to not only deal with cross-border impact, but even to enumerate case studies and provide satisfactory descriptions on what has actually occurred. As for technical and methodological aspects, a significant challenge for assessing risks and resilience stems from the fact that networks have become so complex and, data and information are generally not shared being sensitive evidence (as also demonstrated from the effort conducted to carry compile the comprehensive Table 7 Annex II), that mainly only managers inside each organization actually hold, even if with some limitations, the knowledge necessary to run them properly and foresee potential problems being internally involved in the various procedures and operations. Cross-border and cross-sector cooperation would firstly require, among other subsequent measures, to those managers to meet and cooperate in ad hoc arrangements. The Commission proposed a Council Recommendation for a Critical Infrastructure Blueprint (COM(2023) 526 final) that will enhance the EU's coordination to respond to disruptions of critical infrastructures with significant cross-border relevance by achieving improved shared situational awareness, coordinated public communication and effective response by strengthening the cooperation between Member States and with relevant institutions, bodies, offices, agencies. However, from the point of view of methods and models, more research and practice should be devoted to further develop methods and models to assess and manage transboundary risk and resilience of networks providing essential services. .

3 2 9 Health risks

Regulation (EU) 2022/2371[75] defines serious cross-border threats to health as life-threatening or otherwise serious hazards to health that spread or have a significant risk of spreading across Member States and may therefore require coordination among national health authorities in terms of response activities. The European Health Emergency Preparedness and Response Authority (HERA) has identified the top three cross-border threats to health with the potential highest impact for which medical countermeasures should be made available and accessible. These are pathogens with high pandemic potential, Chemical, Biological, Radiological, Nuclear and Explosives threats and antimicrobial resistance (AMR).

COVID-19 has shown how devastating global health threats can be and how strongly lack of preparedness can hit our social and economic systems. The threat of future pandemics is increasing with the world facing more frequent and more lethal infectious diseases outbreaks, exacerbated by environmental destabilising phenomena and anthropogenic actions, which catalyses the emergence of zoonotic diseases, multidrug resistant microorganisms and new human, animal and plant pathogens. Climate change, deforestation, biodiversity loss, habitat encroachment, intensive food and medicines' production, overpopulation, migration flows, international armed conflicts or increased global mobility, trade and travel are factors aggravating the health stressor landscape that is already in constant evolution and difficult to anticipate.

Even though the occurrence of pandemics is somehow beyond human control, cooperative human action, with its challenges and opportunities, can significantly limit their impact, as we could experience in recent infectious disease outbreaks (COVID-19, Ebola, Zika). Biomedical science and technological solutions were key in responding to the COVID-19 pandemic. Vaccines, diagnostics tests and medicines were developed and deployed at an unprecedented speed thanks to worldwide collaboration. New geopolitical realities require readiness of resilient health systems, reliable surveillance data and market availability and societal uptake of effective countermeasures. Early warning systems, rapid deployment of countermeasures and swift political action are necessary elements for containing future pandemics. They rely on broad accessibility and uptake of technological innovations, for which trustworthy communication to the population is essential, for instance for limiting vaccine hesitancy or promoting public compliance with social measures.

Pathogens with high pandemic potential

Pathogens with high pandemic potential are those able to cause high morbidity and mortality. They include mainly respiratory RNA viral families and vector-borne pathogens, notably arboviruses, mostly of zoonotic origin.

Zoonotic diseases are infectious diseases transmitted between species from animals to humans through direct contact or through food, water and other vectors. They account for the biggest share of outbreaks; approximately 75% of new or emerging infectious diseases affecting humans are zoonotic (Jones et al. 2008). Their incidence often involves interactions between people, wildlife and livestock in dynamic changing environments.

Models of global spatial patterns of zoonotic emerging infectious diseases reveal that tropical forest regions, mammalian species richness and agricultural land use change are the most important variables correlated to zoonosis emergence Allen et al. 2017.

75 Regulation (EU) 2022/2371 https://eur-lex.europa.eu/eli/reg/2022/2371/oj

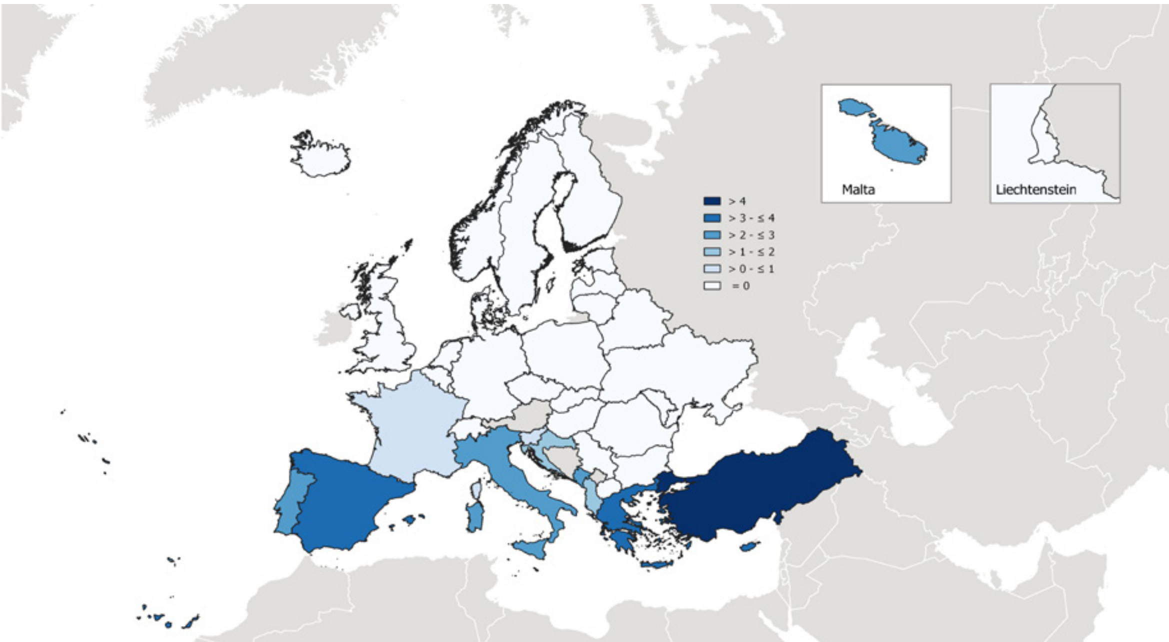
- Airborne pathogens

In 2020, COVID 19 accounted for 8% of all deaths in the EU, representing the third cause of death after cardiovascular diseases and cancer[76]. Respiratory pathogens such as coronaviruses and influenza viruses are a major concern because of their high person-to-person transmissibility and thus high pandemic potential. For some pathogens, the incubation period in infected individuals can last several days before appearance of symptoms. This latent period, combined with social life and global mobility accentuates the seriousness of infection foci and favours virus spreading towards other geographical regions. Most of RNA viruses are unstable and undergo rapid mutations. This can compromise the effectiveness of currently available medical countermeasures. The research community is working towards developing multi-valent COVID-19 and pan-coronaviruses vaccines.

- Vector-borne pathogens

Vector-borne disease account for more than 17% of all infectious diseases[77]. In the EU, the risk index calculated by DRMKC–INFORM[78] for exposure to vector-borne diseases shows a moderate risk **Figure 29**, with the highest values observed in the southern Europe, of higher proximity to tropical areas where most of the vectors come from. Among vector-borne pathogens, the family of arboviruses is raising increasingly concerns as a public health threat. Arboviruses are transmitted by arthropod vectors, such as Aedes mosquitoes, and include Dengue, Zika, Yellow fever, Chikungunya and West Nile viruses. Aedes mosquitoes are usually present in tropical regions but now are starting to proliferate in the south of Europe[79]. Being in most of the cases asymptomatic, viral transmission through human mobility, in particular travelling persons from endemic regions, may favour the virus importation to European countries. Arboviral epidemics have spread over the past decades and are expected to continue increasing due to risk drivers such as climate change, international mobility and expanding urbanisation (Lee et al. 2022).

Figure 29: Physical exposure to vector-borne diseases in the EU taking into consideration exposure to aedes mosquitoes and to malaria, zika and dengue diseases. Data from DRMKC-INFORM risk index



Source: Data from DRMKC-INFORM risk index

76 EUROSTAT (causes of death statistics) https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Causes_of_death_statistics#Major_causes_of_death_in_the_EU_in_2020

77 WHO, Vector-born diseases https://www.who.int/news-room/fact-sheets/detail/vector-borne-diseases

78 JRC, DRMKC-INFORM https://drmkc.jrc.ec.europa.eu/inform-index

79 ECDC https://www.ecdc.europa.eu/en/publications-data/aedes-albopictus-current-known-distribution-february-2023

Antimicrobial Resistance

AMR is the ability of a microorganism to survive in the presence of medicines targeted to neutralise it. It is considered a slow and silent pandemics, mainly driven by the inefficient use and bad consumption habits of antimicrobial drugs, bad sanitisation and lack of access to clean water[80]. Antibiotic-resistant infections cause more than 35,000 annual deaths in the EU/European Economic Area; above 70% of them are healthcare-associated infections[81]. In 2016-2020, Member States have reported a steady increase of bacterial infections resistant to last-line treatments, such as carbapenems[82]. **Table 4** lists the most reported resistant bacteria and the correspondent antibiotic. The largest health burden was caused by third-generation cephalosporin-resistant E. coli and K. pneumoniae, and methicillin-resistant S. aureus.

In view of the increasing burden to health systems, a growing body of public policies, strategies, guidelines and laws have recently appeared to address AMR: The European One Health Action Plan against AMR, the Commission proposal for a Council recommendation on stepping up EU actions to combat AMR in a One Health approach (COM(2023)191) and the corresponding Council Recommendation 9581/23, the European Surveillance of Antimicrobial Consumption programme, the EU Joint Action on AMR and Healthcare-Associated Infections or the Joint Programming Initiative on AMR, to name a few. These policies and initiatives aim at promoting responsible use of antimicrobial drugs, surveillance programmes, research and development.

Table 4: Main antibiotic-resistant bacteria reported in the EU[83]

Resistant bacteria	Antibiotic
E. faecalis / E. faecium	Vancomycin
S. aureus	Meticillin
K. pneumoniae	Carbepenem
	Third generation cephalosporin
P. aeruginosa	Carbepenem
	Multidrug
E. coli	Carbepenem
	Third generation cephalosporin
S. pneumoniae	Penicillin-non-wild-type
	Macrolide
Acinetobacter spp	Carbepenem
	Aminoglycoside
	Fluoroquinolone

Source: ECDC, 2022.

Chemical, biological, radiological and nuclear threats

While nuclear weapons require materials difficult to obtain and complex infrastructures, the development of biological and chemical weapons is at reach to all countries and many non-state actors. Of special concern are toxic chemical and biological agents that can be easily aerosolised and dispersed over large regions.

Dual use of research results in life science is becoming a major potential biological threat (Musunuri et al.

80 EPRS briefing 05-07-2023. Stepping up EU action to combat antimicrobial resistance
81 https://antibiotic.ecdc.europa.eu/en/get-informed/key-messages/health-burden-antibiotic-resistance
82 European Centre for Disease Prevention and Control. Assessing the health burden of infections with antibiotic-resistant bacteria in the EU/EEA, 2016-2020. Stockholm: ECDC; 2022.
83 European Centre for Disease Prevention and Control. Assessing the health burden of infections with antibiotic-resistant bacteria in the EU/EEA, 2016-2020. Stockholm: ECDC; 2022.

2021). In the last years, the vast efforts undertaken for tackling COVID-19 and improving pandemics preparedness have produced many scientific publications and knowledge on the characterization of zoonotic viruses. A new framework for assessing the potential dual use of research should be considered to avoid their misuse. JRC has set up the TIM Dual-Use Web Platform for mapping dual-use technologies listed in the "EU Dual-Use Control List" (Annex I to Regulation (EU) 2021/821) wherein some pathogens are listed.

The European Health Union crises preparedness action

The consequences of the COVID-19 pandemic and the resulting awareness has led to broad actions at EU level and the release of the new Health Union package, to strengthen EU preparedness and response planning. The European Health Union aims at strengthening the coordination at EU-level to protect the health of Europeans and collectively prepare and respond to cross-border health threats. Key initiatives have been the establishment of HERA, revised mandates for European Centre for Disease Prevention and Control (ECDC) and EMA, the European Health Data Space, the Pharmaceutical Strategy, the EU global Health Security and the serious cross-border threats to health regulation. These address the necessity for modernised regulatory frameworks supportive of innovation, digitalisation, research and technologies to develop life-saving treatments, vaccines and medical devices.

The new regulation on serious cross-border threats to health promotes cooperation between Member States, EU bodies and international organisations. It sets provisions for establishing a Union health crisis and pandemic plan, complementing National plans, to promote an effective and coordinated response. The plan includes provisions on joint arrangements for governance, capacities and resources.

In addition to international cooperation, it also advocates for multi-sectoral collaboration and follows the "One Health" approach to addressing current and emerging crises. One Health' is defined as a multi-sectoral approach which recognises that human health is connected to animal health and to the environment, and that actions to tackle threats to health must take into account those three dimensions. Likewise, the regulation underlines the need to ensure an "all-hazards risk approach" defined by WHO in the International Health Regulations of 2005[84], currently under revision. The approach acknowledges that hazards from different sources (natural, technological, societal) often challenge health systems in similar ways and thereby require a multi-sectoral response for better risk reduction and emergency preparedness.

Serious cross-border threats to health covered by the regulation include threats of biological, chemical, environmental and unknown origin, as well as public health emergencies of international concern. The emergence and progression of such threats shall be notified by National competent authorities or the Commission using the Early Warning and Response System (EWRS) and/or the European Surveillance Portal (ESP). Epidemiological surveillance information shall be regularly reported to the ESP for infectious diseases. To assist this process, the Regulation foresees the designation of European reference laboratories to support National ones and align Member States on diagnostics, testing methods and use of tests for surveillance, notification and reporting. Following an alert notification, MS and the Commission should work together and coordinate the response through the Health Security Committee, composed of MS representatives. The Commission may as well recognise a serious cross-border threat to health as public health emergency at Union level, enabling the introduction of union level measures for increased coordination and timely development, stockpiling and joint procurement of medical countermeasures.

84 https://www.who.int/health-topics/international-health-regulations#tab=tab_1

Climate change

As climate breakdown accelerates, so too does the risk of deadly pandemics. Changing environmental conditions can alter species localization and interactions and increase the risk of zoonotic spillover. Many transmission-related biological traits of vectors and the pathogen they carry are climate sensitive. Elevated sea temperatures have led to an increased reproduction of cholera virus. Vector-borne diseases have spread towards new areas due to the migration of mosquitoes. Droughts, extreme precipitation, heat waves have triggered the movement and reproduction of zoonotic pathogens reservoirs (insects, bats, birds) hosting several high-fatality pathogens. Due to their higher ability to better survive in different seasons, the dynamics of seasonal pathogens is changing towards year-round persistence, a pattern usually observed in tropical pathogens. Moreover, climate changes also trigger antimicrobial resistance. For example, drug-resistant Candida auris fungi has emerged worldwide probably by adaptation in response to global warming (Fischer et al, 2022).

Intensive agricultural and farming practices

Expanding and intensifying agriculture and farming creates conditions that favour pathogen circulation within domestic animals, especially those reared in high-density farms. Intensive practices also yield an increased risk to workers, as they suffer larger exposure to animals and plants. When associated to the use of antibiotics the risk of strains of bacteria resistant to antibiotics and with potential to affect human health significantly increases.

Anthropogenic pressure on the environment

Deforestation, diminish quality of wildlife habitats and pushing into the wilderness create biodiversity loss and increase the risk of naturally occurring pandemics. The disruption of environments with high biodiversity and a closer contact of humans and domestic animals with wild species raise the likelihood of new microorganisms affecting humans to arise.

Water sanitisation and access to clean water

Contaminated water is a major amplifier of AMR and water-borne diseases, such as cholera or dysentery. Lack of access to clean water and poor sanitisation increase the risk of consuming water polluted with chemicals, microorganisms or pathogens. Water sanitisation is critical to prevent disease outbreaks.

Demographic changes

Population growth is a driving factor for more intense human-wildlife interaction, which increases the risk of zoonoses.

Global ageing population and the decline of immune capacity in elderly people (an ageing immune system is less capable of containing infectious agents) may increase the probability of pathogen emergence and spillover.

Urbanisation creates new opportunities for the emergence of infectious diseases, in particular arboviral diseases transmitted by mosquitoes well adapted to urban areas. Dense and highly connected cities are as well potential hotspots for rapid transmission of respiratory viruses. Outbreaks of influenza, for example, tend to happen more often in denser urban regions.

Human behaviour also affects transmission. For instance, big gatherings are a catalyst for rapid local transmission, while school attendance modulates transmission of childhood infections.

Increased market and trade (food products)

Several examples in the recent past have shown how international food trade can easily impact the health of people in Europe. Foodborne outbreaks of disease have been linked to chemically contaminated food items (through naturally occurring toxins and environmental pollutants) but also from bacterial and viral contamination of food leading to outbreaks of infectious diseases.

Resilience of healthcare systems

The strength of national healthcare systems and their capacity to absorb a wave of patients while ensuring healthcare for other non-pandemic related cases contributes to the quality of the health crises response.

Health-responsible human behaviour and political will

A rapid deployment of containment measures has a large impact on the mortality levels during a health crisis. The behaviour of the population, their health literacy and willingness to comply with the measures, as well as the political will to deliver strong responses are key factors affecting the risk of outbreak propagation.

Global connectivity

Increased global connectivity enables pathogens to reach new environments more rapidly. International travel brings new risks for the global spread of emerging pathogens

Increased mobility

Human mobility is one of the most evident and relevant aspects of globalization. The higher mobility of people worldwide implies an increased risk of appearance in the EU/European Economic Area of new or re-emerging infectious diseases typically observed in other regions. As well it increases the probability of cross-border spread of local outbreaks. The extent of the mobility-based risk depends, among others, on the agents involved, the disease transmission patterns and the national capacities to reduce disease impact.

Vaccination hesitancy and dis/misinformation

Vaccine hesitancy refers to a generic reluctance or refusal to vaccinate against vaccine preventable diseases despite the availability of immunization services. Diseases from a bygone era, such as measles, for which immunity in communities needs to be very high to stop the disease, have returned to several EU countries. A reduction in vaccination coverage, noteworthy due to falling childhood vaccination rates, contributes to the probability of reappearance. False or misleading information can potentially influence citizen's choices and exacerbate vaccine hesitancy.

Antimicrobials misuse

Antimicrobial consumption has been directly linked to the increase of multidrug-resistant infections. Improper use of antibiotics in humans and animals induce the development of bacterial resistance random bacterial mutations. Responsible prescription and use of antimicrobials can help preventing the emergence of stronger resistance.

Dual-use biotechnologies

Technologies like synthetic biology, gene editing and DNA sequencing could yield accidental unintended or deliberate misuse. They have the potential to cause engineered pandemics or disrupt ecological balances. An engineered microorganism, highly virulent and transmissible, could cause the international spread of a serious outbreak.

Potential laboratory accidents

Pathogens could be released accidentally from bio-laboratories. Innovation in biotechnology and increase of related laboratory premises make more probable laboratory accidents such as experimental errors, misuse or insufficient biosafety precautions from laboratories working on infectious diseases. Harmful Engineered threat agents are potentially more dangerous than viruses with natural origin could be released and cause dramatic outbreaks. Concerns over the security of such laboratories has raised in view of the lack of binding international standards for a safe and responsible work on highly dangerous pathogens.

4.

EMERGING RISKS: NEW HAZARDS AND THREATS AND SOCIETAL CHANGES

4 Emerging risks: new hazards and threats and societal changes

New and emerging risks is a topic of interest identified by many Member States. As it was revealed by the Overview of natural and man-made disaster risks in the EU (European Commission, 2017 and 2021) the category new and emerging risks is treated as a stand-alone topic and it requires further consideration both at EU and national level. The literature available on the subject is growing, and several EU initiatives are also looking into it.

4 1 Defining emerging risks

The literature available on the subject is growing, and several EU initiatives are also looking into it. The definitions provided in the literature are on a broader scale and they may not necessarily related, nonetheless applicable both to natural and man-made disasters. There is a strong need to create a general definition for new and emerging risks at EU level.

When consulting the Oxford Lexico Dictionary (2019) about new and emerging terminology, a clear delimitation between the two terms exist:

- New – Produced, introduced, or discovered recently or now for the first time; not existing before.
- Emerging – Becoming apparent or prominent.

In accordance with Articles 23f and 34 of Regulation (EC) 178/2002, the **European Food Safety Authority** (EFSA) defines and describes "Emerging Risks within its mandate as follows: an emerging risk to human, animal, and/or plant health is defined as a risk arising from a newly identified hazard that may lead to significant exposure, or from an unexpected new or increased significant exposure and/or susceptibility to a known hazard. An evaluation of emerging risk involves the early detection of relevant facts derived from research and/or monitoring programs or episodic observations. The assessment of emerging risks must be adaptable to accommodate changes in the conditions affecting the risks and advancements in detection methods. It should be noted that the assessment of emerging risks is distinct from the assessment of risks under emergency (or crisis) conditions, as the latter are managed through established Commission procedures[1].

The 2014 OECD Recommendation on Governance of Critical Risks[2] defines 'Critical Risks' as:

"Threats and hazards that pose the most strategically significant risk, as a result of (i) their probability or likelihood and of (ii) the national significance of their disruptive consequences, including sudden onset events (e.g. earthquakes, industrial accidents, terrorist attacks), gradual onset events (e.g. pandemics), and steady-state risks (notably those related to illicit trade or organised crime). **Emerging Critical Risks** are any risks that meet those criteria and are also: "Either new risks or familiar risks that are evolving due to new or unfamiliar conditions"

As it is discussed in the Future Brief (European Commission, 2016), there is no single accepted definition of emerging risks. However, emerging risks are generally those that have a high degree of uncertainty regarding the probability of occurrence and the amount of potential loss or harm.

A closely related definition to the disaster risk field is proposed by the European Food Safety Authority[3], where an emerging risk is defined as the risk resulting from a newly identified hazard to which a significant exposure may occur, or from an unexpected new or increased significant exposure and/or susceptibility to a known hazard.

1 Commission Decision 2004/478/EC concerning the adoption of a general plan for food/feed crisis management. Official Journal of the European Union L 160/98.
2 https://www.oecd.org/gov/risk/recommendation-on-governance-of-critical-risks.htm
3 http://www.efsa.europa.eu/en/topics/topic/emerging-risks

From the Occupational Safety and Health Agency's[4] perspective the term of Emerging Risk, even though referring to the occupational risk, describes both the new and increasing risk. By New, it is suggested a risk that was previously unknown or long-standing issue that is newly considered to be a risk due to changes in perception, or coming from a new scientific knowledge. The risk is considered to be increasing either if the number of hazards leading to the risk is growing, or the likelihood of exposure to the hazard leading to the risk is increasing, or the effect of the hazard on the element exposed is getting worse.

The OECD High Level Risk Forum (HLRF) took the initiative to identify emerging risks, or future risks and published their first analytical report that reviews the findings of a pilot online mapping exercise of emerging risks. It is at the time of the publication of the current report in draft and will be further finalised via meetings with experts in the field.

As a conclusion, based on the literature available on the subject, new and emerging risks are seen as the shift in risk, attributable to one or more of the underneath factors:

- The **novelty of the type of hazard** (the situation of a new process or understanding of a process or phenomena that was not considered before);
- Increases in either vulnerability and/or exposure,
- Decrease in the coping capacity.

Risk is a dynamic component of the risk assessments provided by the Member States as it changes with time. As some new risks rises others fade mainly thank to the already implemented and sound preventive actions which clearly shows the need to continue updating the risk assessments.

4 2 A systemic perspective for future risks in the EU

Future risks do not arise in isolation. In a world where everything is interlinked, to understand and hence apply the concept of systemic risk is vital. It means acknowledging that all risks needs to be addressed with a holistic approach. It also mean taking a holistic and systemic perspective to anticipating risk.

At EU level there are many initiatives aiming at anticipating future needs to address new and emerging risks. For example, the EC Competence Centre on Foresight[5] launched a public website focusing on Megatrends in 2018. Megatrends are long-term driving forces that are observable now and will most likely have significant influence on the future. Looking ahead, megatrends can be main sources of future risks, or they can exacerbate other new or current risks. It is therefore relevant to consider the impact of megatrends when examining the future risks landscape.

The Megatrends Hub[6] is a systemic knowledge-management platform and an engagement tool for policy-makers and citizens to help understanding potential future developments and support forward looking thinking. It provides concise information on 14 global megatrends, bringing together qualitative and quantitative views. Each megatrend features current developments and forecasts, indicators, potential implications as well as references for further information.

The 14 megatrends are as follows:

- Accelerating technological change and hyperconnectivity
- Aggravating resource scarcity
- Changing nature of work
- Changing security paradigm

4 OSHA, 2019. Monitoring new and emerging risks https://oshwiki.eu/wiki/Monitoring_new_and_emerging_risks
5 EC Competence Centre on Foresight https://knowledge4policy.ec.europa.eu/foresight_en
6 The Megatrends Hub https://knowledge4policy.ec.europa.eu/foresight/tool/megatrends-hub_en

- Climate change and environmental degradation
- Continuing urbanisation
- Diversification of education and learning
- Widening inequalities
- Expanding influence of East and South
- Growing consumption
- Increasing demographic imbalances
- Increasing influence of new governing systems
- Increasing significance of migration
- Shifting health challenges

The 14 megatrends are not risks in themselves, but ongoing processes of change which may lead to risks. In this way the megatrends can support forward-looking holistic approaches to risk assessment by enabling an analysis of how a possible future risk may be impacted by these ongoing trends. For example, hybrid threats can be understood as part of a larger trend of a changing security paradigm, which may reveal new dimensions. Similarly, considering megatrends may reveal or help to address blind spots. For example, how does continuing urbanisation or increasing demographic imbalances impact financial risks? Such considerations help to assess future risks more systemically, and contribute to better anticipation.

Beyond megatrends, it is also necessary to systematically invest in Horizon Scanning activities intended for the timely detection of emerging trends and events that might have significant future implications, but are not yet on the policy radar or adequately addressed. These activities are detailed in section 5 of this report on strategic foresight.

4 3 Overview of the main emerging risks in the EU

In the context of the risk assessments, there are limitless ways to categorise emerging risks. One way of doing it is by focusing on the assets that might be affected by the future risks; which are the ones to be protected at national level: population, environment and infrastructures. Particular emphasis is given to those infrastructures that are vital to the nation. In the following chapter a detailed discussion is provided covering various areas of interest.

4 3 1 Food security

At the World Food Summit in 1996, food security was defined as 'when all people, at all times, have physical and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life'[7]. This widely accepted definition points to four dimensions of food security: food availability, access, utilisation and stability.

- Food availability refers to the availability of sufficient quantities of food of appropriate quality, supplied through domestic production, imports or food aid.
- Food access refers to individuals having adequate resources to acquire appropriate foods for a nutritious diet.
  Utilisation relates to an individual's nutritional well-being reached through adequate diet, clean water, sanitation, and healthcare.

7 FAO, Trade reforms and food security, Conceptualizing the Linkages, 2003, Chapter 2. Food security: concepts and measurement

- Stability is the condition by which the dimensions of availability, access and utilisation are sufficiently met, and in which the whole system is stable, thus ensuring that households are food secure at all times. Short-term instability can lead to acute food insecurity, and medium- to long-term instability can lead to chronic food insecurity. Climatic, environmental, economic, social, and political factors can all be a source of instability.

Food security is a complex phenomenon difficult to measure directly. The existence of dietary energy gaps, diets of inadequate quality, the inability to meet food preferences and the uncertainty about the future ability to access food are examples of situations that can be associated with a state of food insecurity affecting parts of the population. To determine the existence of such a state and the number and characteristics of population involved it is generally not sufficient to use one simple indicator at a given time. Besides the multi-dimensional nature of the food security concept, the analysis of food insecurity faces **challenges related to the data collection** (timeliness, adequate level of disaggregation, biases associated to survey process, access to areas of concern, etc.), and challenges associated to the methods used to compute indicators using available data.

Global Food Security situation

Due to the multifaceted concept of food security and the diversity of analytical frameworks, but also due to different policy information needs, there are several annual flagship reports on global food security. The State of Food Security and Nutrition Report (SOFI) is jointly prepared by Food Agriculture Organization (FAO), International Fund for Agricultural Development (IFAD), UNICEF, WFP and WHO and informs on the progress towards achieving Sustainable Development Goals (SDG) 2. The Global Report on Food Crises (GRFC) is prepared by the Global network against Food Crises and informs on the size of the needs in food crises prone areas. These reports indicate a worsening trend of the state of food insecurity worldwide.

According to the latest edition of the SOFI (2023), between 691 and 783 million people in the world face hunger in 2022. The number has grown by about 122 million since the outbreak of the COVID-19 pandemic. Hunger is still on the rise in Western Asia, the Caribbean and all sub regions of Africa. About 29.6 percent of the global population – 2.4 billion people – were moderately or severely food insecure in 2022 (SDG Indicator 2.1.2), of which about 900 million (11.3 percent of people in the world) were severely food insecure. Worldwide, food insecurity disproportionately affects women and people living in rural areas. More than 3.1 billion people in the world – or 42 percent – were unable to afford a healthy diet in 2021.

The Global Report on Food Crises (GRFC) has flagged high levels of acute hunger, consistently above 100 million people and increasing since 2016. The latest edition in 2023 estimated that about 258 million people in 58 food crisis countries and territories faced high levels of acute food insecurity (IPC Phase 3 or above or equivalent) and required urgent food assistance in 2022. This represents 22.7% of the population analysed and is the highest number in the seven-year history of the GRFC and 34% higher than the number presented in the GRFC 2022. Protracted conflicts is the main drivers of acute food insecurity while the lingering effects of global economic recession caused by the COVID-19 pandemic and the repercussions of Russia’s war against Ukraine, as well as weather extremes also play a major role. Numbers reported in the GRFC come mainly from the Integrated Food Security Phase Classification (IPC) and the Cadre Harmonisé.

Global risk assessment methods

In an attempt to address the challenge of analysing food security by taking into account its different dimensions and the problems associated to collection and analysis of data, several international organizations joined forces in 2007 to promote the adoption of an analytical framework at global level called the IPC. In the West Africa region a similar initiative promoted the Cadre Harmonisé (CH).

The IPC and CH are analytical frameworks designed to determine the severity and magnitude of food and nutrition insecurity and to identify their key drivers. Today, the IPC and CH are operational in about 50 countries, and are considered the standard reference for consensus-based analysis of food insecurity and acute malnutrition, informing more than six billion dollars in food crisis response decisions annually.

In general IPC and CH are tools for improving food security analysis and decision-making by classifying the severity and magnitude of food insecurity and acute malnutrition based on a food insecurity situation analysis that combines international standards - including food consumption levels, livelihoods changes, nutritional status, and mortality - and triangulates them with several contributing factors (food availability, access, utilization and stability, and vulnerability and hazards) analysed within local contexts; and Identification of key drivers of acute food insecurity. The IPC AFI classification is conducted according to the four functions of the IPC, including: 1) consensus building, 2) methodical evaluation, review and convergence of all evidence available against global thresholds, 3) strategic communication for action, and 4) quality assurance.

More detailed information about Global Food and Nutrition security is provided by the Knowledge Centre for Global Food and Nutrition Security and in particular for the definitions of food security, food crises and related EU policies a synthetic overview is available in the Scientific Brief: Food Security and Food Crises.

Food Security in Europe

The recent crisis with the COVID 19 pandemic and Russia´s war against Ukraine have brought food security in Europe on the political agenda. To stay abreast of these changes that EC has analysed drivers of food security with a special focus on Europe in its SWD (2023) 4 final Drivers of Food Security[8]. This analysis complements the preceding document COM(2022) 133 final Safeguarding Food Security and enforcing the resilience of food systems[9] Main conclusion are presented thereafter: Ensuring the availability and access to food for consumers at reasonable prices are objectives set out in Article 39 of the Treaty on the Functioning of the European Union (TFEU). However, the achievement of these objectives cannot be taken for granted. With high pressure on the global food system, and as food production is predominantly based on natural processes and yields are inherently uncertain, vulnerabilities become more relevant under climate change scenarios and a changed geopolitical landscape. .

The EU is largely self-sufficient for many agricultural products and a net exporter of wheat. However, the EU is a considerable net-importer for specific products which may be difficult to (swiftly) substitute, such as feed protein, sunflower oil or seafood. There is no risk of widespread shortage for consumers. While the stable food supply in the EU is not jeopardised, these vulnerabilities together with increasing input costs in the food supply chain are driving food prices further up. If the significantly higher production costs at farm level are not compensated by higher prices, this may impact supply certainties. In general, for the EU **food availability is not at stake**, though **food affordability** for low-income persons is.

Over the years, the Common Agricultural Policy (CAP) has played an important role in making EU agriculture one of the world's leading food producers, which in turn guarantees the food security for 450 million European citizens and contributes to global food security. European farmers are responding to citizens' demands regarding food security, safety, quality, and sustainability. In fisheries and aquaculture,

8 Commission Staff Working Document - Drivers of food security https://commission.europa.eu/publications/analysis-main-drivers-food-security_en

9 Safeguarding food security https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2022:133:FIN EUR-Lex - 52022DC0133 - EN - EUR-Lex (europa.eu)

the Common Fisheries Policy (CFP) aims to ensure that fishing and aquaculture activities are sustainable and contribute to provide Europeans with nutritional food. At the heart of the European Green Deal, including the Farm to Fork, the Biodiversity and other strategies, the EU set out a long-term strategic vision on how to change the way we produce, distribute, and consume food. This vision as published in the EU pathway[10] towards sustainable food system transformation aims at fair, healthy and environmentally-friendly food systems, while further strengthening their overall resilience.

Risk assessments and other measures

A crucial document in this context is the COM/2021/689 final **Contingency plan for ensuring food supply and food security in times of crisis** and the subsequent establishment of a new **European Food Security Crisis preparedness and response Mechanism (EFSCM)**[11], which aims at improving coordination efforts by European and national administrations as well as relevant non-EU countries and private stakeholders to ensure food supply and food security in times of crisis. The Mechanism, started its work on 9 March 2022,

The disaster cycle used in crisis management includes four main phases: (i) prevention, (ii) preparedness, (iii) response and (iv) recovery. Contingency planning is a part of preparedness which requires identifying the hazards to which the community is vulnerable and the nature of potential impacts. Therefore, the focus is on the preparedness phase and on the support to actors in charge of responding to the crisis. The contingency plan will cover the whole food system starting from inputs up to the delivery of food to consumers through retail or food services.

Key to improving EU preparedness, this contingency plan embraces a collaborative approach between all public and private parties being part of the food supply chain. From the private sector, this includes farmers, fishers, aquaculture producers, food processors, traders and retailers as well as transporters and logisticians for instance. EU, national and regional authorities will also be central to this plan.

The EFSCM relies on a group of experts, combining Member States and some non-EU countries representatives and actors from all stages of the food chain, and a set of rules of procedures governing its functioning.

The group meets periodically, and in the event of a crisis, at very short notice and as frequently as necessary.

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

Twice a year a qualitative assessment of the state of food security in the EU is produced[12]. It is based on the inputs of different members of the EFSCM. In addition, data on food security available is available through the thematical dashboard[13].

So far two recommendations[14] have been published: on crisis communication and on diversity of supplies.

10 EU pathway - SUSTAINABLE FOOD european-union-pathway.pdf (unfoodsystemshub.org)

11 COM(2021) 689 of 12.11.2021 “Contingency plan for ensuring food supply and food security in times of crisis”.

12 1st report on the State of Food Security in the EU (Autumn 2023) https://agriculture.ec.europa.eu/document/download/45fe63e2-526a-42e2-ab41-640ed854931c_en?filename=efscm-assessment-autumn-2023_en.pdf

13 EC Agri-food data portal, Food supply and security https://agridata.ec.europa.eu/extensions/DataPortal/food-supply-security.html

14 Ensuring global food supply and food security Ensuring global food supply and food security - European Commission (europa.eu)

4 3 2 Energy risks: Hydrogen

For some years, the JRC's energy and major hazard sectors have been monitoring emerging trends in the use of alternative fuels, in particular, biofuels, hydrogen, lithium batteries, and solar energy. As the EU and other countries began announcing strategies for moving away from carbon-based fuels, the JRC's Major Accident Hazards Bureau (MAHB) started looking at potential implications of this energy transition in an industrial risk as well as a safety and health hazards context, generally. More specifically, the JRC MAHB has been interested in whether and how much the transition could have for oversight and monitoring by EU competent authorities for industrial accident risks in the context of the Seveso Directive (2012/18/EU).

This chapter specifically evaluates the potential increase in accident risk associated with new uses and infrastructures to facilitate a greater use of hydrogen fuel to replace carbon-based fuels in the EU economy. Hydrogen is an abundant and highly versatile substance that already plays an essential role as an ingredient for chemical manufacturing and oil refining in today's economy. All the same, hydrogen is considered a dangerous substance. Although it is not toxic to humans or the environment, its physical properties make it highly flammable and also complicate efforts to manage it safely. Fire and explosive risk are considered chemical accident risks when they are caused by a raw material, such as hydrogen. Thus, hydrogen use and supporting infrastructure pose a chemical accident risk.

For this reason, various experts with in-depth knowledge of the substances and technologies in question have begun to caution that reliance on hydrogen fuels for the energy transition comes with several safety risks that could affect how soon some foreseen uses can be implemented on a broad scale. In some cases, the potential negative impacts of some technological adaptations could significantly offset their economic viability and/or their attractiveness from an environment, health and safety perspective. Understanding these risks and developing safety strategies to mitigate them, can ensure that the environment, industry, and society as a whole benefit from this energy transition.

Currently, there are already proposals in many EU countries to store, produce or distribute hydrogen fuels. As such, it is important that current knowledge on safety issues associated with increased production and use of hydrogen fuel as well as upscaling distribution, storage and transport infrastructures, is shared with authorities who have responsibility for permitting and overseeing such facilities. In this way, these authorities have more information to decide on whether the proposals are sufficiently elaborated to ensure that safety requirements are met. The information can also help authorities decide as to what measures might be needed to provide a high level of protection against a potential chemical accident, taking into consideration in particular the implications for the safety of workers and the surrounding community.

Furthermore, the difficulty of resolving these safety challenges will continue to grow as the scale of operations associated with the use of hydrogen fuel in the economy increases. In this summary, the description of safety risks assumes that the transition to hydrogen energy sources will take place at the level currently envisioned within Member State energy transition strategies. However, it is very possible that safety risks may become one of the obstacles that could prevent the realisation of some plans in the Member States to use this alternative energy source to reduce their carbon footprint. It is hoped that this chapter may help policymakers and industry operators in reviewing the risk-reward balance of their current energy strategy. Most importantly, they need to have realistic expectations, understanding, in particular, that some planned technological adaptations may not have the outcome expected and/or that they entail technical obstacles that are insurmountable in the foreseeable future.

The authors note that this chapter is only an overview and not an in-depth study. It is based on general knowledge about the hazards associated with hydrogen and on recent studies of accidents in industries that already use hydrogen in their operations. Moreover, the purpose of this report is to summarise the challenges that may need to be addressed before the technologies are deployed in any widespread manner. It does not discuss the considerable work that is already underway in the European Union and elsewhere to resolve them.

Properties of hydrogen relevant for risk management

Hydrogen has several unique properties, including its high flammability, invisibility, odourless, and ability to embrittle metals, that present specific challenges for safety:

Leakage propensity. Hydrogen, due to its small size and high diffusion coefficient, is prone to leakage and easy travel in metal structures. This can compromise the integrity of the systems involved in the hydrogen lifecycle stages, including production, transport, storage, and utilization, in terms of unintended leaks and containment's mechanical integrity. This can pose safety risks and impact the efficiency of hydrogen utilization. Accidents involving hydrogen often occur because the operator did not adequately predict potential hydrogen release points (for instances, through valves and flanges).

Hydrogen embrittlement. Certain materials, particularly steels, are susceptible to embrittlement and more prone to fractures and stress-cracking in hydrogen-rich environments. Such embrittlement can lead to unexpected failures and compromises to the structural integrity of components and equipment.

Wide flammability range. Any transfer or (mis)handling of hydrogen in its production, storage, transportation, and utilization, carries the risk of it escaping and creating the potential for a flammable atmosphere. Hydrogen has a wide flammability range spanning from 4% to 75% hydrogen in air and has a low ignition energy compared to other gases, around 30% of hydrogen in air. Hence, it can ignite and burn in a broad range of hydrogen-air mixtures. Even at a volumetric ratio of hydrogen to air as low as 4%, it has the potential to ignite, making it highly flammable when combined with even small amounts of oxygen.

Detonation potential. Hydrogen's detonation capability is influenced by various factors, such as its wide flammability range, low ignition energy, rapid flame propagation, confinement, and the presence of ignition sources. Concentrations of hydrogen-air within the flammability limits increase the likelihood of detonation. Its low ignition energy makes it susceptible to ignition from various sources such as sparks, open flames, electrical arcs, or hot surfaces. The confinement of hydrogen within closed spaces, such as rooms or pipes, contribute to flame acceleration, which generates high pressures, and ultimately leads to detonation.

Hydrogen fuels – risks and challenges

There is a long history of hydrogen use in EU industries. According to the IEA, demand for hydrogen has grown more than threefold since 1975 and continues to rise. In 2022, the global use of hydrogen has reached 95 million metric tons (Mt) [15] (IEA, Global Hydrogen Review 2023).

However, this upward trajectory was disrupted in 2023 due to the energy crisis and the sharp increase in natural gas prices. Hydrogen is present in chemical and petroleum industries, including chemical, pharmaceutical, oil refining, nuclear, transport industries, and metal processing. Oil refining and ammonia production represent specific applications for "pure" hydrogen. Methanol and direct iron production (DRI) use hydrogen as part of a mixture of gases, such as synthesis gas, for fuel or feedstock. At the moment, hydrogen is predominantly used in industry, but there are hopes that it can eventually be adopted for other uses.

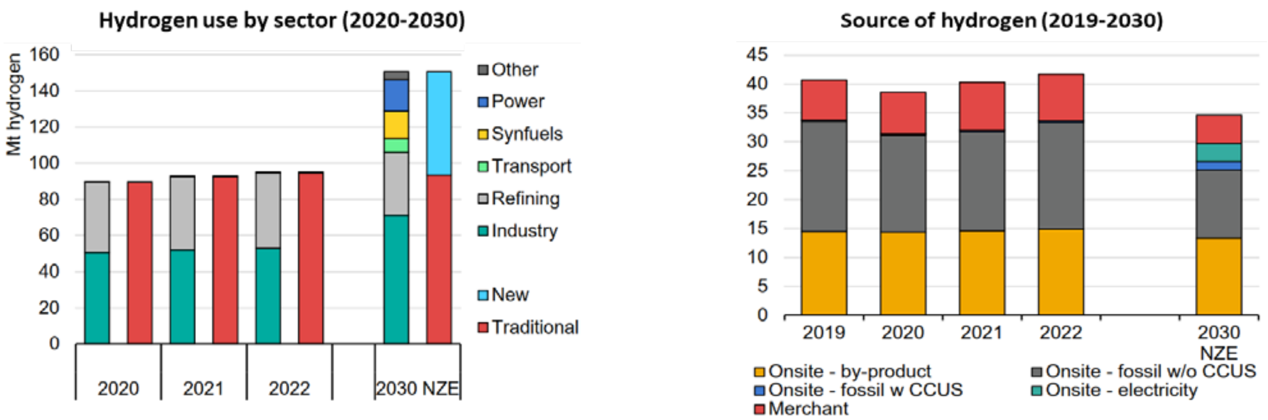
The European Commission has established decarbonisation priorities to facilitate the transition towards

15 International Energy Agency, Global Hydrogen Review 2023, available at www.iea.org

a low-carbon economy. It focuses on promoting the use of renewable sources, such as solar or wind power, for electrification in all sectors and applications. This plan covers several domains, such as transport and mobility, residential consumers, and commercial buildings. In cases where complete electrification is not possible, the use of renewable hydrogen (or its derivatives) is preferred, where technically and economically feasible. This aspect is relevant for industrial processes, non-road transport, and electricity generation and storage. Some ongoing projects in the Netherlands and the United Kingdom, are evaluating hydrogen use in domestic heating and power generation.

As shown in **Figure 30**, the IEA's Net Zero Emissions by 2050 Scenario (NZE Scenario), projects hydrogen usage to grow by 6% annually until the end of the decade. This corresponds to a consumption of over 150 million metric tons by 2030, with new applications accounting for nearly 40% of the demand. Hydrogen consumption in the refining sector exceeded 41 Mt in 2022, surpassing the previous peak in 2018. Approximately 80% of the hydrogen used in refineries is produced onsite, with around 55% originating from dedicated hydrogen production and the remainder generated as a by-product from various operations, such as naphtha crackers. Low-emission technologies contributed to less than 1% of hydrogen production in refineries in 2022. The remaining 20% of hydrogen used is sourced as merchant hydrogen, primarily derived from unabated fossil fuels.

Figure 30: Hydrogen use by sector (left) and source of hydrogen for refining (right), historical and in the Net Zero Emissions by 2050 Scenario



Source: IEA. Licence: CC BY 4.0

According to the NZE Scenario, by 2030, hydrogen consumption in refining is projected to be below 35 Mt. Additionally, low-emission hydrogen is expected to account for more than 15% of total hydrogen usage in refining by 2030.

The number of countries with polices that directly support investment in hydrogen technologies is also increasing. National governments have also increased global spending on hydrogen energy research over this same time frame. In this way, development and demonstration of hydrogen applications by national governments has risen, including research on reducing accident risks associated with production, distribution and storage on a wider scale.

Past hydrogen accidents: Impacts and lessons learned

Risks of hydrogen are well-known and have been studied for decades. Nonetheless, as with all hazardous substances, even minor changes in the equipment, process, or personnel involved can elevate risk. Even with full knowledge of the dangerous properties of hydrogen, it can be a challenge to recognise potential accident triggers or predict fully how an accident sequence involving hydrogen will evolve. For this reason, investigation of hydrogen accidents and sharing lessons learned remains a crucial element of chemical accident risk management in the industries that use it. The EU databases, HIAD[16], eMARS[17],, ARIA[18], and the U.S database H2[19], all collect hydrogen incident reports for the purpose of lessons learned.

Consequences of hydrogen accidents

The consequences of accidents involving hydrogen depends on the initial and boundary conditions, ranging from negligible to very serious, including fatalities and significant damage to premises. In 2020 MAHB reviewed the EU's HIAD and the French ARIA databases. As shown in **Table 5**, both sources recorded fatalities in around 12-13% of incidents and around double that ratio of accidents involving injuries. Of the 105 fatalities recorded in the HIAD database, 34 are attributed to one single event. Apart from human health impacts, property damage and operating losses can also be considerable. Nearly 90% of the cases reported in ARIA recorded significant material damage and over 1/3 also included operational losses. For the events in ARIA, it appears that most impacts were contained on site since a relatively small percentage of events had offsite impacts. However, it provides evidence that mitigation and response measures play a significant role in managing hydrogen incident risk.

In 2020, MAHB identified 32 reports of accidents involving hydrogen occurring since 2000. As shown in **Figure 31**, accidents involving hydrogen were responsible for 13 fatalities and 17 injuries according to the reports.

16 The JRC's Hydrogen Accidents and Incidents Database (HIAD), as a database dedicated solely to hydrogen safety, is the most extensive and structured around hydrogen-specific descriptors detailed. HIAD was established in 2006 within the frame of the European Network of Excellence HySafe and and further developed and populated by the JRC, more recently in collaboration with the European Hydrogen safety Panel of the Clean Hydrogen Partnership.

17 The eMARS database was established to fulfil the requirements of the Seveso Directive. Since 1984, the Directive has required all Member States to report major accidents on Seveso sites according to criteria in Annex VI to the EU's eMARS database for the purpose of lessons learned. The eMARS industries using a minimum of 5 tonnes of hydrogen are subject to the obligations of the Seveso Directive.

18 The Analysis, Research and Information on Accidents (ARIA) database is an initiative of the French Ministry of Environment and is managed by its Bureau for Analysis of Industrial Risks and Pollution (BARPI). ARIA catalogues incidents or accidents that were, or could have been, deleterious to human health, public safety or the environment, according to criteria established in French law. It has over 46,000 accidents and incidents occurring in France and abroad.

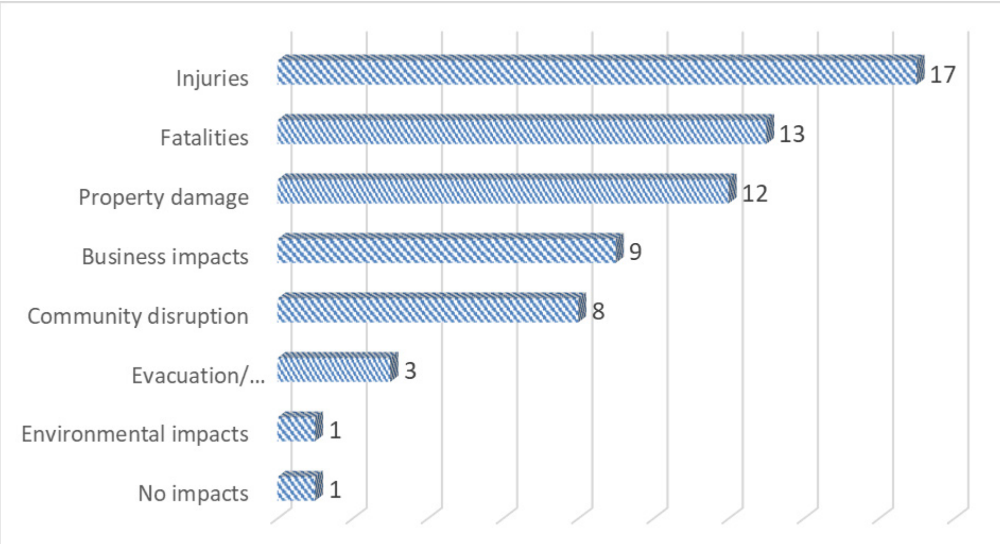
19 The H2 Incident Reporting and Lessons Learned database was launched in 2006 and is maintained by the Pacific Northwest National Laboratory (PNNL) on behalf of the U.S. Department of Energy (DOE). The website is regularly updated with reports and information on hydrogen incidents. The website also includes a wide range of resources related to fuel cell technologies and hydrogen safety, including reports, training materials, and other supporting tools. It facilitates the sharing of lessons learned from hydrogen incidents and near misses.

Table 5: Consequences of hydrogen events reported in HIAD and ARIA

	HIAD (2000-2019)	ARIA (<07/2007)
Impact	**n° of cases**	**N° of cases**
Number of cases	249	213
Events with fatalities	31	25
Events with multiple fatalities	22	
Events with 34 fatalities	1	
Total fatalities	105	
Events with injuries	66	70
Total injuries	320	
Internal material damage		183
External material damage		17
Internal operatin losses		89
Evacuated population		8

Source: JRC, 2020

Figure 31: Consequences of hydrogen accidents in eMARS (2000 - present)



Source: JRC, eMARS database, 2020

Lessons learned from hydrogen incidents

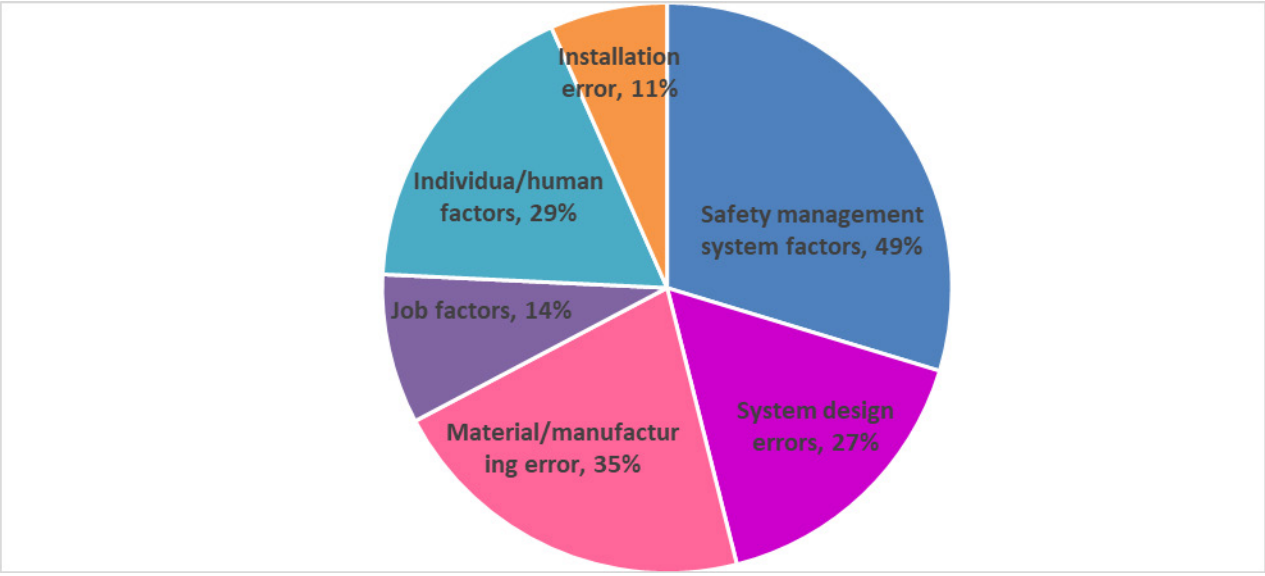
MAHB conducted a limited study of the main characteristics of 41 accidents (since 1984) in 2022 to identify commonalities in the eMARS database. The study identified that the incidents mainly involved one or more of the following elements:

- Processes that involve pure hydrogen and air,
- Processes involving syngas with a significant percentage of hydrogen
- Hydrogen created as a consequence of a reaction (e.g., with metal)
- Chain of events, not initiated by hydrogen, but where a hydrogen containment is ultimately affected and is responsible for the escalation of the incident

- Equipment degradation caused by hydrogen embitterment, hydrogen stress cracking
- Failure to anticipate the presence of hydrogen in mitigation measures
- Build-up of hydrogen in confined spaces
- Hydrogen releases causing jet flames, vapour cloud explosions and pressure bursts, and sometimes causing wider conflagrations when not contained

Wen et al.'s study (Wen et al, 2022) of hydrogen accidents is by far the most extensive study of lessons learned from hydrogen in recent years. A main study conclusion is that risk management of hydrogen is challenging, as captured in the following succinct statement: "The overarching lesson learned is that incidents might consist of several causal events, which if occurred separately, might be trivial but if these minor events occurred simultaneously, they could still result in serious consequences." In their study, causality is divided into six subcategories of underlying factors as shown in **Figure 32**. Within these sub-categories, a number of specific failures are catalogued and described. In their discussion of findings, the authors emphasize the importance of robust safety management systems and staff training crucial elements of hydrogen risk management. The study also produced detailed analyses and recommendations for a variety of situations, including many also targeted towards specific industries. It is impossible to summarise these details in this short report. Rather it is recommended that this study can provide good guidance to companies that plan to enter into a hydrogen-related business for the first time.

Figure 32: Percentages related to the causes of the events considering multiple causes per event



Source: Wen et al. 2022

According to the European Clean Hydrogen Alliance (ECH2A, 2023), current needs regarding the standardisation of hydrogen production can be partially covered with the European regulatory framework already in place including the ATEX and PED directives and the related set of harmonised standards. However, the report, recognises that there is still much to be done in the standardisation process, identifying approximately 400 topics, with many related to gaps currently presented in standardisation. Many safety aspects of hydrogen production and transportation, such as material compatibility, potential explosive atmosphere, leakage and odorisation[20], have been assessed for gaps against existing standards. Hence, existing standards need to be improved and new ones created to address the gaps. These standardisation gaps include among others:

20 Odorisation is the process of injecting odor into a gas so that it can be sensed by smell

- Harmonised safety distances on liquefication[21] plants
- Requirements for design and functioning of protective systems for prevention of flame transmission and explosion propagation for hydrogen applications
- Basic safety levels and measures appropriately graded for users (risk assessment and safety requirements) for:
- Process industry (large plants, specially trained personnel including hydrogen safety)
- Commercial use (small plants, trained personnel without special knowledge of hydrogen)
- Public use
- Specific training and qualification for the operation and maintenance of hydrogen-related equipment
- Requirements for design and functioning of cyber security for hydrogen plants
- Safety for combining energy sources - hybrid systems, e.g. ,battery pack and hydrogen
- Safety topics – rupture and failure frequencies
- Grid corrosion
- Leakage related safety risks and confined spaces
- Missing standards on safety and pressure limits in H2 transportation

Extensive regulatory gaps have been identified by other initiatives as well such as the high-level gap analysis conducted by the International Partnership for Hydrogen and fuel cells in the Economy (IPHE). The critical areas identified by the IPHE relate to both hydrogen infrastructure and mobility/transportation highlighting the need for international collaboration to address gaps in safety, maintenance requirements, approvals and inspections (IPHE, 2021).

Industry initiatives such as the Hydrogen Council have also identified over 400 gaps related to Regulatory, Codes and Standards (RCS) on hydrogen standardisation. Overall, the gaps are related to safety performance and costs categories associated with hydrogen production and its use for mobility. While all gaps are considered highly critical, the first key gap (including many sub-elements) refers to the safety culture in relation to hydrogen (ECH2A, 2023).

Risk considerations in a future hydrogen-fuelled economy

The expected role of hydrogen in the energy transition introduces new risk dimensions. Two key aspects are the larger quantities of hydrogen at stake and the potential penetration of hydrogen systems among the public, including untrained users. While the increase in hydrogen quantities is inevitable, the extent of penetration among untrained users is uncertain. Current experiences may not be representative of the risks associated with the new uses of hydrogen (e.g., electrolysis, compression, transport, distribution). Most plans to produce, transport and distribute on a large-scale the expected quantities of hydrogen have not yet been extensively tested in the field. .

The already established principles developed by the international hydrogen community remain relevant for the safe operation of new hydrogen-based activities. Operators must be aware and understand how to adapt these principles to the new uses and technologies that they plan to implement. Risk management starts with the design phase and continues throughout the operational and maintenance activities, taking into consideration interfaces with the workforce and their connections to other parts of the hydrogen fuel network.

21 Liquefication is the process of condensing gas into a liquid

Experts envision that the current EU policy strategy intends for hydrogen to play a major role in multiple sectors of the economy in future. In particular, the Green Deal has created incentives for new players with less experience to enter the marketplace. Many EU and European Economic Area countries are now already receiving concept proposals for hydrogen fuel projects and some projects are already being implemented in some of them. In present times, hydrogen is handled by a small set of experienced companies, specifically petroleum refineries and air products companies. Therefore, a main concern of the future is the combination of new, untested uses for hydrogen, the potential widespread adoption, increased production and storage capacities, and the entry of numerous first-time hydrogen operators.

The potential use of hydrogen raises a number of questions around hypothetical situations in which hydrogen applications may generate risks when not adequately addressed, including

- Storage facilities for hydrogen: with the increasing volume of hydrogen, there is a need for additional storage sites. These must be carefully located to ensure safety, taking into considering the volumes stored and materials compatibility.
- Hydrogen infrastructure: the delivery of hydrogen from production sites to end-use points requires the development of pipelines, compression and regasification plants, ships and trucks, and fuelling stations. All of these have certain hazards and risks associated with leaks, fire and explosion hazards.
  - *Pipelines.* Hazards are associated with the transportation of hydrogen and hydrogen-natural gas blends through pipelines and integrity of the pipeline. Leakages in pipelines can lead potentially to fire and explosion hazards.
  - *Compression and regasification plants.* Hazards related to the compression and regasification processes includes leaks, fire or explosion. Hazards related to pressure burst and embrittlement of equipment can occur if materials used are incompatible with hydrogen.
  - *Transportation vehicles (ships, train, and trucks).* Hazards can be triggered by road crashes, collisions, or loss of vehicle control during the transportation of liquefied hydrogen (either in pressurized or cryogenic state). Pressure bursts and embrittlement of vessels and containers are potential risks that need to be addressed.
  - *Fuelling stations and dispensers.* Challenges exist in determining appropriate locations for fuelling stations, especially in close proximity to urban areas. Factors such as safety and community acceptance should be considered when selecting fuelling station locations. Hazards arise from pressure burst and embrittlement of storage containers.
- Electrolysis of hydrogen: The permeability of the electrolysis membrane to oxygen and hydrogen can lead to the mixing of hydrogen and oxygen under low-power operating conditions (also known as gas cross-over). This phenomenon poses an explosion hazard.
- Ammonia. Transporting ammonia as a carrier for hydrogen involves certain risks. Ammonia is a toxic gas in ambient conditions and can pose health hazards if released into the environment. There is a risk of leaks during the transportation of ammonia, which in turn can potentially lead to explosion hazards under certain conditions.
- ATEX classification. Due to new technology and increased amounts of hydrogen, there is the need to address the potential changes in hazardous area profiles. This may need potential re-classification according to the ATEX directive. Also, modifications may be required to the ATEX directive to align with the new safety requirements.
- Competence and training. Increased risk of accidents and incidents due to inadequate knowledge and skills of involved parties, including new operators, the workforce, and oversight authorities to handle hydrogen-related risks. Oversight authorities play a relevant role in ensuring compliance with safety regulations and standards.
- Standards and regulations. Lack of harmonized standards and regulations poses significant challeng-

es, including the potential for inconsistent safety practices and inadequate risk management.

- Permitting and inspecting. Lack of clear criteria for permitting and inspection of new processes and technologies introduced in the field of hydrogen. This can result in inadequate safety measures and oversight. Furthermore, the permitting procedures themselves may need improving to ensure effective evaluation and regulation.
- Consequence modelling. Lack of comprehensive consequence modelling to reflect the latest understanding of hydrogen characteristics and behaviours in the new use cases. This affects assessing the potential hazards and risks associated with its use in new applications.
- Land-use and emergency planning. Existing accident scenarios and decision criteria for effective land-use and emergency planning may not adequately address the specific risks associated with the new hydrogen uses and applications. This discrepancy can lead to suboptimal land-use decisions, potentially exposing nearby communities to risks. Also, without up-to-date accident scenarios and decision criteria there is a risk of inadequate emergency preparedness and response measures.

As one example of a gap that needs to be addressed, consequence analysis of hydrogen is currently based on limited statistics that tend to create very large hydrogen dispersion distances. Some of the most significant modelling challenges are associated with uncertainties related to the temperature of highly pressurized hydrogen gas and its unique dispersion and reactivity characteristics. In addition, hydrogen fuels are expected to be transported and stored in bulk in liquid form. Currently, there are few modelling tools and a lack of experimental data for this purpose.

For this reason, the time horizon where hydrogen can be scaled up to be widely used as an alternative source of energy is uncertain and may be at least a decade, if at all. For many challenges, there may be an eventual solution, and indeed, the solution may already be in sight. There are various private and public efforts to underway for this purpose.

Indeed, developing a robust and safe infrastructure for producing, storing, and distributing hydrogen requires large-scale investments in the necessary new facilities and technologies. In the early stages of deployment, the initial cost of such investments could lead to a high cost of hydrogen “at the pump”. Over time, the cost of refuelling may become cheaper after advancements in technology and economies of scale are achieved.

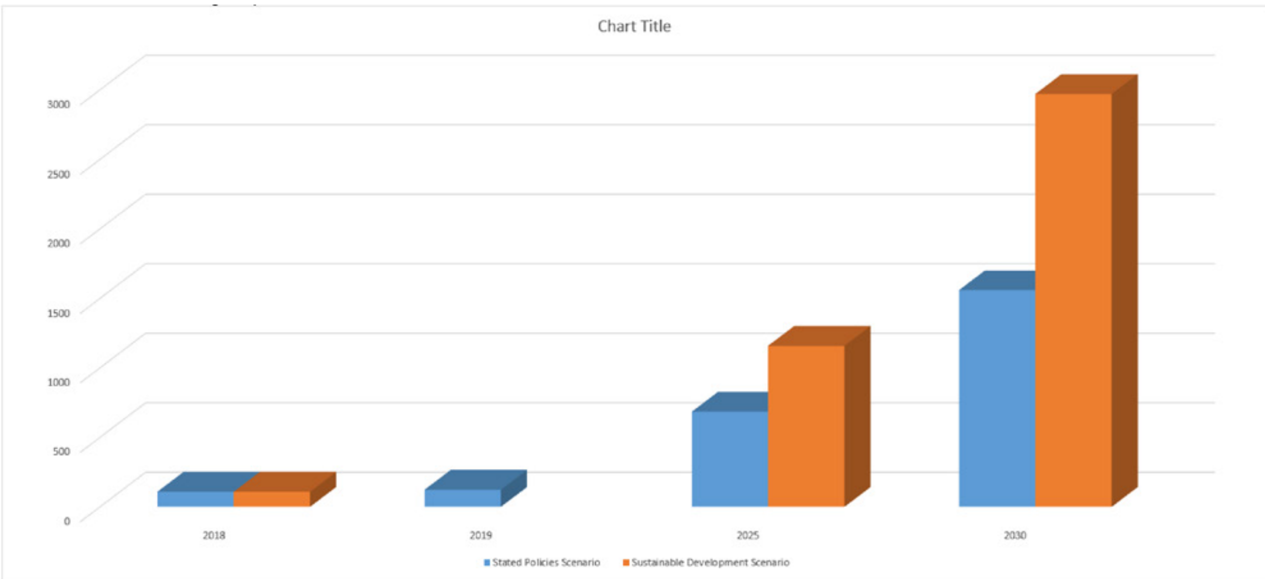
Moreover, as the technology matures, locations and communities exposed to hydrogen risk may increase as networks of production and storage facilities, fuel stations and pipelines are extended across geographic areas. As the technology expands, the risk of hydrogen leakage will become more relevant to a broader population. Communities will need to target mitigation and response strategies to control the hazards, with additional training for responders and potentially new equipment, e.g., new or better detection sensors.

For its part, to help make progress in meeting these challenges, MAHB has been hosting a series of webinars, starting in 2023, for EU and OECD experts and competent authorities intended to foster exchange on these topics. The webinars aim to bring EU and OECD hazardous site inspectors together with hydrogen experts, in both academia and industry, to discuss risks, risk management practices, and strategies that may be needed in future for controlling new sources of risk relative to hydrogen fuels. Many other EU and OECD organisations are conducting research and gathering information that will also hopefully provide the solutions that are necessary before hydrogen fuel becomes mainstream.

4 3 3 Energy risks: Lithium-ion batteries

Battery production, storage and recycling all represent hazardous activities given that batteries are considered a fire and explosion hazard due to their potential for short-circuiting, leaking, and overheating with the latter occurring during a thermal reaction under certain conditions. They also represent health and environmental hazards due to the potential for contamination by toxic materials such as cobalt, lithium, and nickel. While demand is expected to grow in the coming years (see **Figure 33**), safety concerns regarding lithium-ion battery production, storage, usage and recycling need to be addressed. This chapter specifically discusses potential industrial accident risks that may accompany wide spread adoption of lithium-ion batteries for private and public transport and for meeting industrial and commercial energy needs.

Figure 33: Projected Global Annual Li-ion Deployments in xEVs for Scenarios



Source: IEA, 2020 https://www.iea.org/reports/global-ev-outlook-2020

To varying degrees, lithium-ion batteries pose an accident risk across all stages of the life cycle. In production and end-of-life stages (waste disposal and recycling), the risk is that raw materials are released or ignited and hence, the raw materials are exposed (in the case of production) or can be exposed (due to defects that occur in handling or product dismantling). In these situations, the batteries are at a higher risk of causing a chemical accident that can lead to a major fire, explosion and even toxic release (even without a toxic release, fires and explosions are considered a chemical accident if caused by a raw material.) As has been well-documented in the media, lithium-ion batteries themselves can cause major industrial fires when exposed to very high temperatures.

In many cases, these risks are manageable if the appropriate measures are taken. However, there are some situations where measures to control the lithium-ion battery risk may not be practical or are too expensive and therefore, not economically feasible. This chapter describes the risk profile and factors that influence the risk. It is hoped that the information will be useful to policymakers, local authorities, industrial manufacturers and users, waste management operators, and other stakeholders who will be facilitating the adoption of lithium-ion batteries to replace carbon fuels. Notably, this chapter does not address the environmental risks associated with the use of precious metals (e.g., lithium, nickel) in the production of lithium-ion batteries.

In particular, a number of topics that require attention have emerged regarding battery safety for which answers are still being sought. At the moment, there is no central point of reference where battery safety has been systematically addressed for implications at EU or global level. Some scientific articles have been written on particular aspects, including consequence analysis, but an overall picture of potential risks surrounding increased lithium battery usage in the EU and globally has not been the focus of research efforts so far. Risks associated with only some of the facilities that fall within the battery life cycle, mainly production, storage, and waste management sites, are addressed by existing EU legislation. For example, large production and waste management sites may already qualify for oversight under the Seveso Directive (2012/18/EU). Moreover, there are efforts underway at EU level (e.g., intercountry exchange, incident monitoring) to understand and define appropriate mechanisms for managing risks of sites that do not fall under the Seveso Directive, such as battery storage warehouses, and sites with large battery storage units.

While regulatory approaches are already in place or in development, safety measures may be lagging behind in some cases. There are already, and continue to be, publication of new scientific findings, widely available in the scientific literature, that address such topics as accident causality, typical scenarios, modelling parameters, and other aspects, etc. for evaluating risks associated with the handling of lithium-ion batteries in bulk. However, the degree to which this information has been disseminated to operators and oversight authorities is not certain. On the other hand, demand for this type of information, as well as risk management guidance, is increasing and gaps in the knowledge base will likely be addressed at national level if not EU level in due course.

Special attention is particularly needed in regard to major hazard sites, such as Seveso sites, that handle and treat hazardous waste that includes lithium-ion batteries. However, there are also other sites, not covered by the Seveso Directive that could represent a significant hazard, including battery storage warehouses and sites using battery energy storage systems (BESS). Studies of past accidents, that may have been caused, or exacerbated by, the presence of lithium batteries, indicate that lithium-ion batteries can also increase risk at hazardous waste sites. More work and exchange on practices for understanding, preventing and mitigating these risks at hazardous waste sites is needed.

Lithium-ion battery industries in the EU

The EU has supported a modest industry for lithium-ion battery production for the past several years of around 130,000 MhZ per year according to IEA data. In addition, lithium-ion (Li-ion) batteries have been in use for years in many products such as electronics, toys, wireless headphones, handheld power tools, portable computers, small and large appliances, and small electric vehicles, such as scooters and bicycles. Some electronic production companies have their own lithium-ion battery production plants sites, such as Tesla, but all of them use lithium-ion batteries in large volumes. Additional types of facilities that may also handle batteries in large volumes include storage sites and waste management and recycling operations. More recently, capacity for electric vehicle production has also expanded in the EU, especially with the growth in demand for electric vehicles (EVs). According to the European Automobile Manufacturers' Association, EVs and hybrids has doubled its market share, from around 22% to 44%, between 2019 and 2022[22].

Sites that produce handle or store lithium-ion batteries in large volumes are vulnerable to certain chemical hazards. Improper design and manufacturing, and an inadequate safety management system and safety culture, can lead to catastrophic failures, such as fire, thermal runaway, explosion, and release of toxic substances. Other types of industries, including warehouses that store batteries, recycling and waste management facilities, and electronics manufacturers, are also vulnerable to disasters if batteries are exposed to high temperatures, overcharging, or are somehow defective. Commercial industries also

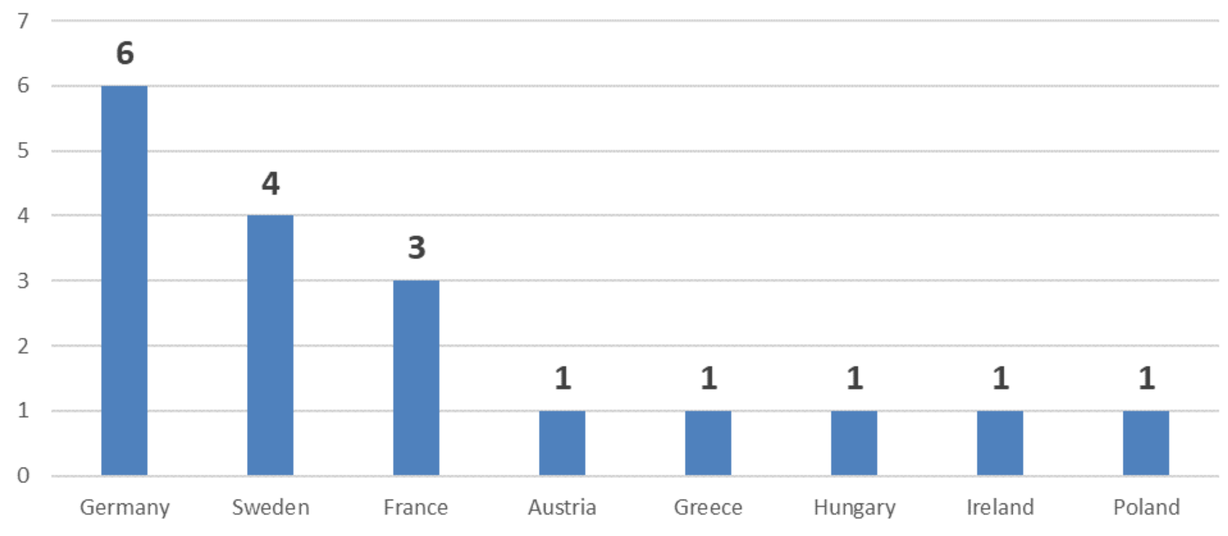
22 https://www.acea.auto/fuel-pc/fuel-types-of-new-cars-battery-electric-12-1-hybrid-22-6-and-petrol-36-4-market-share-full-year-2022/

are at risk of battery fires, notably retail stores selling battery-fuelled vehicles, e.g., bikes and scooters. Sites that use battery energy storage systems (BESS) are another category of industrial site vulnerable to risks from battery failure. Member States will likely need to include such sites in future in land-use planning, especially to ensure that they appropriately distant from major chemical hazards to avoid a domino effect.

Figure 34 shows that there are currently 18 production sites registered as Seveso sites in the EU's eSPIRS database, mostly located in Germany, Sweden and France, associated with electronics and electronic engineering and battery production. With the exception of fireworks, the Seveso Directive does not cover finished products[23] and therefore, the presence of a large volume of lithium-ion batteries does not qualify a warehouse as a Seveso site. There are also hazardous waste management operations covered by the Seveso Directive that may handle electronic products and batteries. It is unclear about the future presence of major hazard (Seveso) sites in the EU that will involve lithium-ion batteries production or waste management.

It is also not certain how much usage of battery energy storage systems will be increasingly used across in industry generally. However, a recent JRC report states that BESS usage by industry in the EU more than doubled from 2020 to 2021 and demand for this energy source is expected to escalate dramatically through 2030 (Bielewski et al., 2022).

Figure 34: Seveso sites identified in eSPIRS as lithium-ion battery production sites



Source: JRC, eSPIRS data, 2022

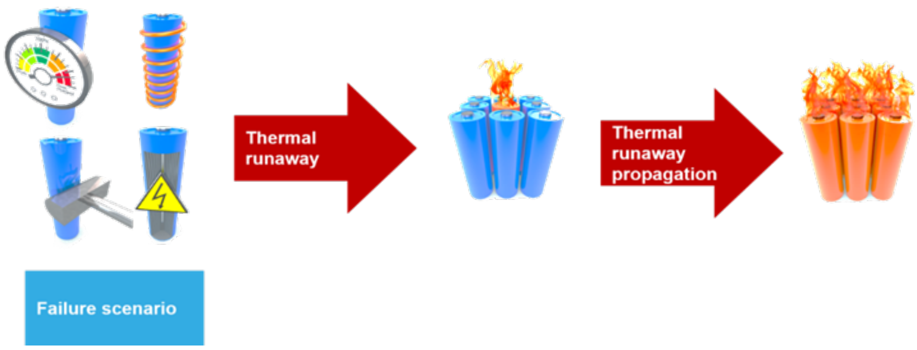
Risks associated with lithium-ion batteries

Lithium reacts strongly with water and air. In the event of loss of containment on the battery or storage cell casing, hydrolysis in the presence of water or humid air can form gaseous hydrogen electrolyte leakage (ionized lithium). Such a reaction can generate an explosion, especially in a restricted or confined space or in contact with an ignition source. Lithium is also known to easily catch fire in the presence of oxygen. As indicated in **Figure 35**, physical damage to the battery casing, exposure to elevated temperatures, design defects, and electrical.

23 Battery production and recycling sites may come under the Directive, depending on whether they meet the Seveso substance criteria thresholds, but not storage. Likewise, electronics production sites can only come under Seveso based on the presence of substances covered by the Directive, and not solely on use of lithium-ion batteries in the form of a finished product.

The hazard associated with lithium-ion batteries may increase at the end of life, where they may be collected, processed, or recycled in waste management operations. They are a particular storage risk in many circumstances (e.g., shipping containers and warehouses, waste management, and various other situations) because it can be difficult for the operator to assess and verify the charge status of the batteries or their specific composition, especially when dealing in large volumes and with a variety of different suppliers. They may not be aware of damaged batteries that are vulnerable to infiltration of water or air. In addition, the packaging, handling, transport and storage operations could result in unforeseen mechanical impacts. Moreover, the hazard may increase depending on the composition of other waste stored with the batteries, particularly if the other waste includes highly combustible or flammable elements.

Figure 35: Thermal runaway propagation of a lithium battery



Source: JRC, 2022

At the moment, there is limited accident history both in terms of battery production and batteries in waste treatment and recycling to provide guidance on potential accident scenarios. However, several events in recent years have raised concerns about battery fires and even transport of battery-powered vehicles. For example, a fire at a warehouse storing around 180,000 to 200,000 pounds of lithium batteries in Morris, Illinois in June 2021 prompted the evacuation of around 4,000 residents for 4 days, due to risk of exposure to toxic fumes. In January 2023, a similar fire incident occurred at a battery warehouse containing thousands of lithium-ion battery packs in Rouen, France (CTIF, 2023).

There have also been numerous fires caused or exacerbated by the presence of lithium-ion batteries in industries not specifically associated with battery production or storage, including waste management and electric vehicle manufacturing. The US Environmental Protection Agency identified 245 incidents that were likely to have been caused, by lithium-ion batteries in the waste (USEPA, 2021). Similar trends have been spotted in the EU by the JRC in the EU's GMI-CHEM database of chemical accidents reported in the global media.

The Library of Reference in Industrial Accidents Analysis (BARPI) of the French Ministry of Environment recently analysed 36 incidents involving lithium batteries (34 lithium-ion and 2 lithium metal polymer batteries) in its ARIA database (that has a far wider scope of industrial facilities than the eMARS database). They studied only incidents occurring in production facilities, large battery storage facilities, and batteries in non-electronic equipment (e.g., not mobile telephones). The incidents all somehow evolved from conditions that caused a runaway reaction (see **Figure 35**), often because of a defect or degradation in one or more of the batteries, caused by errors in production, testing, repair or maintenance, as well as, in a few cases, inappropriate storage conditions. (BARPI, 2022)

Most recently, there has been considerably visibility in regard to massive fires involving a large volume of cars packed together in a confined, or partially confined space. In October 2023, an enormous fire enveloped a large indoor parking lot fire at Luton Airport, United Kingdom (2023) (Skye News, 2023), destroying around 1,500 cars, a collapse of the car park structure, and suspension of all incoming and outgoing flights for 18 hours. Moreover, fires involving car parks on ferries carrying electronic vehicles (Fremantle Highway, Stena Scandica) (BBC, 2023; DMAIB, 2023) have brought further attention to potential increased risk when there is a percentage of electric vehicles in the mix.

At the moment, reports and preliminary indications from these ferry and car park incidents do not seem to point to EVs as a critical contributor. Notably, fires in parking garages in Liverpool, United Kingdom (2017) and at Stavanger airport in Norway (2020) do not implicate the presence of electric vehicles in causality. (MS&FR, 2018; Storesund et al.,2020) Rather, outdated fire suppression systems, increased flammability of car parts in general, and electrical faults in building infrastructure, cited as the main contributing factors.

However, some expert communities, notably the shipping industry and the insurance industry, continue to have concerns that, as the EV market share increases, the potential for EVs to play a more significant role in future disasters will increase. (Nautilus International, 2023; Browne Jacobsen, 2023; Autoweek, 2022), While their predictions cannot be conclusively confirmed or refuted, there are lessons learned from recent car park and ferry incidents for a number of actors, including EV vehicle engineers, fire fighters, builders, architects, and permitting authorities, to name a few. If adopted in a timely fashion, the changes that they implement as a result of these events may have a realistic chance of reducing the risk before such fears are realized.

Battery energy storage systems and energy transition

A battery energy storage system (BESS) is a type of energy storage system that uses batteries to store and distribute energy in the form of electricity, with lithium-ion batteries being the most popular type of BESS. There has been a considerable increase in the use of BESS systems in the EU, notably in Italy and France, but most likely in many other EU countries. There are a number of incentives that make the use of this technology attractive for certain industries but also elevate hazard exposure. (Barelli et al., 2021) Electricity production must much consumption within the power grid. Hence, these systems are considered one of the fundamental pillars in the energy transition allowing energy from multiple sources to be stored for later use. This includes excess electricity coming from wind or solar farms as well as power from the grid during periods of low demand. There are several advantages of BESS such as:

- Peak shaving (management of energy demand)
- Load shifting (shift consumption when energy grid costs are high)
- Integration with renewable energy sources capturing the excess electricity
- Less dependency on the power grid

Despite the numerous advantages, BESS have been involved in a number of serious accidents, such as: a thermal runaway and explosion at a BESS power station in April 2021 in Beijing, China, which resulted in the death of two firefighters and the fire (Beijing Emergency Management Bureau, 2021, and China Electric Power Technology, 2021). In April 2019, a cascading thermal runaway and deflagration at a BESS facility in Arizona, USA caused four firefighter injuries (McKinnon et al., 2020) A shelter-in-place was issued in November 2017 at Drogenbos, Belgium following a fire of a BESS and the release of toxic fumes during trials on storing 20MWh of renewable energy. (Vollmacher, 2022) Moreover, between 2017 and 2019, South Korea experienced at least 28 fire accidents involving BESS leading to extensive regulatory inspections and the shutdown of more than 500 BESS stations. (Barelli et al., 2021; Conzen et al., 2022)

According to various reports, there were a number of factors that contributed to these incidents. In large part, the causes were attributed to one or more of the following conditions:

- Poor temperature control
- Cell defects

- Damage during construction and transportation
- Operation of the BESS outside of design/specified parameters (i.e., temperature, humidity, charge rate, and state of charge)
- Poor operational control
- Insufficient protection systems against electrical faults (i.e., short circuits)
- Poor integration of BESS systems (battery/energy/power management systems)

Although it is not expected for independent/standalone BESS stations to be covered by the Seveso Directive (since battery units are considered finished products), the risks of introducing these stations within or in the vicinity of hazardous installations should not be overlooked. Critical points include addressing the inherent fire hazards within risk assessment, partitioning and safety distances onsite, proper land use planning as well as establishing adequate and up-to-date emergency procedures and training to respond to potential fire scenarios involving lithium-ion BESS.

Other risk considerations in a future lithium-ion fuelled economy

Minerals such as cobalt, lithium, manganese, nickel, and graphite, are crucial components of lithium-ion batteries. There may be concerns over the sustainable supply of these critical materials as the lithium-ion based electric market grows. Currently, most of the world's lithium reserves are concentrated in a few regions, which could lead to potential geopolitical risks and supply disruptions.

In addition, there are concerns about the environmental impacts (and social) of lithium mining and processing, which can lead to water scarcity, land degradation and/or land displacement, and the increased amount of fossil energy required to extract and process the mineral. In addition, as the lithium-ion batteries demand rises, the safe disposal and recycling of used lithium-ion batteries will become of ecological concern as well as liability and investor risk concerns. Safety will become increasingly relevant as there is an increase in manufacturing, handling and using large-format lithium-ion batteries such as those used in BESS.

In sum, there is still much more that needs to be explored and understood in order to ensure that the EU and other parts of the world are prepared for managing new and greater safety risks that will accompany the widespread use of lithium-ion batteries as a replacement for hydrocarbon energy sources. The greatest danger is that proliferation of production, storage, and recycling sites, as well as large battery energy storage systems, occurs faster than the ability for operators and authorities to develop mechanisms and practices that assure effective prevention, preparedness and response to incidents.

4 3 4 Hybrid threats

Hybrid threats constitute a combination of different tools, some expected and known, some unexpected and clandestine, applied to achieve an undeclared strategic objective, and without officially admitting of doing so as they are designed to remain below the threshold of detection and attribution. The common denominator for hybrid threat actors is their desire to undermine or harm democratically established governments, countries or alliances. By their very nature, hybrid threats constitute a risk to European values, governments, countries and individuals.

Hybrid threats have become increasingly common over the past 10-15 years, and we can fully expect them to grow both in frequency and impact in future. Their overarching aim is to constrain the freedom of manoeuvre of democracies in order to discredit its model compared to authoritarian regimes or gain other advantages over democracies. In particular, hybrid threat actors may be characterised by their wish to:

- undermine and harm the integrity and functioning of democracies by targeting vulnerabilities of different domains, creating new vulnerabilities through interference activity, exploiting potential weaknesses, creating ambiguity and undermining the trust of citizens in democratic institutions;
- manipulate established decision-making processes by blurring situational awareness, exploiting gaps in information flows, intimidating individuals and creating fear factors in target societies; and
- maximise impact by creating cascading effects, notably by tailoring attacks, combining elements from specific domains to overload even the best prepared systems, with unpredictable, negative consequences.

Hybrid threats have a strong cross-border aspect by nature and cannot be countered only at national and/ or regional level, therefore a concerted effort across Europe, involving all relevant partners, is crucial.

Role of the JRC

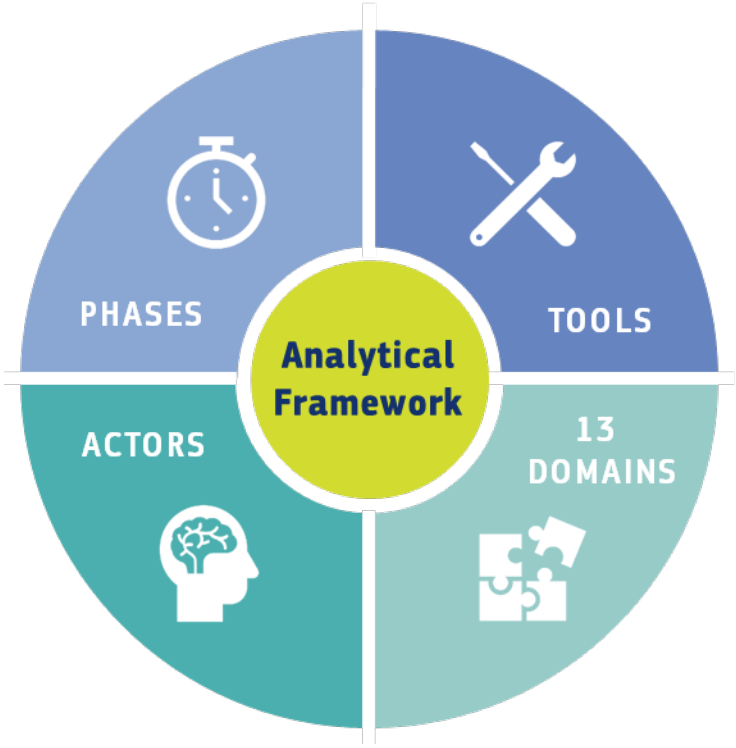
In 2020, the JRC together with the Centre of Excellence for Countering Hybrid Threats (HCoE) published “The landscape of Hybrid Threats: A conceptual Model" (Cullen et al. 2021) The conceptual model covers the key elements that form the landscape of Hybrid Threats: (a) the **actors** that apply hybrid mechanisms, (b) the **phases** of a hybrid campaign, (c) the **tools** applied, and (d) the **domains** targeted, in order to achieve the hostile actor’s strategic objectives (**Figure 36**). The report proposed an analytical framework which since its publication became the de-facto standard when speaking about Hybrid Threats in the EU and its Member States.

As outlined in recent EU policy initiatives such as the “Communication on the EU Security Union Strategy[24] and “A Strategic Compass for Security and Defence”[25] we are seeing fast-moving developments and an increased level of sophistication in hybrid threats. As not all vectors of hybrid threat activities can be foreseen, building resilience against hybrid threats is crucial. Resilience against hybrid threats needs to be designed and implemented at all levels, and has to consider resilience measures, not only from multiple domains’ perspective but also as a comprehensive ecosystem approach. In other words, developing resilience against hybrid threats necessitates looking beyond resilience in individual areas, building it systemically while considering dependencies and interdependencies between the different parts of society. To address this issue, a systems-thinking approach to hybrid threats, with representation of society as a whole is needed. In “Hybrid Threats: A Comprehensive Resilience Ecosystem”, Jungwirth et al. 2023 a model to facilitate decision-making for policymakers is suggested.

24 COM(2020) 605

25 A Strategic Compass for Security and Defence https://www.eeas.europa.eu/sites/default/files/documents/strategic_compass_en3_web.pdf

Figure 36: Graphical representation of the Conceptual Model



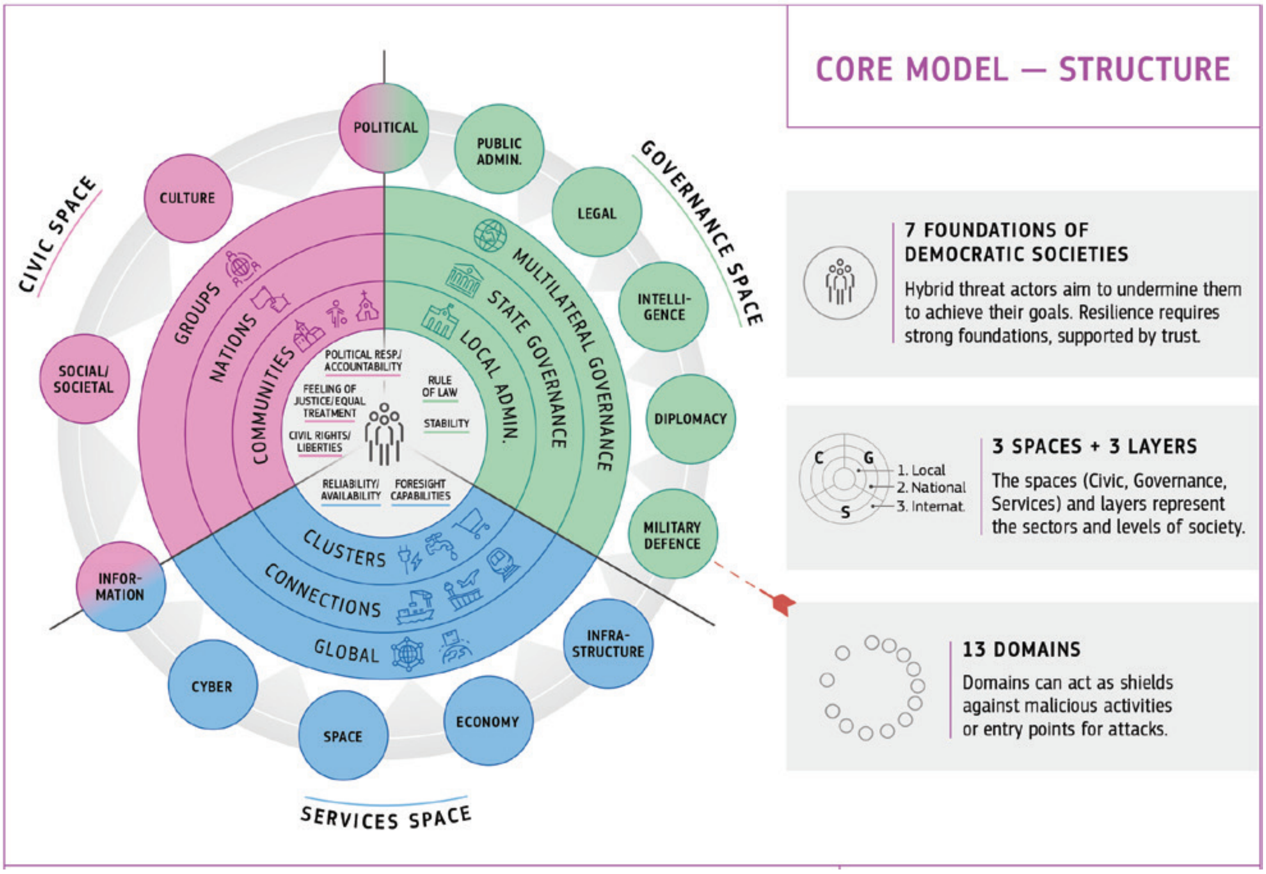
Source: Giannopoulos et al. 2021

The Comprehensive Resilience Ecosystem (CORE) model allows policymakers to estimate how adversaries employ hybrid threats in order to alter democratic decision- making capabilities. It shows how the hybrid threat activity bit by bit challenges democratic systems by introducing different types of stress. It also allows monitoring the dependencies and possible cascading effects. This is important for the detection of hybrid threats. Foresight plays a crucial role in this process. The CORE model is based on the following elements (**Figure 37**):

1. Seven foundations of democratic systems lie at the heart of the ecosystem. The foundations are the ultimate goals that hybrid threat actors aim to undermine, while scoring some of their own strategic interests.
2. The domains from the conceptual model also are an integral part of the ecosystem. If resilience is well developed in the domains, they can act as shields against malicious activities. On the other hand, a lack of resilience in the domains can open entry points for hostile actors.
3. The ecosystem consists of three spaces – Civic, Governance and Services – which represent the three sectors of society.
4. The layers of the ecosystem represent the different 'levels' that exist in society – from the more local levels to international levels.

The connections between the four types of elements represent the whole-of-society approach. Since elements are interconnected, resilience-building measures for one element will affect other elements, positively or negatively. Actors behind hybrid threats aim to exploit the various elements and their interconnectedness to maximise their impact. Therefore, policymakers need to understand the interdependencies between the various elements, in order to build resilience against hybrid threats and for early detection of malign activity.

Figure 37: Graphical representation of the CORE model



Source: Jungwirth et al., 2023

Hybrid threats, characterized by their complex and multifaceted nature, pose significant challenges to national security and international stability. As evidenced by the situation in Ukraine, these threats can indeed escalate into full-blown conflicts, demonstrating the need for robust and adaptable crisis management frameworks.

Looking forward, it is important that MSs and international bodies collaborate to enhance their understanding and mitigation strategies for hybrid threats. The way forward involves several key initiatives and actions such as:

- Engaging the private sector, particularly technology companies and critical infrastructure providers, is essential in protecting against cyberattacks and disinformation campaigns
- Educating and involving the public can be a force multiplier in recognizing and responding to hybrid threats. Communities that are informed about the nature of these threats are less likely to be influenced by disinformation.
- Building a consensus on the definition and response to hybrid threats at international forums such as the United Nations, NATO, and the European Union can help streamline and strengthen the global reaction.
- Updating national and international legal frameworks to better address the unique challenges posed by hybrid threats is necessary. This includes laws related to cybersecurity, foreign interference, and emergency powers. On that regard, JRC released a SWD(2024) 12 final[26], on a gap analysis on hybrid resilience baselines at EU level .

26 Sensitive distribution, exclusively on a need to know basis.

- Conducting table top exercises that simulate hybrid threat scenarios can help prepare governments and societies for the complex dynamics of a real-life crisis.
- As projected, the element of hybrid threats should be integrated more comprehensively into national risk assessments to ensure that potential vulnerabilities and response strategies are identified pro-actively.
- National emergency and crisis management plans must be dynamic and flexible, allowing for rapid adaptation as hybrid threats evolve.
- Investing in research to understand the psychological, social, and technological aspects of hybrid threats will aid in developing more effective countermeasures.

Finally, recognition of hybrid threats as a significant concern is only the first step. The real test lies in the integration of this awareness into practical, coordinated actions that go beyond traditional security measures. It will require a holistic approach that leverages the strengths of diverse sectors and fosters resilience at all levels of society, the so-called whole-of-society approach. By staying ahead of the curve with pre-emptive measures and strong partnerships, we can hope to mitigate the risks posed by these complex challenges.

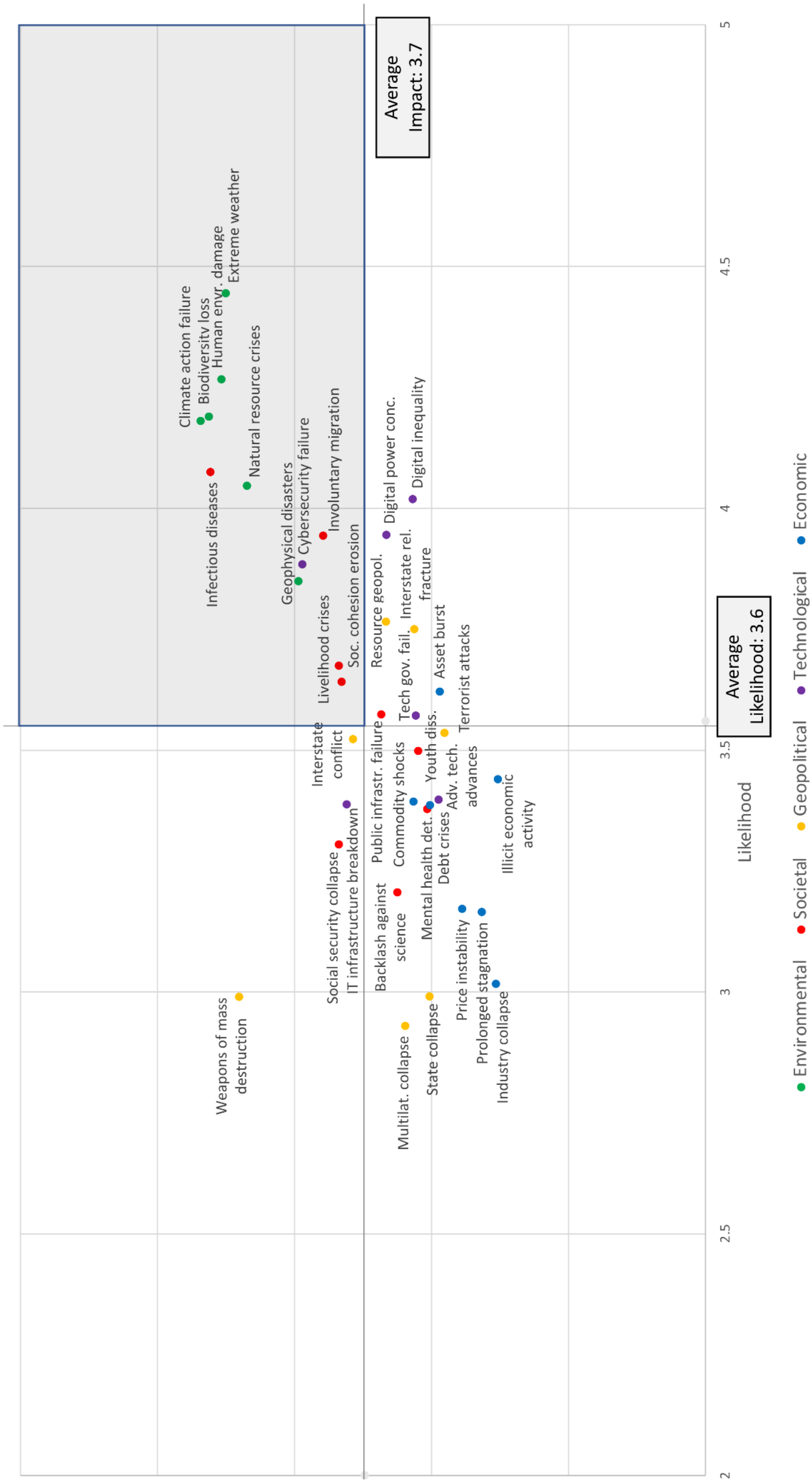
4 3 5 Biodiversity loss

Biodiversity corresponds to the variety among all living organisms on Earth and the ecological complexes of which they are part. This includes diversity within species, between species and of ecosystems. Besides having an intrinsic value, **biodiversity is a vital asset for human societies** as it provides essential services for human existence and well-being (Millenium Ecosystem Assessment, 2005). This includes provisional services (e.g., provision of food, medicine, and energy), regulation services (e.g., regulation of climate, air quality, and water quality) and cultural services (e.g., spiritual, recreational and educational). Currently, unsustainable use of natural resources is driving biodiversity to decline worldwide faster than at any time in human history, putting at risk current and future well-being (IPBES, 2019).

Recent major reports have highlighted the risk that biodiversity loss represents for human lives by altering the services that biodiversity provides. The first one is the global and regional assessment reports on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES; Brondízio et al., 2019; IPBES, 2018) providing independent, interdisciplinary and extensive reviews on the status, trends, and future of the links between people and nature (Díaz et al., 2019). The second one is the global risks assessment report of the World Economic Forum (WEF; World Economic Forum, 2021), based on a survey of business leaders on their perception of global risks. The third one is the risk perceptions report of the global network of scientists Future Earth (FE; Future Earth, 2021), based on a survey of scientists on their perception of global risks. The WEF and FE surveys respectively ranked it at the top 4th and 2nd risk in terms of impact and at the top 5th and 3rd risk in terms of likelihood (**Figure 38** and **Figure 39**), though business leaders tend to underestimate the urgency compared to scientists (Garschagen et al., 2020; FE, 2021). Both surveys further highlighted that biodiversity loss was strongly inter-connected to four other global risks – failure to take climate action, infectious disease, extreme weather events, and human environmental damage – that, together, may lead to a global systematic crisis. The risk of biodiversity loss is also well recognised at policy level, both in the EU Biodiversity Strategy for 2030[27] and the Kunming-Montreal Global Biodiversity Framework[28], and is since 2021 one of the risks considered in the Recommendations for National Risk Assessment for Disaster Risk Management in EU (Poljansek et al., 2021). Therefore, the scientific, business and policy contexts converge in identifying biodiversity loss as a major global risk that needs urgent consideration.

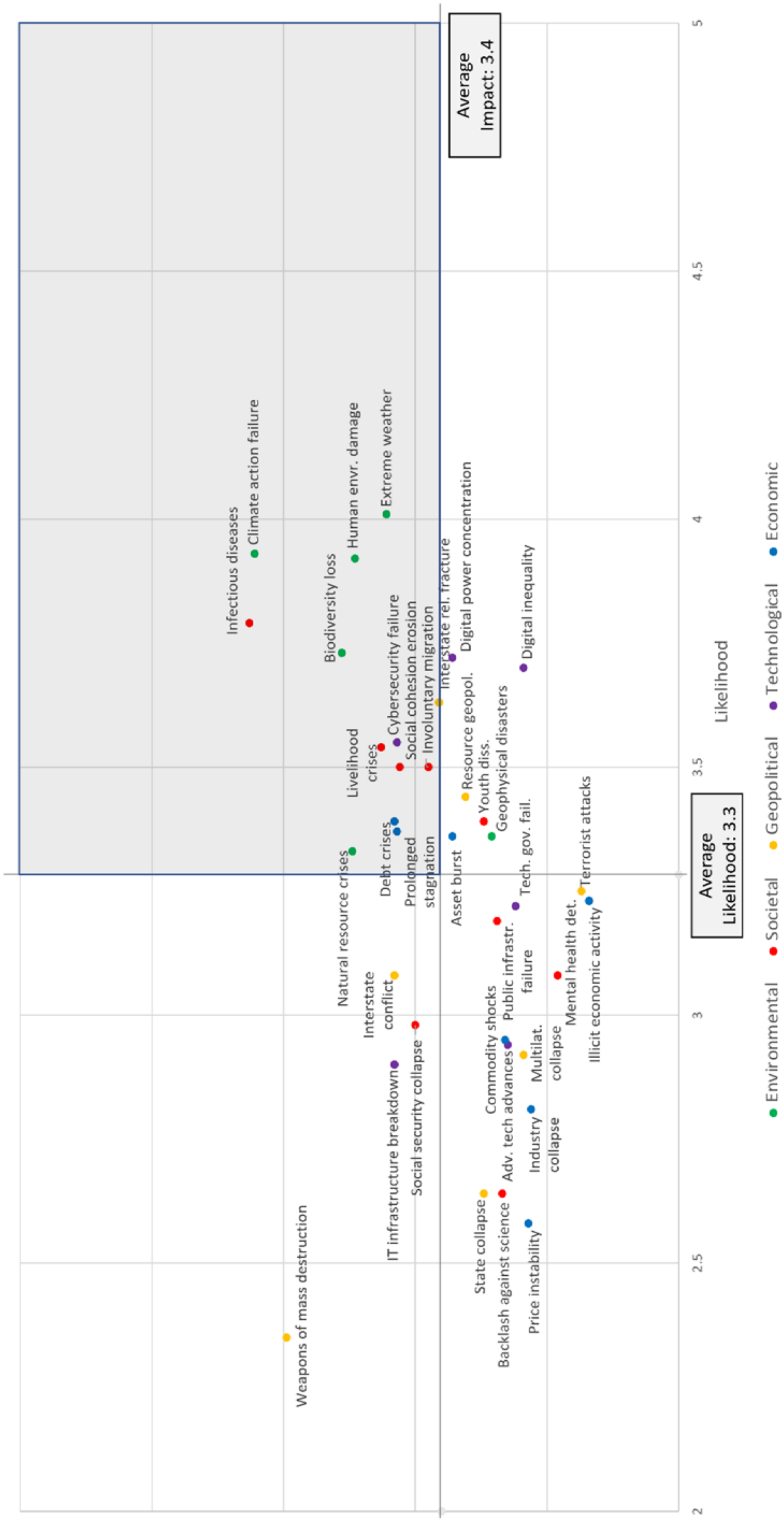
27 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0380
28 https://www.cbd.int/doc/decisions/cop-15/cop-15-dec-04-en.pdf

Figure 38: The Global Risks Landscape 2021 perceived by scientists



Source: Future Earth, 2021

Figure 39: The Global Risks Landscape 2021 perceived by business leaders



Source: Future Earth, 2021

Risks related to biodiversity loss

The IPBES global and regional assessment reports (Brondízio et al., 2019; IPBES, 2018) provide the most extensive and up-to-date information (more than 15.000 scientific publications) on past biodiversity loss, the direct and indirect drivers of biodiversity decline, and risk of biodiversity loss under different future scenarios. They consider the services that biodiversity provides to humans through the lens of nature's contributions to people (NCPs), referring to all the contributions that humanity obtains from nature (see Chapter 3 in Brondízio et al., 2019).

Globally, most of the >50 indicators used to assess past trends in biodiversity since 1970 show a net deterioration (see Chapter 2 in Brondízio et al., 2019). For instance, the abundance of naturally present species has declined by 23% on average in terrestrial communities; and the global biomass of mammals has fallen by 82%. The observed declines in biodiversity have resulted in declining NCPs for 14 out of the 18 categories: while more food, energy and materials than ever before are now being supplied to people in most places, this frequently undermines nature's many other contributions such as pollination and regulation of air and freshwater quality. Recent work on the link between biodiversity and human health has also highlighted that biodiversity loss appears to increase the risk of human exposure to both new and established zoonotic pathogens (e.g., Keesing et al., 2021).

In Europe and Central Asia, including the sub-regions of Western and Central Europe that encompass all EU countries, trends in biodiversity between 1950 and 2016 are quite like global ones: biodiversity is deteriorating in all ecosystems (IPBES, 2018). Similarly, to the global trends, biodiversity declines in Europe and Central Asia have resulted in the alteration of NCPs. There are negative trends for most nature's regulating, and some non-material, contributions to people. Importantly, the population of Europe and Central Asia uses more natural resources than are produced within the region and depends on net imports of natural resources. Some of these imports negatively affect biodiversity and NCPs in other parts of the world. This is why the assessment of biodiversity loss at the EU level should not only consider the EU territories but encompass the entire globe.

Drivers of biodiversity loss

Global declines in biodiversity and NCPs are due to **5 main direct drivers**, which are (by order of importance):

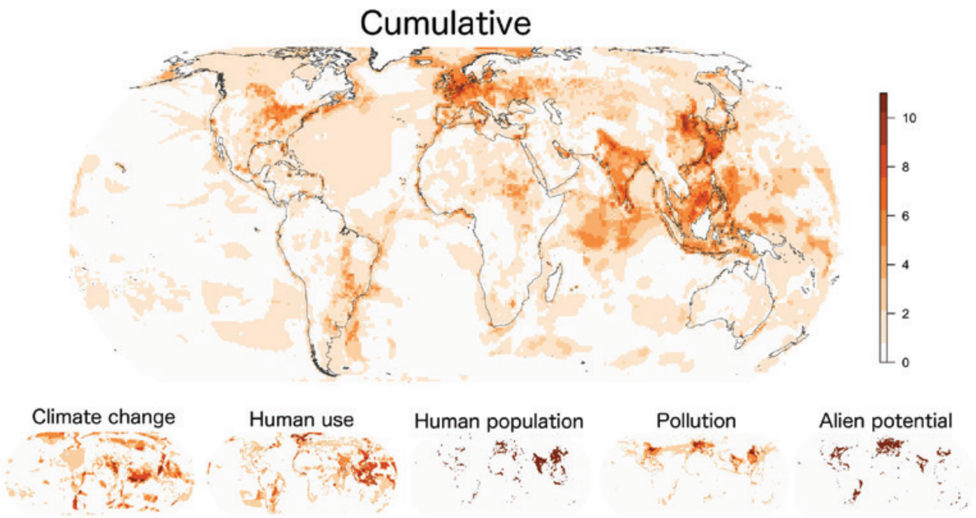
Land/sea use change and its consequences, including an increasing fragmentation and thus decreasing connectivity of natural and semi-natural areas
Direct exploitation (first driver of biodiversity decline for the marine realm) and its consequences, including land degradation
Climate change associated with global warming and changes in weather patterns
Pollution (e.g., plastics, nutrients) and its consequences, including eutrophication (i.e., the enrichment of water by nutrients resulting in degraded water quality)
Invasive alien species (plants, animals, pathogens and other organisms that are non-native to an ecosystem, and which may cause economic or environmental harm or adversely affect human health).

Such direct drivers result from an array of underlying societal causes (e.g., human population dynamics, land demand, consumption patterns, and trade) which are called indirect drivers.

The direct drivers of decline in biodiversity and NCPs in Europe and Central Asia are the same than at the global scale, although their relative importance is not as clear. Land use change is one of the major direct drivers of biodiversity and NCPs declines, and, although protected areas have expanded, this alone cannot prevent biodiversity loss. The impact of climate change on biodiversity and NCPs is increasing rapidly and is likely to be among the most important drivers in the future, in particular in combination with other drivers. Natural resource extraction, pollution and invasive alien species continue to negatively impact biodiversity and NCPs.

The drivers (direct and indirect) of biodiversity decline can be interpreted as the hazards biodiversity is facing. Bowler et al. (2020)the spatial relationships among different drivers, and whether they differ between the terrestrial and marine realm has yet to be examined. 2. We compiled global gridded datasets on climate change, land-use, resource exploitation, pollution, alien species potential, and human population density. We used multivariate statistics to examine the spatial relationships amongst the drivers and to characterize the typical combinations of drivers experienced by different regions of the world. 3. We found stronger positive correlations among drivers in the terrestrial than in the marine realm, leading to areas with high intensities of multiple drivers on land. Climate change tended to be negatively correlated with other drivers in the terrestrial realm (e.g., in the tundra and boreal forest with high climate change but low human use and pollution used the best available knowledge to comprehensively map these hazards across the planet, first individually and then cumulatively. **Figure 40** shows regions of the world exposed to high intensities of multiple drivers. The main map shows the number of the 16 driver variables for which each grid cell was in the highest 10% of values within each realm. Regions in the darkest orange are exposed to high intensities of multiple variables, whereas those in off-white are exposed to lower intensities (i.e., within the 90% quantile of values) of all variables. The smaller plots below show the same for each of the separate drivers.

Figure 40: Regions exposed to high intensities of multiple drivers



Source: Bowler et al., 2020

Risk analyses of biodiversity loss

There are several **qualitative and quantitative** methodologies to analyse the risk of biodiversity loss, which differ regarding the drivers they address and the biodiversity indicator(s) they use to characterize the impact. To best picture risk, the methodology should be quantitative, address all the drivers of biodiversity loss and document the impacts using a set of indicators that comprehensively represent biodiversity and the services it provides under multiple scenarios (UNISDR, 2017). However, such methodology does not exist yet for biodiversity loss. Best methodologies currently available globally provide quantitative forecasts of biodiversity and/or the services it provides under multiple scenarios, but they address a limited number of drivers (e.g., IPBES, 2019; Leclère et al., 2019; Schipper et al., 2019).

For example, the IPBES global assessment report (IPBES, 2019) used multiple models to forecast the combined impacts of land use and climate change on biodiversity and NCPs in the different regions of the world. Three scenarios archetypes are proposed (see chapter 4 in Brondízio et al., 2019): global sustainability combines proactive environmental policy and sustainable production and consumption with low greenhouse gas emissions, regional competition combines strong trade and other barriers and a growing gap between rich and poor with high emissions, and economic optimism combines rapid economic growth and low environmental regulation with very high greenhouse emissions. They can be interpreted qualitatively or quantitatively in terms of possible futures for drivers of biodiversity loss (e.g., Kim et al., 2018). The results show that biodiversity and nature's regulating contributions to people are projected to decline further in most scenarios of global change over the coming decades, while the supply and demand for nature's material contributions to people that have current market value (food, feed, timber and bioenergy) are projected to increase. However, the magnitude of the impacts on biodiversity and NCPs is expected to be smaller in the scenario of global sustainability.

Quantitative forecast modelling can also be conducted at European (e.g., Veerkamp et al., 2020) and national scales (e.g., Princé et al., 2015). Quantitative approaches can also be complemented by more qualitative ones using evidence based literature like for instance, in the IPBES regional assessment for Europe and Central Asia (IPBES, 2018) where results showed trade-offs between the different biodiversity indicators and related NCPs. The scenarios for Western and Central Europe, prioritizing an increase in food provision through agricultural expansion or intensification, led to trade-offs with regulating contributions to people and biodiversity. The scenarios assuming pro-active environmental decision-making and cooperation between countries or regions were the most effective in mitigating these negative trade-offs and could even lead to positive impacts on biodiversity and NCPs.

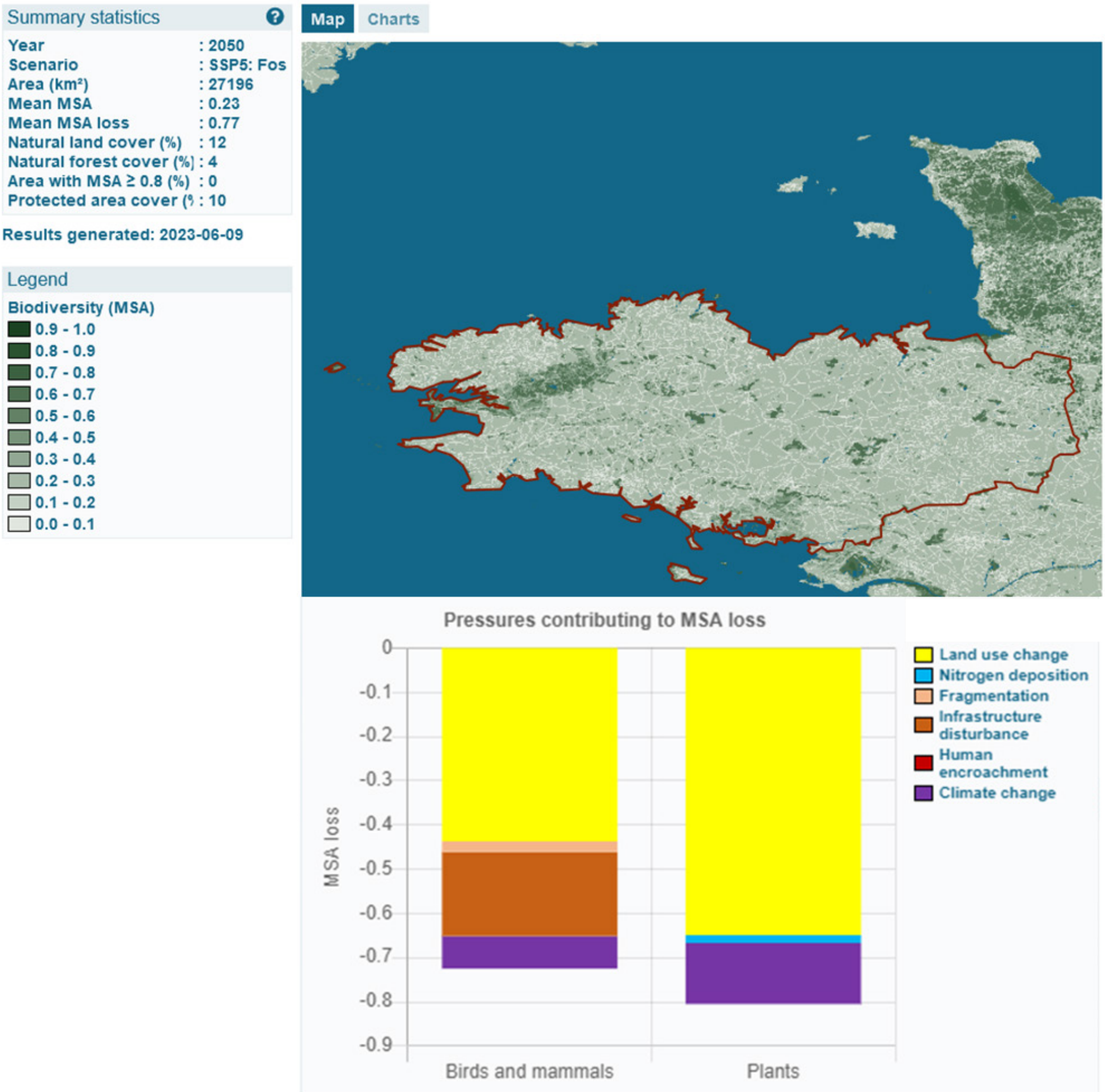
Importantly, the above mentioned examples and most scientific studies only consider a few drivers in scenarios of biodiversity loss (mostly climate change and land use) so they likely underestimate the projected (negative) impacts. In addition, risk analysis of biodiversity loss, and especially quantitative modelling of projected impacts, is very demanding in terms of technical and analytical skills – which makes it very challenging for policymakers to develop on their own. Three avenues for policymakers wishing to assess risk of biodiversity loss at national scale are nonetheless possible:

- Collaborate with scientific experts in quantitative forecast modelling for biodiversity to develop new risk analysis of biodiversity loss relevant for the country. This is probably the most appropriate avenue to have risk analyses adapted to the country profile, focusing on the drivers of biodiversity loss that are the most relevant for the country and making the most of the data available at national scale, but this requires to find and fund scientific collaborators.
- Focus on current exposure of the country to the risk of biodiversity loss, without searching to forecast biodiversity loss and its consequences under different scenarios. For this avenue, policymakers can find information on the drivers of biodiversity loss and the conservation status of species and/or habitats by country on platforms such as the Digital Observatory for Protected Areas[29] or the Biodiversity Information System for Europe[30].
- Use already developed quantitative forecast models made accessible to policymakers through platforms or software. For this third avenue, and although it shows limitations in terms of drivers of biodiversity loss and indicators to represent biodiversity loss, the only operational tool currently available to our knowledge is Globioweb[31]. This platform allows the user to forecast future biodiversity intactness (expressed as Mean Species Abundance) for a specific region under three scenarios (sustainability, regional rivalry and fossil-fueled development), and taking into account six drivers of biodiversity loss (land use, road disturbance, fragmentation, hunting, atmospheric nitrogen deposition and climate change). An example of the outputs of this tool is provided in **Figure 41**. As research on quantitative forecast modelling for biodiversity is flourishing, it is likely that other oper tional tools allowing policymakers to assess risk of biodiversity loss will become available over the next years.

29 DOPA EXPLORER https://dopa-explorer.jrc.ec.europa.eu/
30 BIODIVERSITY INFORMATION SYSTEM FOR EUROPE https://biodiversity.europa.eu/countries
31 GLOBAL BIODIVERSITY MODEL FOR POLICY SUPPORT https://www.globio.info/globioweb

Figure 41: Outputs from Globioweb forecasting the future of biodiversity intactness in 2050 for the region of Brittany (France) under the scenario "fossil-fueled development".

The upper panel shows summary statistics as well as a map of biodiversity intactness (expressed as Mean Species Abundance). The lower panel highlights the pressures contributing to loss of biodiversity intactness for birds and mammals on the one hand and plants on the other hand. Under this scenario, Brittany is expected to have a decrease of 77% in biodiversity intactness mainly due to land use change



Source: JRC, 2023 (based on outputs generated by Globioweb)

4 3 6 Financial risks

Europe is facing challenges associated with the rapid digitalisation of our society, the impact of climate change, and the recent surge in commodity prices. The capacity to navigate these structural changes will depend on the possibility to ensure an efficient allocation of investments into the real economy. Owing to the pivotal role of the banking sector in supporting the real economy, it is crucial to comprehensively understand the challenges and risks faced by the financial sector in order to ensure long term financial stability. In an ever-changing world, especially considering the current challenging economic environment, banks and other financial intermediaries may face pressures on their balance sheet and experience a significant decline in the quality of their assets. Concerns regarding assets quality may arise due to increased credit risk stemming from the deteriorating macroeconomic outlook and the energy crisis triggered by geopolitical tensions. Depending on the extent of banks' exposure to affected economic sectors, a surge in defaulted loans could significantly erode banks' capital base and slow down credit expansion. While future risks can never be completely ruled out, establishing a regulatory framework that promotes resilience within the European financial system is essential to mitigate potential systemic events, support economic growth, and facilitate the green and digital transition.

This chapter offers an overview on the regulatory actions undertaken by the EU to substantially reduce the risk of systemic crises. Finally, the chapter delves into the challenges ahead, as the structural changes that come with the green and digital transition and expose banks to a number of emerging risks.

Financial resilience

The story behind the events of the 2008 global financial crises serves as a concrete example of the implications systemic financial risks have on the economy and society. It underscores the significance of timely and appropriate policy responses. All in all, financial crises are not so different from humanitarian or environmental emergencies, as they all have repercussion on assets and, ultimately, on people. Therefore, policymakers should be prepared to act swiftly, protect citizens, and take decisive actions to enhance the resilience of the system by reducing the probability and impact of future crises.

During that period, the EU experienced a decline of approximately 4% in GDP, and the number of unemployed people in the EU-27 rose by 5.4 million between March 2008 and May 2009 (Hodson and Quaglia, 2009). Regulators at global level emphasized the urgent need to enhance risk management frameworks, reduce moral hazards, and prevent contagion effects within the banking system. The aim was to avoid situations where the default of one institution could have adverse effects on the rest of the system or extend beyond the banking sector itself. Consequently, the regulatory framework underwent evolution, with efforts focused on building a more resilient European financial system and preventing the fragmentation observed during the global financial crisis.

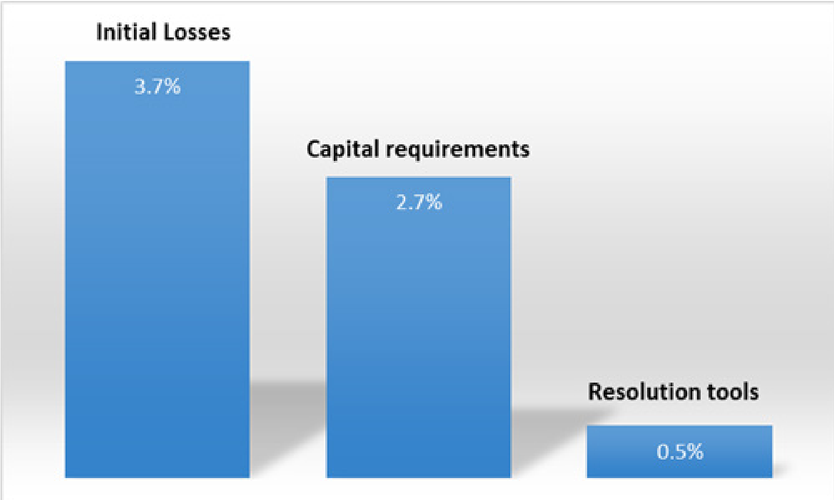
Over the subsequent decade, the EU implemented several policy measures commonly known as the "financial safety net". These measures aimed to safeguard financial stability and minimize costs borne by taxpayers in the event of banking crises. This included rules to determine the appropriate level of capital in relation to the riskiness of each bank[32], as well as the introduction of an insolvency[33] and resolution[34] framework. This framework provided a set of instruments applicable at different stages of the lifecycle of distressed banks.

Of course, these financial reforms yielded positive outcomes supported by scientific evidence. A study conducted by the European Central Bank (ECB) (in 2020), reveals a significant increase in the euro area

32 575/2013 Capital Requirement Regulation and 2013/36/EU Capital Requirements Directive IV
33 2014/69/EU Deposit Guarantee Scheme Directive
34 2014/59/EU Bank Recovery and Resolution Directive

banking system' ability to absorb losses while minimizing costs to taxpayers. This is attributed to the reduction in banks' probability of default since 2007 and the boost in their loss-absorbing capacity through larger capital buffers and the new resolution framework. Furthermore, empirical research by Benczur et al. (2016) assesses the overall reduction in potential public finance costs resulting from the adopted policies. The results indicate a decrease in final contingent losses from 3.7% of EU GDP to 0.5%. Specifically, increased capitalization reduces financing needs by approximately 30%, while the resolution tools played a significant role in reducing financing need by 60% (see **Figure 42**). Deniz et al. (2022) document the resilience of banks during the COVID-19 pandemic, with their findings highlighting these reforms as drivers of such resilience. Finally, the European Commission (2022) supports the general view that the implementation of the financial regulatory agenda aided banks in maintain resilience during the pandemic.

Figure 42: Public finance losses due to banking crises (% EU GDP)



Source: EC, JRC elaboration (Benczur et al., 2016)

Despite the progress made in promoting a stable and integrated financial system in the European Union, there remain unresolved issues that could leave small-medium banks vulnerable under adverse circumstances (Bank for International Settlements, 2020, Parisi at al 2020, Bellia et al. 2023a). In response, the European Commission (2023) recently adopted a legislative proposal for a comprehensive review of the bank crisis management and deposit insurance framework to further enhance rules for handling bank failures while safeguarding taxpayers. Bellia et al. (2023a) contributed to this revision by conducting a broad assessment of policy options for managing bank crises in an orderly and economically efficient manner, while protecting financial stability and depositors and reducing reliance on taxpayers' money. Among other findings, the authors find that harmonization at the EU level and higher levels of protection for temporary high deposit balances (up to 500 000 EUR) - resulting from important life events such as real-estate transactions – would safeguard households' wealth and enhance financial stability.

Considering the challenges ahead and the need to maintain consumer confidence to avoid events similar to the recent banking crises involving US and Credit Suisse, there is much to be done to prevent fragmentation and ensure a financial sector that fulfils its role in society. One area of improvement refers to the establishment of a common depositor protection mechanism, notably a European scheme that guarantees coverage for all deposits up to 100 000 EUR. Bellia et al. (2023a) demonstrate that such a system would cover 90%-95% of deposits from taxpayers that would otherwise remain unprotected under the status quo. This would represent a significant step towards reinforcing financial stability, reducing vulnerability to local shocks, and ensuring that depositor confidence in a bank is not dependent on its location.

Future risks: climate change and environmental degradation

In recent years, there has been a growing focus on the impacts of climate change and environmental degradation. It is now widely recognized that these issues are not just long-term concerns, but have the potential to generate short-term stresses in the financial and economic sector. These challenges could become a new source of financial instability, with risks spreading throughout the entire financial system and being amplified through feedback loops between the financial sector and the real economy.

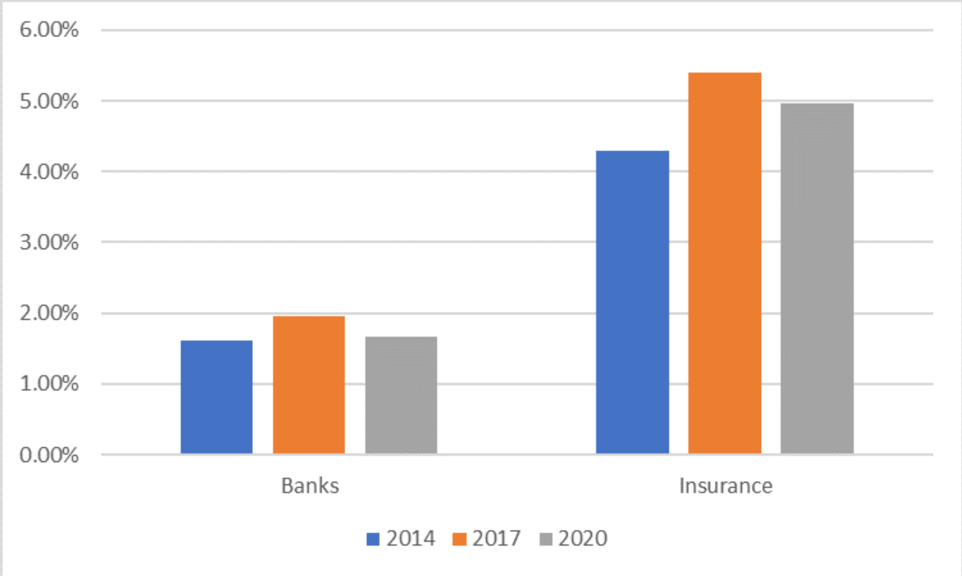
Financial risks arising from climate change and nature-related risks can be categorized into two groups. The first category is transition risk, which stems from the financing economic activities that will need to be either abandoned during the low-carbon transition or will be affected by more stringent regulations aimed at preserving or restoring nature and ecosystem services. Examples of such activities include fossil fuel-related sectors, energy-inefficient production processes and buildings, or industries with a high impact on nature. The risk lies in the possibility of relevant physical assets, such as coal mines, becoming stranded and resulting in financial losses. Since investors look ahead, uncontrolled financial dynamics could lead to sudden depreciation of 'high-carbon' financial assets at any time. The second type of financial risk associated with climate change is physical risk, which arises from climate-related catastrophic events becoming more frequent and severe owing to climate change, as well as the loss of nature and ecosystem services resulting from the depletion of natural capital. Banks could be negatively affected if their borrowers are unable to repay their debts due to events like floods or hurricanes, which cause losses and damages to their real estate properties, plants, and facilities. Similarly, firms in specific regions, for example those in the agricultural sector, may face difficulties owing to heatwaves and droughts, leading to an increase in unlikely-to-pay and non-performing loans.

Ensuring the resilience of banks and financial institutions to these risks is of paramount importance to prevent failures and safeguard the financial system. The financial industry, as a whole, needs to identify, measure, and monitor these risks. One approach developed by Battiston et al. (2017) and Alessi and Battiston (2022) calculates the share of a financial portfolio that will be impacted by the climate transition (**Figure 43**). Additionally, the JRC RDH[35] is a designated platform for collecting geolocalised data on climate-related losses in the new Strategy on Adaptation to Climate Change[36]. By coupling this data with information on collateral and plants, it is possible to quantify the financial exposure to physical risk. For instance, the ECB (2023a) has recently published analytical indicators on the percentage of the banks' portfolio at risk due to floods, wildfires, landslides, subsidence, windstorm and water stress. Furthermore, in terms of nature-related loss, Hirschbuehl (2023) quantifies the share of production of listed European firms exposed to at least one ecosystem service, while Becker et al (2023) find that exposures to biodiversity risks are high across the largest European banking sector. A recent ECB (2023b) study reveals that 75% of bank loans are to firms dependent on ecosystem services.

35 See: https://drmkc.jrc.ec.europa.eu/risk-data-hub.

36 https://climate.ec.europa.eu/eu-action/adaptation-climate-change/eu-adaptation-strategy_en

Figure 43: Share of transition risk exposure of financial investments of selected financial investors

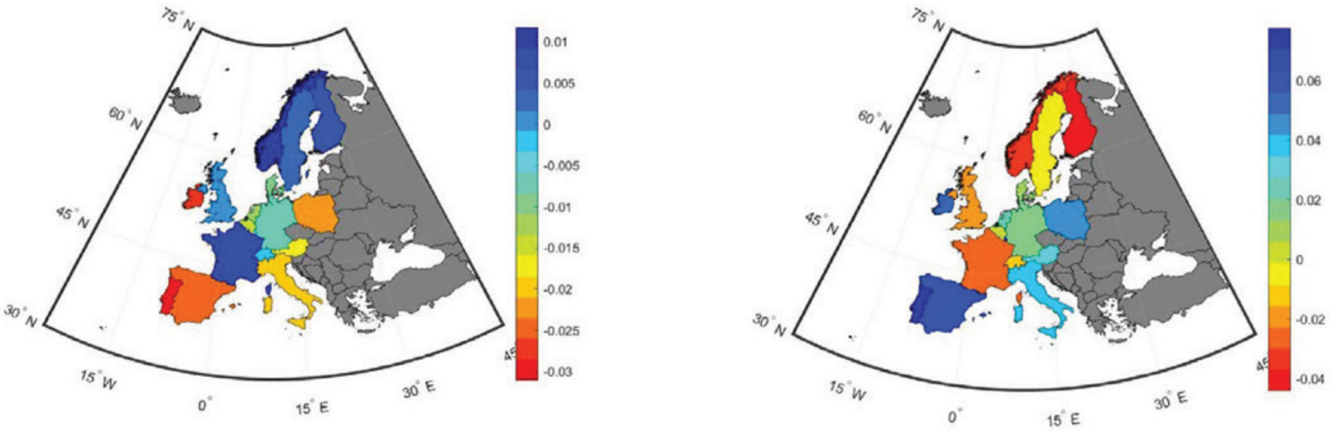


Source: EC, JRC elaboration (Alessi and Battiston, 2022)

The next step is to understand the consequences of these risks at both the individual and systemic levels.

Although quantification of nature-related financial risks is still in its early stages, several scientific studies have conducted stress tests to provide quantitative evidence of the potential losses due to climate-related physical and transition risk. For example, Ojea-Ferreiro et al. (2022) suggest that for European financial firms the climate transition risk varies widely across financial institutions. Banks experience more systemic impacts in the disorderly transition scenario than in the hot house world scenario, while the opposite occurs for the other financial firm types, but especially for real estate firms (see **Figure 44**). Alessi et al. (2022) estimate that a sudden repricing of assets financing polluting activities could lead to losses of around 400 billion for the EU banking system, equivalent to 1% of total assets or 3% of GDP, just below the amount of losses due to the Global Financial Crisis. Focusing on climate-related physical risk, a study by Bellia et al. (2023a) quantifies that bank losses triggered by flood events could increase substantially under a 3°C scenario, potentially reaching 1% of total bank assets in regions prone to such geographic risk. While insurance can help reduce the overall cost for taxpayers by transferring risk, there are limitations due to concerns about insurability and affordability. Bellia et al. (2023b) emphasize the urgent need for adaptation and mitigation strategies to manage climate-related financial risks. The authors' report that 33 billion of assets in the EU are exposed to floods each year, with only about a quarter covered by insurance. The analysis shows that an increase of EUR 10.8 billion in written premium (+58%) is needed to level up the insurance climate penetration in the EU to at least 50%. The paper also estimates that uninsured floods, when considered together with potential insurance defaults, have the potential to generate EUR 27 billion in public finance contingent losses every year, and that reducing the climate protection gap by increasing insurance penetration could lower this impact by up to 50%. Finally, Fatica et al. (2022) find that an average flood deteriorates firms' assets by about 2% and their sales by about 3%, without clear signs of full recovery even after 8 years. A subsequent paper (Barbaglia et al., 2023) shows that firms exposed to a flood event are up to 30% more likely to default on their loans in the two years following a disaster.

Figure 44: Climate-related risk at country level: the maximum possible loss (deterioration in their returns in percent) of a financial institution under a disorderly transition scenario (on the left) and a hot house world scenario (on the right)



Source: JRC elaboration (Ojea-Ferreiro et al. 2022)

In light of the scientific evidence, it is crucial to enhance the resilience of the financial system to climate and environmental risks. One option is to increase capital buffers to account for increased risks, as suggested by (Alessi et al. 2022). Another approach is for financial institutions to promote their counterparts' green transition, rather than simply cutting credit lines to high-carbon counterparties, which could have potentially systemic consequences. Similarly, in relation to physical risk exposures, financial institutions should encourage the adoption of climate adaptation measures by their counterparts.

Future challenges: digital transition

The increasing influence of digitalization and new technologies is shaping the lives of European citizens, necessitating the European financial sector to expand its digital operations and embrace innovation. The introduction of more innovative products is beneficial for consumers and improves market efficiency. Notably, digital finance has the potential to offer citizens direct and cost-effective access to a wide range of services and financial options. This empowers individuals to make sustainable investments, manage their savings, and handle payment using new instruments. Since digital finance is driven by technology, it is essential to consider the broader aspects of the technologies involved in the digital transformation of finance, including distributed ledger and blockchain. For example, Anderberg et al. (2019) explore various issues related to blockchain and its impacts.

From a financial stability perspective, the growing influence of digitalization and new technologies presents both opportunities and challenges. Even positive disruption in the financial sector could pose risks if not properly designed and managed. These risks include cybersecurity threats and data breaches, which need to be addressed through robust security measures and regulatory framework. Although new products and services, potentially offered by unregulated operators, enhance access to financial services, they also leave room for fraud or misuse, exposing consumers to risks. Digital currencies, in particular, are gaining traction and warranting careful examination of their intrinsic risks and impacts on the global market. Van der Auwera et al. (2020) provides a detailed examination of the inherent risks associated with cryptocurrencies. Flore (2018) early on assesses the disruptive potential of digital currencies in the global remittance market, which serves as a critical channel for foreign currency in many nations. Bellia and Schich (2020) find evidence that the design and collateral of stablecoins are crucial for their stability. Petracco Giudici and Di Girolamo (2023) and Bellia and Cales (2023) explore the potential impacts of different levels of substitution of the digital euro for bank deposits on bank balance sheets and profitability.

Their findings suggest that demand scenarios up to 3000 euro digital euro take-up per household do not pose risks to financial stability on an aggregate level, although they do have asymmetric impacts across banking systems and could lead to shifts in the structure of balance sheets and interbank markets. High levels of digital euro adoption may present challenges to the profitability of banks, particularly for small banks that heavily rely on deposits as a finding source, potentially leading to substantial decreases in profits. Despite the risks, digital finance has also the potential to enhance financial stability through improved efficiency, accessibility, and monitoring capabilities. The use of technology and digital platforms enables quicker risk identification and intervention, transparent financial transactions, reduced costs and better access to financial services. Striking a balance between risk management, regulatory measures, and the benefits of digital finance is crucial to ensure a stable and secure financial environment.

By leveraging the opportunities presented by digitalization while mitigating associated risks, the European financial sector can create a stable and secure environment that promotes innovation, consumer welfare, and market efficiency. It is crucial for financial institutions, regulators, and policymakers to collaborate and stay proactive in adapting to the evolving digital landscape to ensure the resilience and sustainability of the financial system in the digital age.

4 3 7 Armed Conflict risks

Armed conflict remains one of the biggest threats of our time. Following a relative decline in violence in the early 2000s, the number and intensity of violent conflicts have increased in recent years. The ongoing war in Ethiopia, Russia's invasion of Ukraine and the Gaza war have led to a sharp rise in conflict-related fatalities, making 2022 the deadliest year since the Rwandan genocide of 1994 (Davies et al., 2023).

While internal conflicts still far outnumber conflicts between states, the latter have also become more frequent. In addition to the war in Ukraine, smaller interstate conflicts in recent years include Kyrgyzstan-Tajikistan, Israel-Iran, India-Pakistan and India-China, while concerns mount over a potential Chinese invasion of Taiwan. Moreover, civil wars are becoming increasingly internationalized, (Davies et al., 2023) as seen for example in Yemen, Syria or the Democratic Republic of the Congo, where rival states have intervened by supporting opposing sides.

Beyond the tragic losses of human life and the destruction of infrastructure, violent conflict can have other far-reaching effects. These can include economic devastation, social disruption, famines, health crises, mass migration, and environmental damage. Additionally, large-scale violence can spread across regions, potentially destabilizing nearby states or drawing them into the conflict. The best way to avoid these outcomes is to prevent emerging conflicts before they descend into large-scale violence.

Effective conflict prevention requires an understanding of the root causes of conflict, as well as the capacity to detect potential conflicts at an early stage. This chapter explores the current understanding of key conflict risk factors and summarizes recent advancements in the development of conflict early warning systems.

Defining Armed Conflict

This brief uses conflict definitions by the Uppsala Conflict Data Program (UCDP), which differentiate between the following types of conflict:

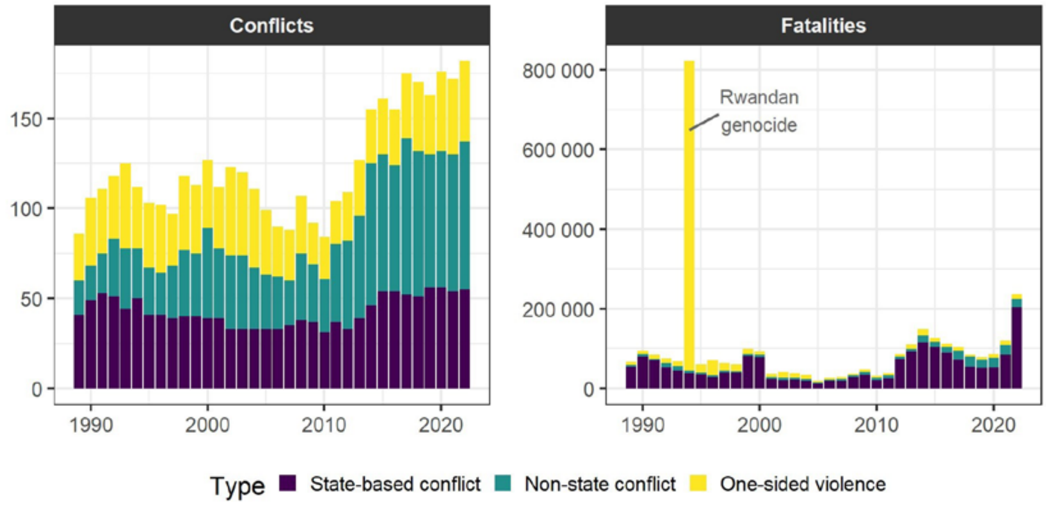
- **Interstate Conflicts** involve violent conflict between the governments of two or more internationally recognized independent states.
- **Internal or Intra-state Conflicts** are violent conflicts that occur within the boundaries of a single state, and may take several forms:

- **State-based Conflicts** are fought between a state government and non-governmental groups, also referred to as civil conflicts or civil wars.
- **Non-state Conflicts** involve clashes between two or more non-governmental groups.
- **One-sided Violence** refers to scenarios where governments or non-government deliberately use violence against unarmed civilians.

To differentiate armed conflict from other types of violence, researchers commonly use a fatality threshold. For instance, UCDP designates violent episodes as armed conflict if they result in at least 25 battle-related fatalities within a year. Another key characteristic of armed conflicts is that violence is carried out by organized actors, and typically revolves around stated political disputes.

Figure 45: Trends in armed conflict, 1989-2021.

The number of armed conflicts has risen in recent years, mostly due to an increase of non-state conflict. Conflict-related fatalities nearly doubled from 2021 to 2022, mainly as a result of the Ethiopian civil war and Russia's invasion of Ukraine. Note: The "state-based conflict" category includes both interstate and internal conflicts.



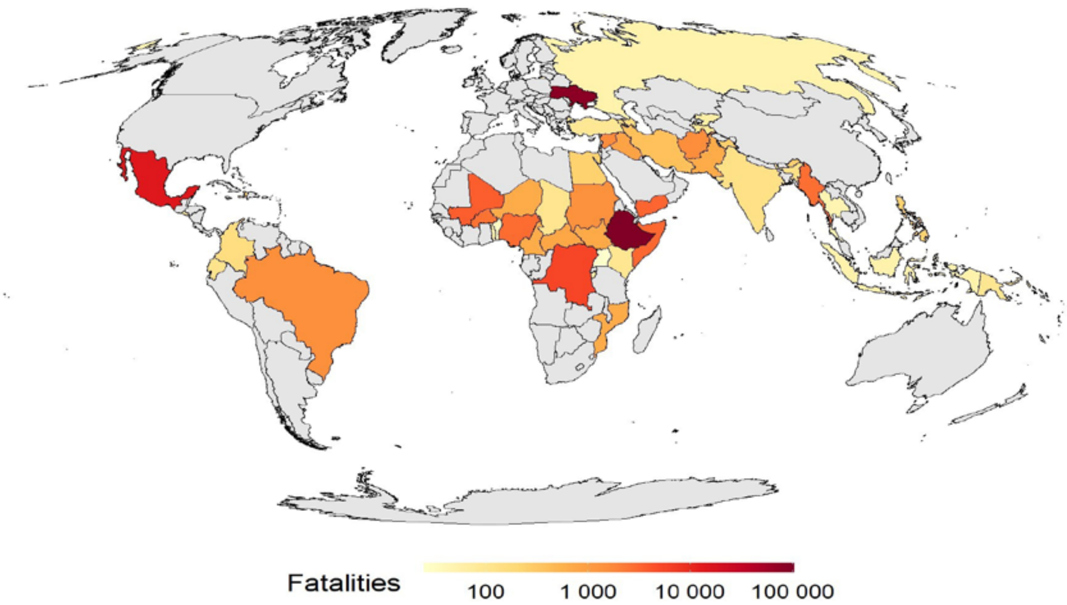
Source: Uppsala Conflict Database Program (UCDP)

Armed conflict: Root causes and risk factors

In the last three decades, a large research literature has studied the root causes of conflict. Much of this work leverages quantitative data and statistical methods to determine correlations and causal links between specific variables and the risk of conflict. While this field of research continues to evolve, there is a growing consensus around a set of key risk factors, divided into the following categories:

Political institutions: Internal conflicts occur mainly in countries with weak state capacity, where governments are less able to maintain political order (Fearon et al. 2003). Within these countries, remote areas with limited state presence tend to be more prone to conflict (Müller-Crepon et al., 2021). Democracies are less likely to enter into wars with other democracies and to use violence against their own citizens compared to other states (Hegre, 2014). However, semi-democratic states seem to have a higher risk of internal conflict than either full democracies or autocracies (Hegre, 2014).

Figure 46: Conflict-related fatalities in 2022



Source: UCDP

Socio-economic factors: Countries with low levels of economic development are most susceptible to internal conflict (Hegre et al., 2006). One possible explanation is that the absence of economic opportunities or relative deprivation may motivate young men to join armed groups (Blattman et al., 2010). Several studies have found that political and economic inequality between ethnic groups may also heighten internal conflict risk. In particular the exclusion of ethnic groups from political power can stoke resentment and incite mobilization against the state (Stewart et al., 2011; Cederman et al., 2013). Some research also suggests that countries with greater gender equality are less conflict-prone, but this relationship remains less well understood (Forsberg et al., 2015).

The conflict trap: Most conflicts concentrate in areas that have already experienced conflict in the past (Hegre et al., 2006). Conflicts can cause lasting economic setbacks that can further destabilize countries. Furthermore, past violence can generate lasting resentment among societal groups, while the proliferation of arms and existing rebel networks can lower the threshold for renewed violence (Bara, 2018). Conflicts also frequently spread across borders (Buhaug & Gleditsch, 2008). For example, armed groups often use neighbouring countries as safe havens (Salehyan, 2011), which can cause internal strife to escalate into broader regional conflicts (Gleditsch et al., 2008).

Climate change and conflict: Experts generally agree that climate change affects the risk of internal conflict (Mach et al., 2019). Climate change may exacerbate pre-existing risk factors such as poverty and food insecurity, while climate-related scarcity can generate conflict among societal groups that compete over the same resources (Eberle et al., 2020). However, compared to other risk factors, the impact of climate on conflict has been very small thus far (Pörtner et al., 2019). Moreover, the link between climate and conflict depends on a variety of other factors, including the location and timing of climate events, pre-existing inequalities and tensions between groups, and a society's overall resilience. A significant source of uncertainty is how conflict risk will behave under future climate scenarios that lack historical precedent (Mach et al., 2019).

Conflict forecasting

Building on recent insights into important conflict risk factors, conflict researchers are also developing more comprehensive models to estimate near-term conflict risk. Such conflict forecasting models can alert policy makers about potential conflicts that might otherwise be overlooked and can help to identify priority areas for conflict prevention (Hegre et al., 2017).

Existing models typically project conflict risk several months or even years into the future. Some models are designed to evaluate overall country risk, while others aim to identify potential conflict hotspots within specific countries. The purpose of forecasting models is not to predict each individual conflict, but to provide general risk assessments using recent historical data. Such data is fed into machine-learning models capable of analysing complex relationships between variables, identifying patterns, and make predictions based on large quantities of data. These predictions are continually validated against actual conflict outcomes, allowing researchers to regularly assess and improve a model's accuracy.

Conflict forecasting models typically combine data on past conflicts in an area and its neighbouring regions with information on protests, political tensions, socio-economic variables, and political risk factors. Some models also consider geographical, demographic, and climate-related indicators. This data is gathered from a variety of sources, which may include expert assessments, large-scale processing of news reports, government statistics, and geo-spatial data such as maps and satellite imagery.

While conflict forecasting models are becoming increasingly accurate and reliable, significant challenges remain. For instance, while models can accurately identify most instances of conflict, they often struggle to anticipate conflicts in previously peaceful countries (Mueller & Rauh, 2022). Other challenges include predicting the scale of conflict and assessing the risk of rare types of conflict such as interstate wars. In a broader sense, forecasting models may fail to capture complex behavioural patterns and historical contingencies, and data limitations can cause models to overlook important developments (Cederman & Weidmann, 2017). Therefore, it remains crucial to supplement the output of predictive models with other sources of information, including qualitative data and expert assessments.

Armed conflict: Risks to the EU

In recent years there has been an alarming increase in the frequency and magnitude of violent conflicts worldwide. Although the risks of armed conflicts within the EU are substantially lower than in other regions, the threat is not negligible. Notably, Europe remains vulnerable to terrorist attacks. In some cases, terrorism threats are mostly "home-grown", while others are directly linked to foreign actors and conflicts abroad, such as ISIS in Iraq and Syria. Furthermore, Russia's Invasion of Ukraine in 2022 has prompted serious concerns about a possible resurgence of interstate wars. In January 2024, German Defence Minister Pistorius warned that Russia could attack a NATO country within 5 to 8 years (Camut, 2024). Finally, violent conflicts outside of the EU can create additional risks and challenges for Member States, such as increased refugee flows, growing risks of humanitarian disasters and disease outbreaks and the risks of internal conflicts escalating into broader regional wars, as shown most recently in the case of Gaza.

Given the far-reaching and destructive consequences of armed conflict, it remains essential to invest in effective conflict early warning and prevention. This in turn requires in-depth knowledge about the root causes of conflict, coupled with state-of-the art data analysis tools and expert knowledge, and close collaboration between researchers, country experts and policy makers.

Conflict Early Warning: EU Initiatives

The increasing availability of data and recent advancements in machine learning have enabled the development of new conflict forecasting systems in both academic settings[37]

and within international organisations and governments. Since 2014, the EU has developed its own Conflict Early Warning and Analysis Toolset, which aims to inform and guide EU foreign and security policy, particularly in conflict prevention and peacebuilding, through evidence-based and data-driven conflict analysis and risk assessment. Quantitative conflict monitoring and risk forecasting tools play a key role in this system, helping to identify emerging conflicts at an early stage.38

The Global Conflict Risk Index (GCRI) provides one of the main inputs into the EU Conflict Early Warning and Analysis Toolset. Developed by the DG.-JRC the GCRI assesses conflict risk for 140 countries over the upcoming four years. These projections are based on data on 22 conflict risk factors and are updated annually (Schvitz et al., 2022). The European External Action Service (EEAS) combines GCRI data with qualitative assessments to annually select up to five countries as priority targets for conflict prevention efforts.

More recently, the JRC developed the Dynamic Conflict Risk Model (DCRM), which provides sub-national conflict risk estimates within the same 140 countries up to six months ahead. The DCRM is updated monthly and uses near-real time information on conflict and protest events, combined with a wide range of political, socio-economic, geographic, and climate-related indicators. Whereas the GCRI gives policy makers an overview of country-level conflict risk in the medium term, the DCRM offers more frequent updates on short-term conflict risk at the local (sub-national) level. This makes the DCRM particularly suitable for ad-hoc analyses and continual monitoring and conflict analysis activities conducted out by EEAS and its partnering DGs. Both models together with other analytical tools for conflict monitoring and forecasting are available on the Science4Peace portal developed and maintained by the JRC.39 Through the use of these tools, and their combination with qualitative data and expert input, the EU is in a better position to anticipate and mitigate conflict risks, in line with the Common Foreign and Security Policy.

37 Prominent examples of academic forecasting projects include the Violence and Impacts Early Warning System (VIEWS) or the Conflict Forecast Project. See: https://viewsforecasting.org/ and: https://conflictforecast.org/.

38 For more information on the EU Conflict Early Warning and Analysis Toolset, see the Joint Staff Working Document: https://data.consilium.europa.eu/doc/document/ST-12580-2023-INIT/en/pdf

39 Science4Peace https://drmkc.jrc.ec.europa.eu/initiatives-services/global-conflict-risk-index#documents/1435/details/27561/science4peace-a-quantitative-toolkit-for-conflict-early-warning-and-crisis-management-

4 3 8 Disinformation

The exposure of citizens to large-scale disinformation[40], including misleading or outright false information, is a major challenge for Europe. While disinformation is not a new phenomenon, it became much more widespread in recent years. Thanks to social media, anyone can create content and disseminate it on a much greater scale than ever before. The uncovering of information operations aimed at influencing democratic processes has shown that disinformation poses a substantial threat to democracy by hampering citizens' abilities to make informed decisions. Moreover, recent developments, such as Russia's military aggression (and information war) against Ukraine and advances in generative Artificial Intelligence (AI), have highlighted the dangers of disinformation to modern society. In addition, disinformation erodes trust in institutions and in digital and traditional media and harms our democracies. It can polarise debates, create or deepen tensions in society and undermine electoral systems and have a wider impact on European security. It impairs freedom of opinion and expression, a fundamental right enshrined in the Charter of Fundamental Rights of the European Union41. Within this context, fighting disinformation in the era of social media and online platforms has to be coordinated among all relevant actors, from institutions to social platforms, from news media to single users.

The European Commission is working to implement a clear, comprehensive and broad set of actions to tackle the spread and impact of online disinformation in Europe and ensure the protection of European values and democratic systems.

European Commission initiatives

The European Commission has been at the forefront of the fight against disinformation, with several initiatives. In 2017, the topic of disinformation become particularly important and the EU released a "Communication on tackling online disinformation: a European approach"42. The document outlines the European Commission's strategy to combat online disinformation and emphasises the need for transparency. It empowers users, safeguards the integrity of elections, and promotes a coordinated European approach.

In view of the increased risks of manipulation of electoral process and in the context of the European Parliament Elections in 2018, the European Commission released a "Communication on securing free and fair European elections"43. The document aims to ensure the resilience of the Union's democratic systems, where disinformation affects the integrity and fairness of the electoral process and citizens' trust, and as such challenge democracy itself.

Both communications highlight the role played by the civil society and the private sector in tackling the spread of disinformation. They were the base for the "Action Plan against Disinformation"44 in 2018. The Action Plan focuses on four key areas serving to build EU's capabilities and strengthen cooperation between Member States by:

- Improving detection, analysis and exposure of disinformation;
- Stronger cooperation and joint responses to threats;

40 Disinformation is "verifiably false or misleading information that is created, presented and disseminated for economic gain or to intentionally deceive the public, and in any event to cause public harm", European Commission Communication "Tackling online disinformation: a European approach" https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52018DC0236 (2018)

41 EU Charter of Fundamental Rights https://ec.europa.eu/info/aid-development-cooperation-fundamental-rights/your-rights-eu/eu-charter-fundamental-rights_en

42 Communication - Tackling online disinformation: a European approach https://digital-strategy.ec.europa.eu/en/library/communication-tackling-online-disinformation-european-approach

43 Securing free and fair European elections https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52018DC0637

44 Action Plan on disinformation https://commission.europa.eu/publications/action-plan-disinformation-commission-contribution-european-council-13-14-december-2018_en

- Enhancing collaboration with online platforms and industry to tackle disinformation; and
- Raising awareness and improve societal resilience.

In April 2018, the Commission proposed an EU-wide Code of Practice on Disinformation[45] to support an independent network of fact-checkers, and online platforms to stimulate quality journalism. The Code of Practice is voluntarily and its first version sets out commitments to mitigate the spread of disinformation, including improving transparency, ensuring the integrity of advertising and preventing monetisation of disinformation.

In 2020, the Commission adopted the European Democracy Action Plan[46]. The Plan sets out a comprehensive response, building on existing EU work and firmly rooted in European values and principles. It aims to strengthen EU democracy and address disinformation challenges.

Later during the same year, with the increase of health-related disinformation and the evolution of COVID-19 pandemic, the EU launched a programme to counter disinformation related to the COVID-19 pandemic – COVID-19 disinformation monitoring programme[47]. The programme involves close cooperation with online platforms, fact-checkers, and public authorities to keep people informed about the virus and vaccines, and to identify and debunk false information. It aims to ensure accountability towards the public of the efforts made by platforms and relevant industry associations to limit online disinformation related to COVID-19.

The European Democracy Action Plan and the COVID-19 disinformation monitoring programme, led in 2021, to a revision of the Code of Practice on Disinformation. Within this process, the Commission first published its Guidance to strengthen the Code of Practice[48] and later, in 2022, a new Strengthened Code of Practice on Disinformation[49]. The new version of the Code is a stronger instrument to fight disinformation. The Code is a self-regulatory code, targeting larger participation with more stakeholders on board who to take commitments that all together can fight disinformation. The strengthened Code of Practice contains[44] commitments and 128 specific measures, covering:

- Demonetisation – cutting financial incentives for purveyors of disinformation;
- Transparency of political advertising – especially important in the context of election campaigns;
- Ensuring the integrity of services – aiming to strengthen the measures to reduce manipulative behaviour used to spread disinformation (e.g. fake accounts, bot-driven amplification, impersonation, malicious deep fakes);
- Empowering users – aiming to reinforce the tools available to users to flag disinformation;
- Empowering researchers - the Code foresees that online platforms provide better support to research on disinformation;
- Empowering the fact-checking community – the Code foresees fact-checkers as an important pillar and aims to ensure their work is integrated on the platforms' algorithms;
- Transparency centre and Task-force;
- Strengthened Monitoring framework.

45 Tackling online disinformation: Commission, EU-wide Code of Practicehttps://ec.europa.eu/commission/presscorner/detail/en/IP_18_3370

46 Protecting democracy https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/new-push-european-democracy/european-democracy-action-plan_en

47 COVID-19 disinformation monitoring programme https://digital-strategy.ec.europa.eu/en/policies/covid-19-disinformation-monitoring

48 Guidance to strengthen the Code of Practice on Disinformation https://ec.europa.eu/commission/presscorner/detail/es/qanda_21_2586

49 2022 Strengthened Code of Practice on Disinformation https://digital-strategy.ec.europa.eu/en/library/2022-strengthened-code-practice-disinformation

From a legislative perspective, the Commission approved The Digital Services Act package. The package consists of the adoption in 2022 of two acts – the Digital Services Act (DSA) and the Digital Markets Act (DMA). As announced in the Acts package, they "aim to create a safer digital space where the fundamental rights of users are protected and to establish a level playing field for businesses."[50]

The two acts also aim at regulating the fight against disinformation. Among many others, the DSA adds a legal framework to the Code of Practice on Disinformation, so that it is not self-regulatory anymore.

All of those initiatives reflect the European Commission's ongoing efforts to address disinformation, promote media literacy, enhance transparency, and collaborate with various stakeholders to protect democratic processes and public discourse from the harmful effects of disinformation.

Role of the JRC

The disinformation threat continues to undergo a technological evolution as well, related not only to the evolution of online platforms. While there are many benefits from the digital transformation, with the advancement of the AI, incl. Generative AI, the EC pays attention whether online services do apply algorithmic systems to further disseminate disinformation or harmful content affecting the online fundamental rights.

These concerns, laid down in the DSA, are the fundament for the establishment in April 2023 of the European Centre for Algorithmic Transparency (ECAT). The ECAT, an integral part of the JRC, aims to research the way the "algorithmic systems shape the visibility and promotion of content, and its societal and ethical impact" contributing "to a safer, more predictable and trusted online environment."[51]

As part of the European Commission, the JRC also carries out extensive research to facilitate the efforts of the EU policy makers to mitigate the harmful effects of disinformation.

One of the first JRC investigations in the field is a study, conducted in 2018, on "The digital transformation of news media and the rise of disinformation and fake news" (Martens et al. 2018) and contributed to defining the tools for tackling disinformation online. The report contains an overview of the relevant economic research literature on the digital transformation of news markets and related impact on the quality of news.

Later in 2020, the JRC together with an international team of experts adopted a behavioural science approach to investigate the impact of online platforms on political behaviour in the study "Technology and Democracy: understanding the influence of online technologies on political behaviour and decision-making."[52]

Within another study, conducted in 2020, "The Landscape of Hybrid Threats: A Conceptual Model"53, the JRC also researched a new conceptual framework on hybrid threats aiming to increase the understanding of hybrid threats and facilitate the development of effective measures to improve resilience against these threats.

Hybrid threats by hostile actors are a growing problem for EU, Member States and citizens, combing different types of tools and organised actions, such as disinformation, economic pressure, abuse of

50 The Digital Services Act packagehttps://digital-strategy.ec.europa.eu/en/policies/digital-services-act-package

51 European Centre for Algorithmic Transparency https://algorithmic-transparency.ec.europa.eu/index_en

52 Social media influences our political behaviour and puts pressure on our democracies, new report finds https://joint-research-centre.ec.europa.eu/jrc-news-and-updates/social-media-influences-our-political-behaviour-and-puts-pressure-our-democracies-new-report-finds-2020-10-27_en

53 The JRC proposes a new framework to raise awareness and resilience against hybrid threats https://joint-research-centre.ec.europa.eu/jrc-news-and-updates/jrc-proposes-new-framework-raise-awareness-and-resilience-against-hybrid-threats-2020-11-26_en

migrants, cyber-attacks and other covert actions. These aspects are at the focus of another recent (April 2023) JRC research - "Hybrid Threats: A Comprehensive Resilience Ecosystem"[54]. In the study, JRC researchers examine trends and present an innovative approach for countering hostile actions and strengthening Europe's resilience.

During the COVID-19 pandemic, JRC looked at how to better prepare for future crises and protect lives, in a research about the "Learning lessons from the pandemic: combining risk mitigation measures to tackle COVID-19."[55]

The analysis of the preparedness for future crisis, focusing on the most spread narratives, their consequences, factors predicting how likely people are to believe or share them, and the most efficient ways to counter them, are investigated in a study from February 2023 "Misinformation on COVID-19: what did we learn?"[56].

The JRC carries out research on disinformation from identifying sources that potentially spread disinformation to tracking trending narratives. This work seeks to detect such stories early on to allow for actions to prevent their spread.

The European Media Monitor (EMM)[57] developed by JRC monitors about 450,000 articles per day from online news sites. With such an extensive volume of information, it is necessary to classify the information by policy area and identify the most widespread stories. As the monitoring cannot rely on technology alone, human analysis is necessary.

For this reason, the **JRC DISINFO team (JRC Unit T.5)** studying disinformation works closely with the EMM team to research and analyse the phenomenon of online disinformation. The Disinfo team aims at producing tools to help media analysts and fact checkers detect and manage disinformation.

Examples from its work related to cross-border threats of disinformation can be provided for several areas. Different topics and subjects from citizens' daily life are affected by the spread of disinformation. Those range from general health-related topics, to concrete health issues, such as the COVID-19 pandemic and the disinformation related to the COVID-19 vaccination rollout; disinformation related to elections; to geopolitical developments; to specific policy area; disinformation spread about climate change, migration, and many more.

During the COVID-19 pandemic, the established a process that allows for near real-time monitoring of COVID-19 mis/disinformation. Using the EMM system, the team analysed content from unverified sources – online sources that were indicated by independent fact checkers and other mis/disinformation experts as frequently spreading mis/disinformation – to track the main mis/disinformation narratives related to COVID-19 pandemic.

The coronavirus pandemic evidenced how the so-called infosphere is susceptible to information disorder, especially in contexts of uncertainty, emergency, and general confusion. The World Health Organisation (WHO) coined the term "infodemic" to describe the social phenomenon of having "too much information including false or misleading information in digital and physical environments during a disease outbreak."[58]

While the team continues to regularly perform the monitoring related to COVID-19 mis/disinformation,

54 A new method to help policymakers defend democracy against hybrid threats https://joint-research-centre.ec.europa.eu/jrc-news-and-updates/new-method-help-policymakers-defend-democracy-against-hybrid-threats-2023-04-20_en

55 Learning lessons from the pandemic: combining risk mitigation measures to tackle COVID-19 https://joint-research-centre.ec.europa.eu/jrc-news-and-updates/learning-lessons-pandemic-combining-risk-mitigation-measures-tackle-covid-19-2020-05-08_en

56 Misinformation on COVID-19: what did we learn? https://joint-research-centre.ec.europa.eu/jrc-news-and-updates/misinformation-covid-19-what-did-we-learn-2023-02-21_en

57 EMM https://data.jrc.ec.europa.eu/collection/EMM

58 WHO Munich Security Conference https://www.who.int/director-general/speeches/detail/munich-security-conference

they published a paper on “Trend analysis of COVID-19 mis/disinformation narratives–A 3-year study” (Kotseva et al. 2023). The study analyses a substantial quantity of data, collected from considerable number of unverified sources and extended time period. The team collected over 1.3 million COVID-19 related news articles from unverified sources, from 36 countries and 24 languages, in the period between 01 January 2020 and 31 December 2022. In addition to the objective to identify and analyse the main mis/disinformation narratives around COVID-19, the research aims to also structure them and develop a codebook detailing these COVID-19 related mis/disinformation narratives.

It is necessary to note that the findings are contingent on the unverified sources monitored throughout the data collection process. The database of unverified sources that the study is based on contains many American, Russian, and Western European sources compared to a lower number of sources from many Eastern European countries. This translates into an inability to quantitatively compare narratives across countries. However, the country-based analysis is merely meant to highlight the narratives that were most widespread in any given country for which a significant number of articles is annotated.

Over the analysed three-year period (1 January 2020 – 31 December 2022) the team identified 12 supernarratives related to COVID-19 mis/disinformation. **Figure 47** shows the spread over time of these 12 supernarratives. The heatmap shows that whereas the “fearmongering,” “criticism of EU and inter/national actors,” “criticism of restrictions,” and “claims of authoritarianism and dystopia” supernarratives were predominant during the early phase of the pandemic, “vaccine-related narratives” became the main concern of unverified sources in 2021 and 2022.

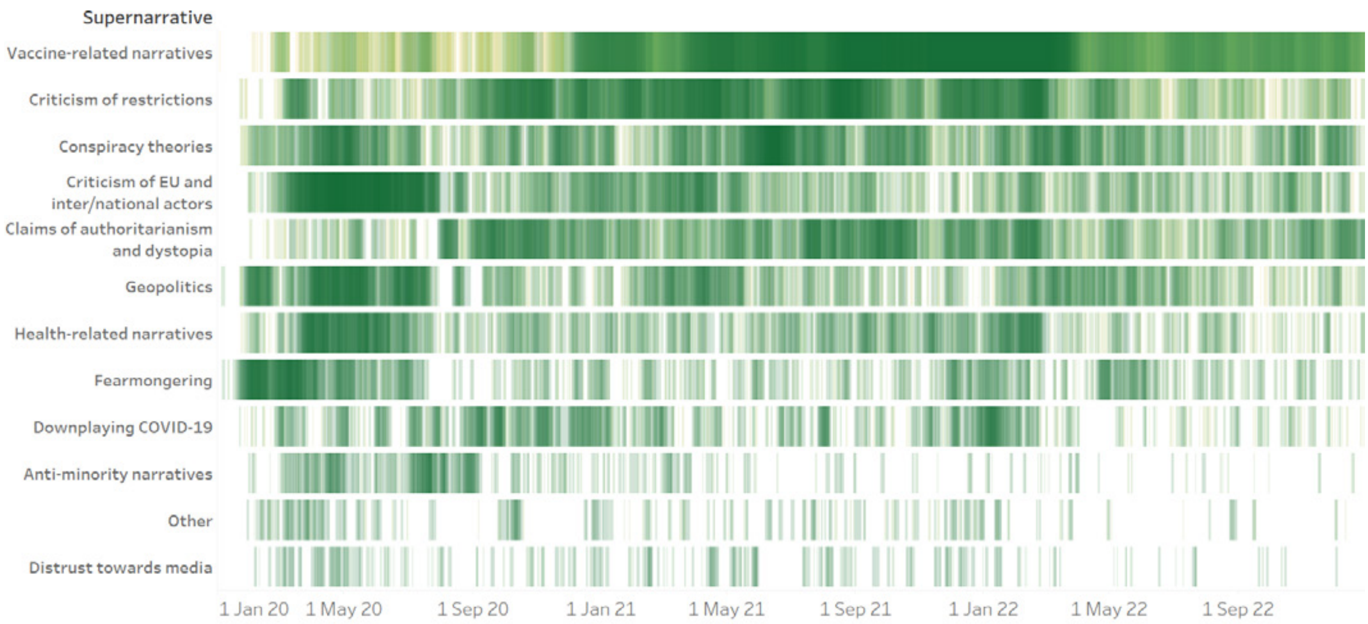
In the study, there is a special focus on disinformation narratives addressing anti-vaccination narratives. The analysis shows that there are often real events behind mis/disinformation trends, which unverified sources misrepresent or take out of context.

Three types of anti-vax content are identified:

- “anti-vax narratives” undermining the safety and effectiveness of COVID-19 vaccines and discouraging readers from getting vaccinated;
- “anti-mandatory vaccination narratives” taking a stance against compulsory vaccination and fomenting fear over its possible implementation; and
- “anti-vax conspiracy theories” alleging that COVID-19 vaccines were part of a scheme by the elites to further exert their control over the masses.

Each narrative is further categorised by identifying subnarratives (**Figure 48**).

Figure 47: Heatmap showing the spread of the 12 supernarratives (01 Jan 2020 to 31 Dec 2022). The heatmap allows the reader to analyse and compare the evolution of the supernarratives over time.



Source: Kotseva et al. 2023

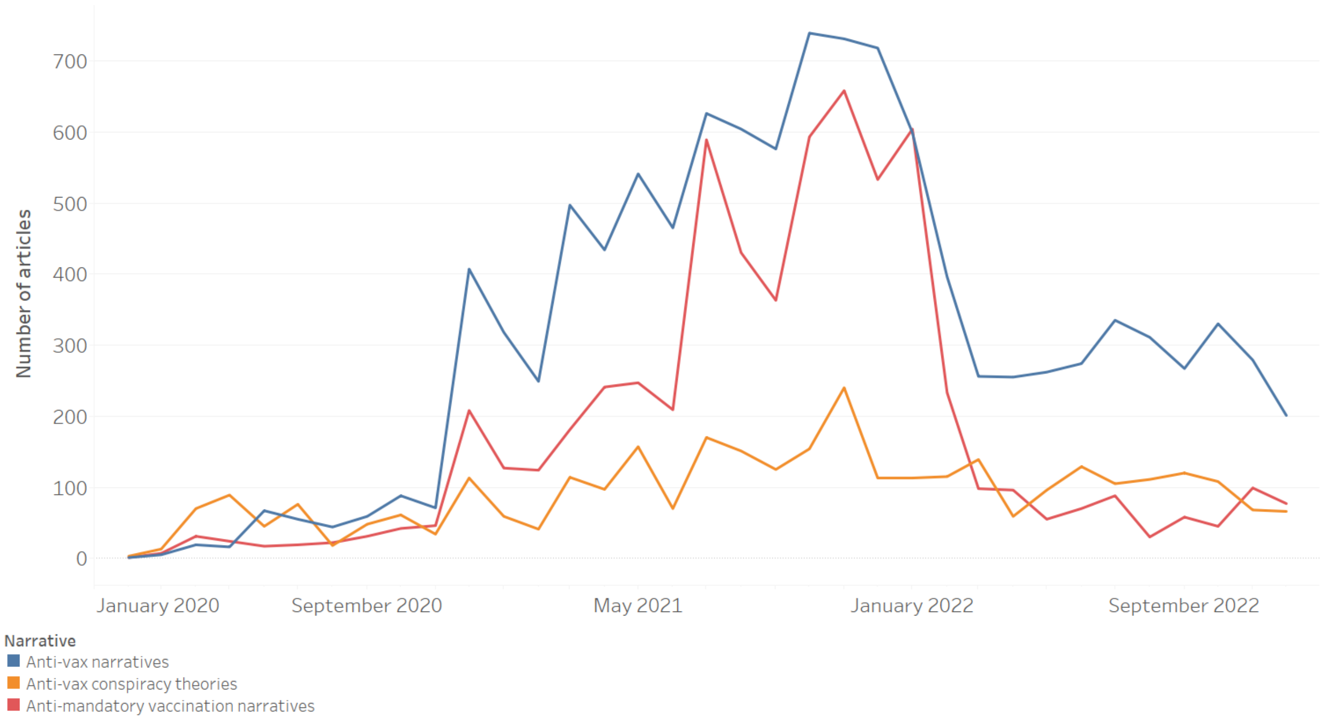
Figure 48: Heatmap showing the spread of anti-vax subnarratives, divided by narratives (01 Jan 2020 to 31 Dec 2022).

Source: Kotseva et al. 2023

While "anti-vax conspiracy theories" were present since the beginning of the pandemic, "anti-vax narratives" and "anti-mandatory vaccination narratives" started to increase sharply in November 2020 (see **Figure 49**) as preliminary data on the effectiveness of COVID-19 vaccines became available.[59]

As noted above, one of the main limitations of the study is the uneven country coverage of the list of unverified sources, which contains many American, Russian, and Western European sources compared to a lower number of sources from Eastern European countries. Taking this limitation into account, data were normalised, in order to make the results comparable. The country-based analysis focuses on the top seven countries for which a significant number of articles is annotated. These are the United States, Germany, Russia, Bulgaria, the Netherlands, Poland, and Spain. Annotated data from these seven countries represents over 80 per cent of the whole dataset.

Figure 49: Timeline showing the spread over time of "anti-vax narratives," "anti-mandatory vaccination narratives," and "anti-vax conspiracy theories."



Source: Kotseva et al. 2023

Figure 50 shows the country distribution of all anti-vax narratives and subnarratives. The colour of the square indicates the country's ranking based on the total number of articles per subnarrative - a darker square represents the country with the highest percentile of articles per subnarrative, etc. The size of the square indicates the normalised number of articles per country per subnarrative, that is, the number of articles tagged as each subnarrative compared to the total number of monitored sources per country - the bigger the square, the more articles from the monitored sources of a given country have been assigned to the subnarrative in question.

Given the constraints of the database of unverified sources, it is not surprising that the USA is consistently associated with the darkest square - the USA is the country with the highest percentile of articles per anti-vax subnarrative, because it is the country for which we monitored the highest number of unverified sources. Similarly, Germany and Russia often present the second and third darkest squares because they are the second and third countries for numbers of monitored sources.

59 https://www.pfizer.com/news/press-release/press-release-detail/pfizer-and-biontech-announce-vaccine-candidate-against

It is far more interesting to compare the sizes of the squares in **Figure 50**, as the size of the square indicates the normalised number of articles per country per subnarrative, given the numbers of monitored sources per country. While most of the anti-vax subnarratives appear to be similarly widespread across the analysed countries, four subnarratives appear to be more widespread in some countries than others.

The "against booster shots" subnarrative was particularly widespread among Bulgarian sources. According to data from the European Centre for Disease Prevention and Control (ECDC), Bulgaria has the lowest COVID-19 vaccination rate in the EU with only 30 per cent of its population having completed the primary course of vaccination and only 12 per cent having received a booster shot[60]. It is plausible to assume that the anti-vax claims spread by Bulgarian unverified sources had a direct effect on the Bulgarian population's willingness to get vaccinated and boosted.

Figure 50: Country distribution for anti-vax narratives

Source: Kotseva et al. 2023

The "anti-vax VIPs and doctors" subnarrative was particularly popular among Bulgarian and Polish unverified sources. This is not surprising given that in both Bulgaria and Poland, many politicians, celebrities and doctors expressed vaccine scepticism. There are plenty of news reports on Bulgarian doctors who

60 https://vaccinetracker.ecdc.europa.eu/public/extensions/COVID-19/vaccine-tracker.html#uptake-tab

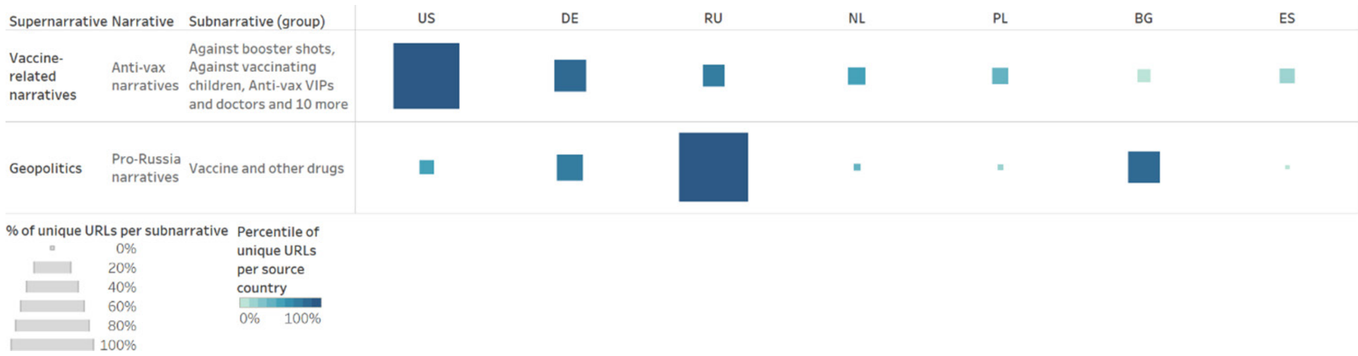
"aren't sure COVID-19 vaccines are a good idea"[61], Polish politicians "flirting" with anti-vax voters[62] and Polish celebrities "expressing reservations" about COVID-19 vaccines[63], etc. The "widespread vaccine hesitancy" subnarrative was especially widespread among Polish unverified sources. Throughout 2020, Polish unverified sources reported on several surveys that were carried out before COVID-19 vaccines became available and found that a large segment of the Polish population was not willing to get vaccinated against COVID-19.

Finally, conspiracy theories "blaming global elites" and alleging that "vaccines help control people" were especially popular among Bulgarian unverified sources. Throughout 2020 and 2021, Bulgarian unverified sources published several articles accusing Bill Gates of being "behind everything."

A further filtering of the analysed data by language and source country also shows differences in perception pointing to country-specific trends. This is particularly useful for analysing events of geopolitical interest, such as the promotion of the Sputnik V vaccine termed as vaccine diplomacy. One can identify different portrayals of events among unverified sources from several countries and spot disinformation for political gain.

As shown in **Figure 51**, the analysis yields an interesting finding about Russian unverified sources' coverage of vaccine-related content. Russian unverified sources were among the main spreaders of "anti-vax narratives" - in the dataset, Russia ranked as the third source country for the spread of "anti-vax narratives," only after the US and Germany. At the same time, Russian unverified sources had the highest number of articles promoting "pro-Russia narratives" around the Sputnik V vaccine and several Russia-developed COVID-19 treatments.

Figure 51: Table showing the source country distribution of "anti-vax narratives" and "pro-Russia narratives" around the Sputnik V vaccine and several Russia-developed COVID-19 treatments



Source: Kotseva et al. 2023

Russian unverified sources, as shown in **Figure 52**, spread anti-vax narratives mainly in foreign languages. English, German, and French articles comprised around 67 per cent of all articles from Russian unverified sources annotated as spreading "anti-vax narratives." In comparison, only 15 per cent of articles from Russian unverified sources annotated as spreading "anti-vax narratives" were in Russian. This indicates that Russian unverified sources mainly focused on spreading anti-vax narratives among foreign audiences.

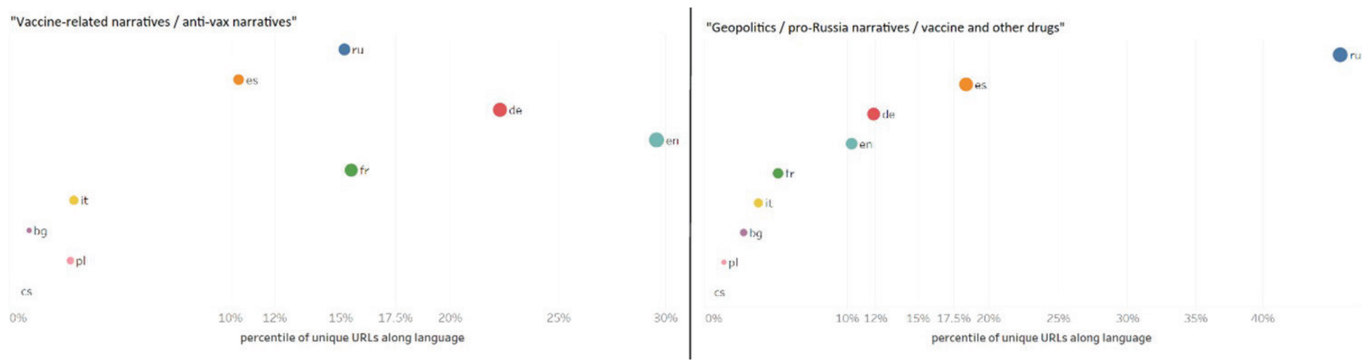
On the other hand, Russian unverified sources promoted the Sputnik V vaccine both in Russian and in a variety of foreign languages. Forty-five percent of the articles annotated as "geopolitics / pro-Russia narratives / vaccines and other drugs" were in Russian. The remaining 55 percent were, in descending or-

61 https://www.euronews.com/my-europe/2021/05/18/in-bulgaria-even-doctors-aren-t-sure-covid-19-vaccines-are-a-good-idea
62 https://www.politico.eu/article/poland-vaccine-skeptic-vax-hesitancy-political-trouble-polish-coronavirus-covid-19/
63 https://www.dw.com/en/anti-vaccine-sentiment-rife-in-poland/a-56100878

der, in Spanish, German, English, French, Italian, Bulgarian, Polish, and Czech. This indicates that Russian unverified sources focused on promoting the Sputnik V vaccine both at home and abroad. An in-depth analysis of the data, moreover, shows that Russian unverified sources portrayed the Sputnik V vaccine as an instrument for the Kremlin to demonstrate international solidarity and assert itself as the global leader that would save the world from the pandemic. This is in line with existing research finding that the Kremlin used the Sputnik V vaccine as a tool to strengthen its influence abroad[64].

In **Figure 52**, the scatter plot shows the language coverage of all articles by Russian unverified sources annotated as "vaccine-related narratives / anti-vax narratives" (01 January 2020 – 31 December 2022) and all articles by Russian unverified sources annotated as "geopolitics / pro-Russia narratives / vaccine and other drugs" (01 January 2020 – 31 December 2022).

Figure 52: Focus on Russian unverified sources



Source: Kotseva et al. 2023

Ongoing work

The identification and analysis of COVID-19 related mis/disinformation narratives, understanding their evolution across countries and languages also support the development of effective public health messaging campaigns. Vaccine-related mis/disinformation may open the door to pseudoscience, such as homeopathy and other so-called "alternative medicine" methods, and outright dangerous charlatanry, such as drinking bleach. Eventually, this irrational behaviour undermines our trust in medicine as a scientific discipline and in public health authorities and their expertise within democratic societies. Thus, it is important to understand mis/disinformation narratives, their evolution and outreach in view of developing efficient public health communication to protect democratic processes and public discourse from the harmful effects of disinformation.

The approach of quantifying trends over time, e.g. the rise of anti-vax content in parallel to the development and approval of vaccines against SARS-CoV-2, also allows for the comparison of the spread of mis/disinformation narratives with general news content, e.g. from EMM. Indeed, the COVID-19 pandemic has demonstrated that many mis/disinformation narratives are based on factual events that are misrepresented or taken out of context.

The analytical approach presented here, is used as blueprint to study other topics around which a large volume of mis/disinformation can be found. Work is ongoing to analyse mis/disinformation on other health-related topics, on geopolitical issues, disinformation related to elections, to specific policy area, disinformation spread about climate change, migration, and many more.

64 https://imrussia.org/en/news/3358-the-rise-and-fall-of-sputnik-v%E2%80%94a-new-report-by-imr

5.

STRATEGIC FORESIGHT FOR BETTER ANTICIPATION

5 Strategic foresight for better anticipation

Disaster resilience goals identify anticipation as one of the key areas to effectively manage disaster risks, including the identification and understanding of new and emerging risks, their potential impacts and scenario-building capabilities. This comes with the recognition that the risk landscape is increasingly complex (climate change, multi-risk assessments, and cascading effects) and so anticipation is not limited to individual risks but require broader set of tools and approaches that capture systemic aspects, complexities and diverse stakeholder positions. This is where foresight practices come in. Foresight is a systematic participatory process to create collective intelligence about the medium- to long-term potential futures and provide strategic knowledge – its fundamental premise being that future cannot be predicted but can be actively influenced and created (Störmer et al. 2020).

The most popular way of exploring the potential futures, also in DRM, is through exploratory or uncertainty scenarios (Jafari et al. 2019). Their broad scope and way of dealing with uncertainty help perceive alternative views on changes to and dynamics of risks and test the effectiveness of potential solutions (Riddell et al. 2019). However, scenarios are only one step in the process of foresight – starting from scoping the issue, detecting trends and signals of change, through analysis of uncertainties, understanding the evolution of drivers and trends and their implications, generating strategies to react to potential future developments and finally monitoring current developments in view of the insights that were generated. It is therefore not only useful to consider the use of particular tools but attempts are increasingly made to integrate future-oriented processes and foresight principles into the framework of risk governance (Aubrecht et al. 2013 and Ridell et al. 2020).

Given that the uncertainty and volatility in the increasingly connected world poses complex challenges for decision-making, this reality should be considered when designing and employing strategies and policies in all areas. Adapting to a reality of fast-paced and interconnected changes means moving beyond the idea that the future is a set trajectory to instead plan and prepare for a range of possibilities. Such a practice is part of strategic foresight. Strategic foresight applies the methods, practices and knowledge from foresight and futures studies in the context of decision-making for a particular organisation, such as a company, government or ministry. In policymaking, foresight can, for example, be used to stress-test how given policies would fare in a range of possible futures, or to explore effective a given strategy would be in the face of range of possible disruptions. Strategic foresight is an organised and systematic process to engage with uncertainty to support anticipation in policy or strategy decisions. It can help to improve resilience and agility of an organisation, and it is in this way an essential tool to support risk management and preparedness.

Foresight has increasingly become a part of the European Union's policymaking process[1]. The Commission 2019-2024 appointed a Vice-President for Foresight, Maroš Šefčovič, to bring anticipation and foresight into the spotlight at the highest levels of organisation. Annual strategic foresight reports contribute to raising awareness on key areas of change in the future and provide a common ground for reflecting on EU policies with a systemic and forward-looking approach. The European Commission also engages in foresight activities with the Council and the European Parliament. Through the European Strategy and Policy Analysis System (ESPAS) has initiated an ongoing horizon scanning process. All this contributes to building an anticipatory governance process, where forward-looking approaches inform decision-making and help increase resilience.

The European Commission has been adopting strategic foresight in its long-term planning in various ways. A network for strategic foresight has been established, where directors from across the Euro-

1 European Commission, Communication from the Commission to the European Parliament and the Council, 2020 Strategic Foresight Report: Strategic Foresight – Charting the Course Towards a More Resilient Europe, COM(2020) 493 final

pean Commission engage in foresight. A similar network is in place with representatives from the EU Member States. These networks meet regularly and help to foster an anticipatory and future-oriented culture. The different directorates-general of the Commission also undertake a wide range of specific and focused foresight exercises within their policy domains. The JRC's EU Policy Lab supports EU policy-making by providing strategic and future-oriented input, developing an anticipatory culture inside the European Commission, developing different methods and tools to make foresight practically useful for decision-making processes[2].

Strategic foresight starts with a better understanding of what are the emerging and novel elements on the horizon. Horizon scanning is a structured and continuous activity whose objective is to detect at an early stage and to analyse emerging issues that are at the margins and that could potentially have significant impact on society and policy. The overarching purpose of horizon scanning is to provide timely awareness of what is new or changing to allow early discussions on the intended and unintended consequences of these developments. It has both an alert and a creative function – informing about observed marginal but also enabling reflection on potential future developments (Amanatidou et al. 2012).

There are different types of horizon scanning activities depending on their purpose, methods and objectives (see **Table 6**). Among the dimensions to consider for scanning is whether it is general, i.e. tries to capture the widest possible set of issues or topical – focusing on a concrete area or topic. While risk and threat identification has been the most common activity in public administration, they are usually targeted to specific area, such as public health, defence, food security (Paulović et al. 2022).

Table 6: Types of horizon scanning

Trend watching	Weak signals identification	Emerging technology watch	Risks/threats identification	Foresight scenario building
Identifying early stage trends	Searching for unknown unknowns	Potentials and threats of emerging technologies	Early warning for anticipating, preventing, and framing risks and threats	Preparing the ground for further foresight work
Isolating specific information from broad range of data	Looking for unconnected issues, involve diverse people	Expert polling, technology analysis	Assessment of probability and impact, indicators monitoring	Identification of weak signals and drivers of change
Prioritisation of new developments through trends	VUCA[3] – change happens faster than we can conceptualise	Explaining technology, showing implications	Timeliness, carefully framed language	Getting support of people for the foresight

Source: EC, JRC

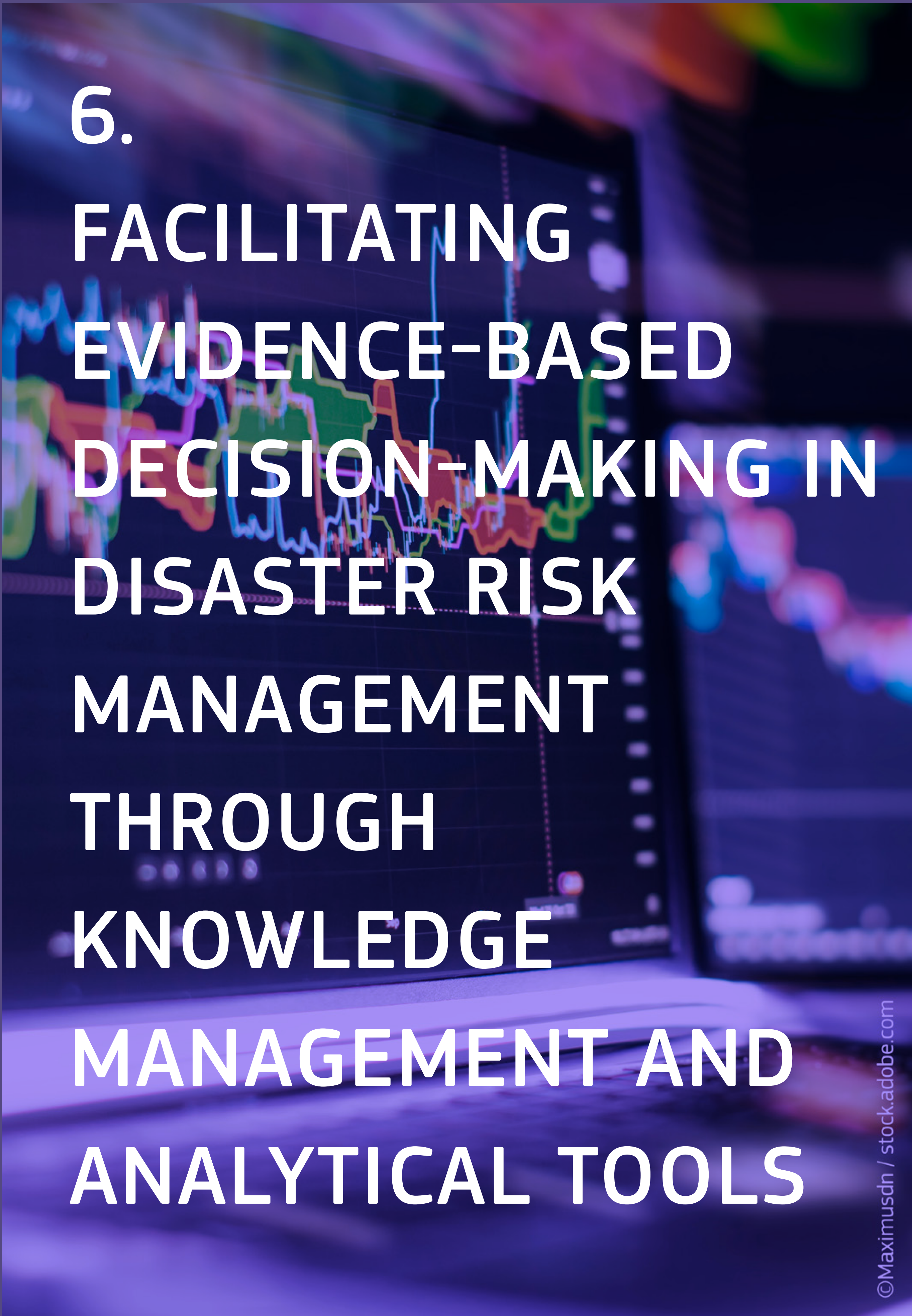
The process of scanning starts with an identification of signals, filtration, prioritisation, assessment and communication (Hines et al. 2019). Within that structure, various different methodologies and organisational approaches are practised (Krzysztofowicz et al 2018, EEA report, 2023)[4]. The ESPAS horizon scaning is a continuous activity covering wide range of changes across the STEEP categories (social, technological, economic, environmental, and political). The results are published regularly on the ESPAS website[5].

2 EU Policy Lab https://policy-lab.ec.europa.eu/index_en
3 Volatility, uncertainty, complexity, and ambiguity
4 EEA, Horizon scanning-tips and tricks. A practical guide, Eionet Report, 2023, https://www.eea.europa.eu/ds_resolveuid/X276TWQMFE
5 https://www.espas.eu/

Building on existing early warning mechanisms across the EU institutions, agencies and bodies, this project establishes a rolling process to produce reports that engage colleagues across the ESPAS institutions and bodies in a continuous, longer-term, cross-cutting reflection around emerging and potential future trends. It also aims to create an EU community of practitioners/experts able to identify and inform about emerging signals of change.

Foresight processes on future risks can be built on horizon scanning. Using specific horizon scanning signals to explore systematically and holistically how a given signal could trigger developments that lead to risks brings valuable insights to support anticipatory decision-making. Such foresight processes can complement traditional risk assessment methods to help minimise and abate the risks identified and help shape a better future. The foresight study Risks on the Horizon (European Commission, 2024) is an example for how horizon scanning can be used for very early anticipation of risks. It presents 10 clusters of future risks, each with potential future developments that could lead to these risk clusters. By exploring both potential triggers, risks, and opportunities arising from horizon scanning signals, this foresight process combines participatory approaches with future risk analysis to bring holistic and anticipatory input for risk assessments. Complementing traditional disaster risk anticipation approaches with foresight suggests two steps for further action. The first is to integrate future-oriented processes and foresight principles into the framework of risk governance and the second is to connect this framework to wider anticipatory governance frameworks developed in the EU.

6. FACILITATING EVIDENCE-BASED DECISION-MAKING IN DISASTER RISK MANAGEMENT THROUGH KNOWLEDGE MANAGEMENT AND ANALYTICAL TOOLS



6 Facilitating Evidence-Based Decision-Making in Disaster Risk Management through Knowledge Management and analytical tools

In response to the rapidly evolving risk landscape both within the EU and globally, there is a pressing need to adapt and enhance our strategies for DRM. This challenge is compounded by the emergence of new risks and the intensification of existing ones, driven by factors such as climate change, urbanization, and technological advancements. To effectively address these challenges, a collective effort is essential, one that harnesses a multi-disciplinary approach and fosters collaboration across various sectors and borders. This includes integrating cutting-edge scientific research into policy-making, enhancing data-driven decision-making, and investing in community-based initiatives that help building societal resilience.

The increasing complexity of modern disaster management, both locally and globally, demands an evolved role for science in policy-making. The EU, with its advanced DRM systems, exemplifies this shift. The establishment of the DRMKC marks a significant stride towards integrating scientific knowledge into disaster risk reduction policies, plans, and strategies.

6 1 Disaster Risk Management Knowledge Centre

The DRMKC plays a crucial role in the European Union's approach to DRM. Its mission is multifaceted and centred around the integration and coordination of DRM efforts across EU member states. Here are the key aspects of its role and mission:

- Science-Policy Interface: One of the core missions of the DRMKC is to bridge the gap between scientific research and policy-making in DRM. It aims to ensure that the latest scientific findings and technological advancements inform EU policies and strategies for disaster risk reduction and management.
- Knowledge Integration and Sharing: The DRMKC acts as a central hub for collating, managing, and disseminating knowledge related to DRM. It gathers information from a variety of sources, including scientific research, expert analysis, and field data, to provide a comprehensive and accessible resource for all stakeholders involved in DRM.
- Collaboration and Network Building: The DRMKC fosters collaboration between different actors in the field of DRM, including EU institutions, member states, research communities, and non-governmental organizations. By building networks and partnerships, it facilitates the exchange of information, best practices, and innovative solutions.

Supporting Evidence-Based Policy Making: The DRMKC supports the development of evidence-based policies by providing policymakers with reliable data, research findings, and risk assessments. This helps in making informed decisions that can effectively reduce the risk of disasters and manage their impacts.

Capacity Building and Training: The DRMKC is also involved in capacity building and training activities. It develops and disseminates guidelines, tools, and methodologies to enhance the capabilities of EU member states in disaster risk assessment and management.

Multi-Hazard Approach: Recognizing the complex and interconnected nature of risks, the DRMKC adopts a multi-hazard approach to DRM. This approach considers various types of hazards, including natural, technological, and human-made, and their potential interdependencies.

Promoting Resilience and Preparedness: Part of the DRMKC's mission is to promote resilience and preparedness among communities and governments. This includes advocating for risk-aware cultures, encouraging investment in disaster risk prevention and reduction, and enhancing the capacity of communities to respond and recover from disasters.

Guiding Research and Innovation: The DRMKC also plays a role in guiding research and innovation in the field of DRM. It identifies knowledge gaps and emerging risks, thereby directing research efforts to areas that are most beneficial for improving DRM practices.

The establishment of the UCPKN in December 2021, featuring a robust Science Pillar spearheaded by the DRMKC, has significantly advanced the science-policy interface in the field of DRM.

6 2 The Science Pillar of the UCPKN

The Science Pillar, is integral to the UCPKN. It primarily focuses on integrating scientific research and evidence into civil protection practices and policy-making. It serves as the bridge between the scientific community and policy-makers, ensuring that civil protection strategies and decisions are based on the latest scientific evidence. It also aims at facilitating research and analysis in DRM, focusing on areas critical to civil protection, such as risk assessment, prevention, preparedness, and response. To enable a seamless uptake of science into policies, the Science Pillar manages and disseminates scientific data and research findings relevant to civil protection, making it accessible to stakeholders within the network (e.g. are the Knowledge Network Newsletters with a dedicated section on new scientific innovations and knowledge synthesis that support decision-making and operations).

The Science Pillar plays also an advisory role through the provision of expert advice and recommendations to civil protection practitioners and policy-makers, based on scientific research and analysis. By fostering the development, the Science Pillar facilitates the uptake of innovative solutions and technologies that enhance DRM and civil protection.

In summary, the, UCPKN, with the DRMKC leading its Science Pillar, forms a robust framework for enhancing the EU's capabilities in DRM and civil protection. The Network ensures that civil protection policies and practices across the EU are informed by the latest scientific knowledge, promoting cooperation, innovation, improved anticipation, prevention and effective response to disasters.

6 3 Risk Data Hub

Disaster risk management across Europe, addressing various types of risks (man-made, technological, and natural), is governed by multiple policies that include diverse sectors such as environmental, industrial, civil protection, security, and health. These policies operate at different scales, from Europe-wide to national and sub-national, and involve various operational actions like preparedness, mitigation, adaptation, prevention, response, recovery, and restoration. A range of research and technological developments are motivated to support the implementation of these policies and actions across various scales reaching local level. However, the effectiveness of DRM depends greatly on the efficiency of managing relevant information.

The availability of harmonised and openly accessible data is fundamental for the analysis and assessment of risks as well as in the reporting and curating of disaster loss data. The lack of harmonisation represents an important challenge for data sharing and comparison, and in particular for cross-border cooperation, within the EU and Europe as a whole. The access to open source data is especially important as it offers models of interoperability across Europe for DRM related activities.

Since 2017, the DRMKC is developing the RDH[1], a platform designed to bring foundational knowledge on disaster risk in Europe. The aim is to establish a centralised hub, offering key information useful for

DRM at various geographical levels. One of the main objectives is to collect, analyse, and harmonise scientific data related to disaster risk and losses in Europe.

1 EC, JRC, DRMKC RISK DATA HUB https://drmkc.jrc.ec.europa.eu/risk-data-hub

The EU Climate Adaptation Strategy[2], adopted in 2021, outlines a central role for the RDH as it foresees that the Commission will promote and support the use of the RDH as dedicated platform to promote common rules and specifications for the recording and collection of climate related physical climate risk data and climate-related losses. The Strategy further endorses partnerships between the private and public sectors in order to facilitate the harmonisation and collection of data by making it as accessible as possible to the public. Systematically collected, comparable and robust disaster damage and loss data, are an essential element of the risk assessment and management processes. Thus, the Council of the European Union's conclusions[3] on risk management capability on 24 September 2014, call on the Commission to 'Encourage the development of systems, models or methodologies for collecting and exchanging data on ways to assess the economic impact of disasters on an all-hazard basis'.

Furthermore, the RDH was designed with collaborative aspects in mind, aiming at reinforcing the connection between local and international dimensions by bringing publicly available risk and loss data. The information in the RDH can also serve as a baseline data for disaster risk mitigation. Additionally, the RDH facilitates the dissemination and the utilization of existing research findings in the formulation of DRM policies at various geographical levels, and eases cross-border risk assessment at a Europe-wide level. The disaster risk definition in the RDH follows the disaster risk framework from UNDRR which is defined as the interaction of hazard, exposure, and vulnerability.

The RDH offers different tools such as geoportals and dashboards that cover all the components of disaster risk. More specifically, the RDH data viewer enables users to browse through reliable and robust open geospatial datasets related to multi-hazards and exposure data at a Europe-wide level (see **Figure 53** and **Figure 54**). Similarly, the vulnerability dashboard (**Figure 55**) delivers useful information on the susceptibility of communities expressed through five dimensions (social, economic, political, environment, physical). In addition, the RDH section on disaster loss data provides valuable information related to past disaster events which affected Europe, that enable to draw lessons from previous disasters in order to enhance preparedness for future events. Finally, the RDH hosts disaster risk and loss information obtained from partners and research projects. For example, one set of research results available on the platform includes visualizations of potential losses attributed to climate change, as estimated by the PESETA IV project.

The need to have such multi-hazard platform to link science and policy, past and future, local and global dimensions was identified after having reviewed the National Risk Assessments prepared by the Union of Civil Protection Mechanism's participant countries and then submitted to the Commission during the 2015 exercise. There is an evident gap between the knowledge developed by the scientific community and the one reaching this essential deliverable due under the UCPM. The RDH is a concrete answer to this need but the only way to succeed on this objective is to be able to engage with the two ends of the bridge - scientists and policy-makers – to co-design and co-develop this common bridge.

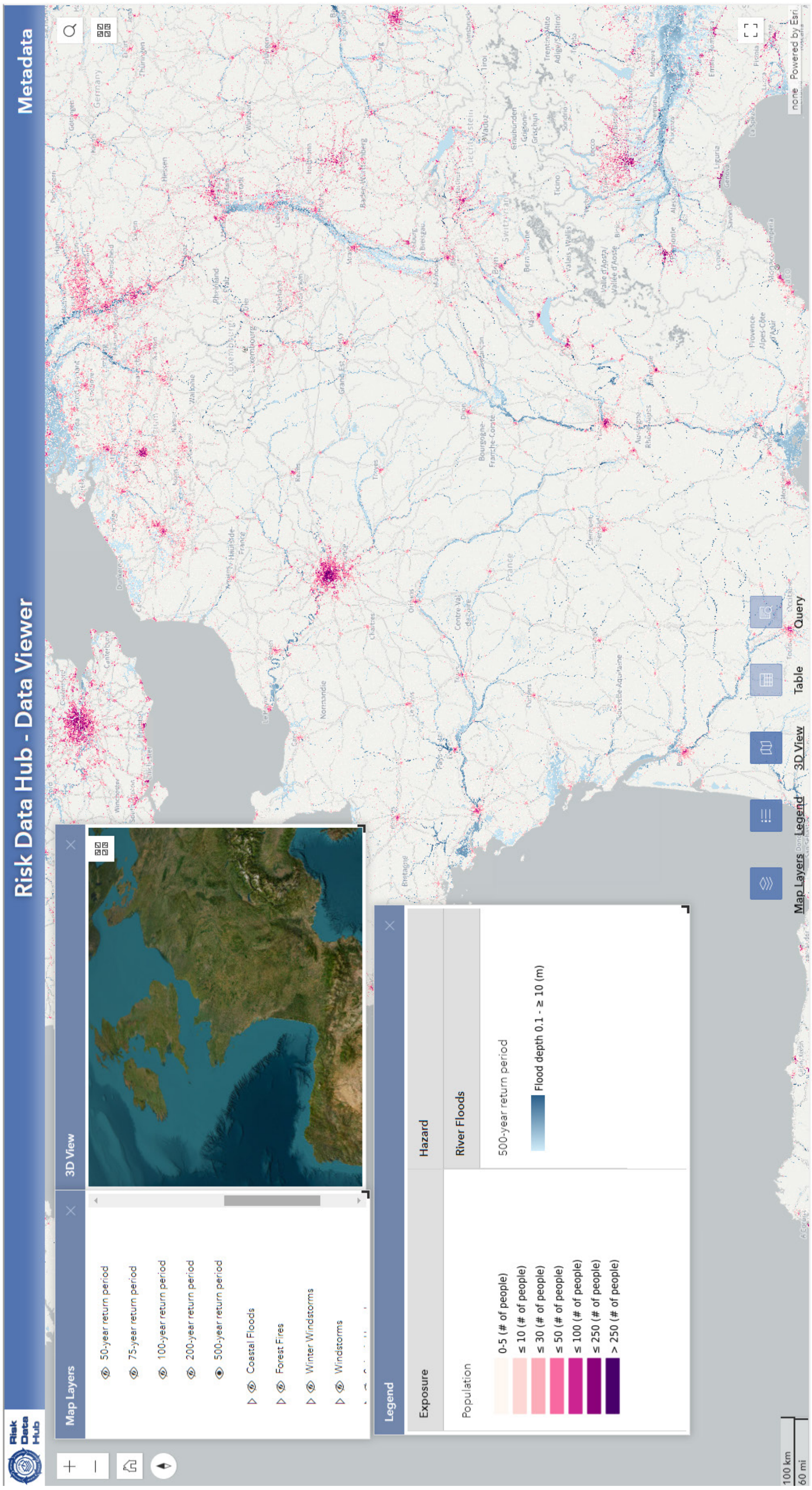
The RDH use of a harmonised approach for risk and loss data, and European-wide coverage for baseline data and assessments, facilitates cross-border risk assessment.

2 The new EU Strategy on Adaptation to Climate Change https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX-:52021DC0082

3 https://data.consilium.europa.eu/doc/document/ST%2013375%202014%20INIT/EN/pdf

Figure 53: RDH Data Viewer, showing exposed asset (population) and hazard layer for river floods (200-year return period).

The underlying data comes from the JRC Disaster Management Unit (JRC.E1), specifically from the Global Human Settlement Layer (GHSL) and the Floods Team.



Source: JRC RDH, 2024

Figure 54: RDH Data Viewer, showing exposed asset (population) and hazard layer for river floods (200-year return period).

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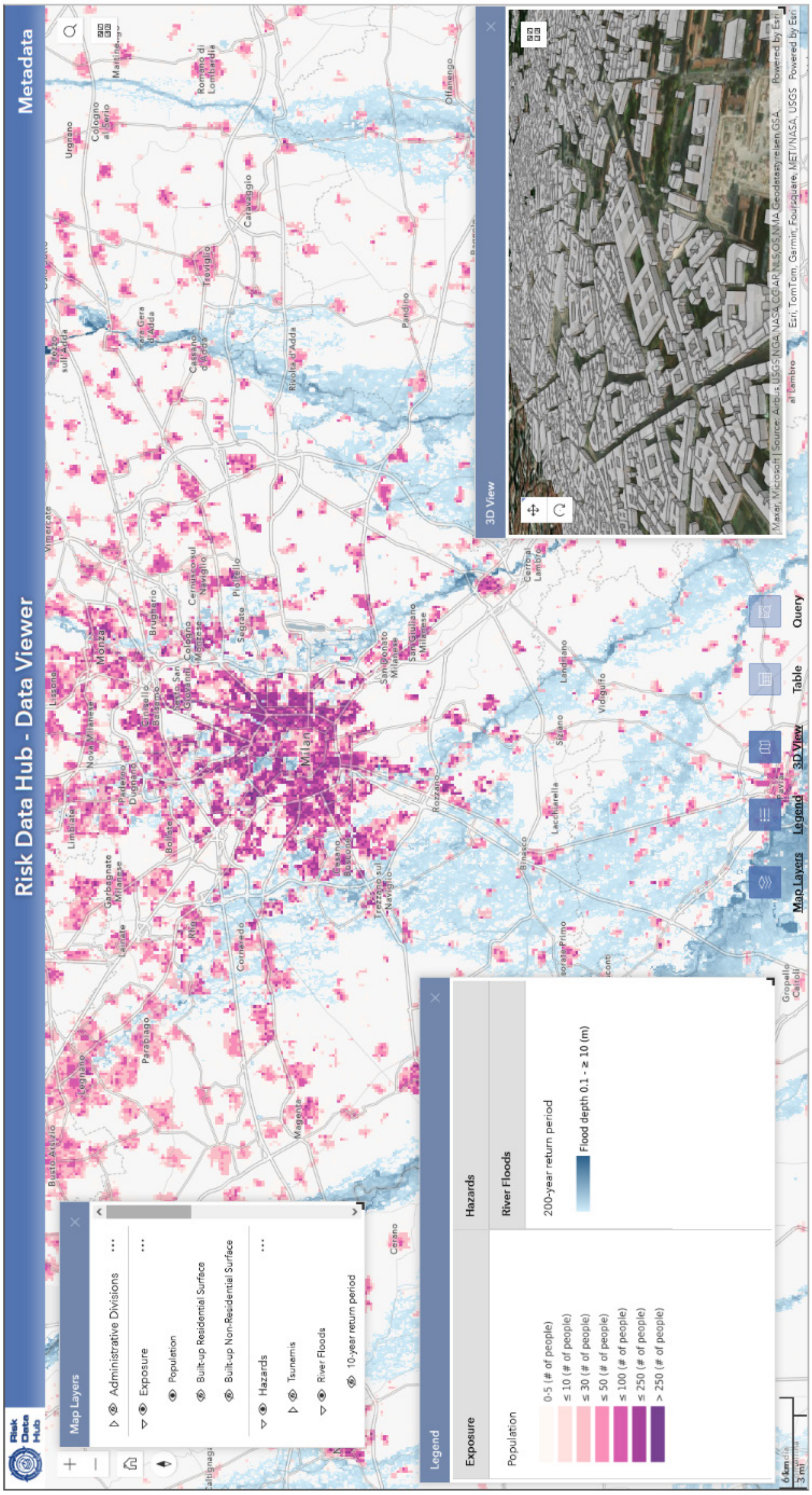
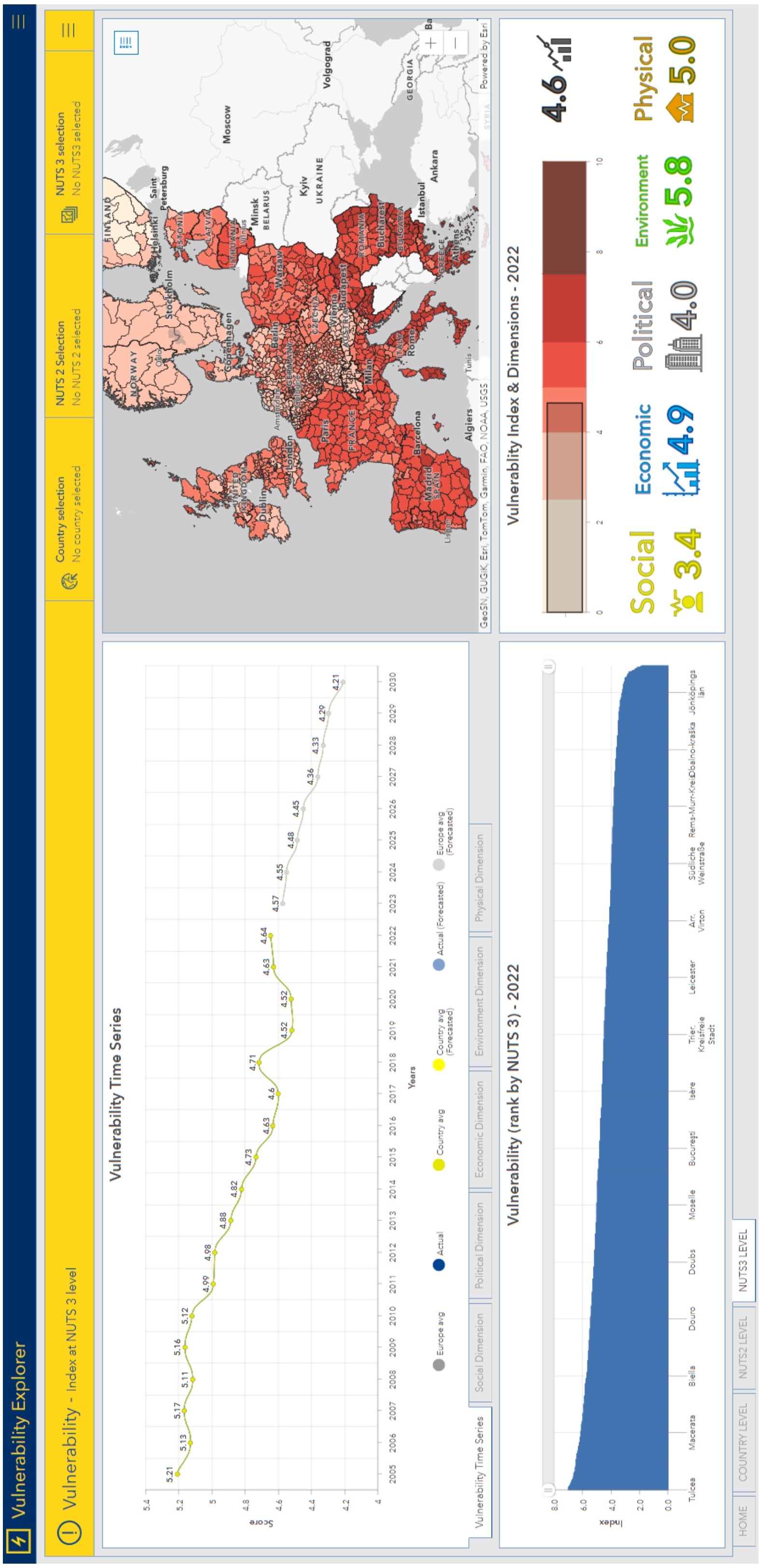


Source: JRC RDH, 2024

Figure 55: RDH vulnerability dashboards showing European average vulnerability at the level of NUTS3[4] averaging five dimensions (social, economic, political, environmental and physical).



Source: JRC RDH,

4 Common classification of territorial units for statistics (NUTS). NUTS3 are smaller regions, generally with population between 150'000 and 800'000 inhabitants

Conclusion

This report attempted to give an EU perspective of some the cross-border and emerging risks that Europe is facing through analytical lenses drawing upon the latest scientific evidence of the JRC.

The analysis and mapping of the different risks presented in the report required different methodologies depending on the nature of the hazard. It would be spurious to pretend that we fully understand all the hazards that society faces and their potential consequences. The common denominator for many of the outcomes of risk assessment analysis described in this report is the process that follows a structured approach: identification of potential hazards and their probability, knowledge of what is exposed to that hazard and the vulnerability of that exposure to the hazard. A combination of both quantitative (e.g. probabilistic or stochastic models) and qualitative methods (e.g. deterministic scenario impacts) has been adopted in the risk assessment processes underpinning the results presented in this report. These approaches for assessing risk are applicable essentially in the context of known risks (cross-border risks in the context of this report), while for emerging risks which have a high degree of uncertainty in terms of probability of occurrence, other approaches were used to assess such risks: horizon scanning, expert elicitation, scenario analysis, stress testing and simulations, Delphi methods, etc.

There is a recognized need to refine risk assessment methodologies, transitioning from qualitative to more quantitative analyses, to diminish uncertainties and bolster model accuracy. Challenges vary across different types of hazards, assets and risks, with emerging areas such as hybrid threats where appropriate conceptual models are still being developed. In contrast, fields like Natech, critical infrastructure, and biodiversity loss strive to incorporate interdependent risks into their assessment models. The key takeaways from the scientific contributions in this report underscore the intricate linkages between various elements essential to the risk assessment process. Among these, the availability and quality of risk and loss data stand out as foundational. Enhanced data availability allows for more accurate risk identification across different sectors and supports the justification for including specific risks in national risk assessments. This, in turn, aids in designing comprehensive risk scenarios considering different stakeholders and phases of DRM.

The complexity, interconnectedness and dynamic nature of risks are a reason to continually update this report as new data becomes available, enabling the identification, evaluation and modelling of new and evolving risks.

Multi-hazard risks

While this report has touched upon various individual risks, the complex and interconnected nature of hazards today necessitates a deeper focus on multi-hazard risk assessment. Multi-hazard scenarios often manifest compounded impacts that are not fully captured through single-hazard assessments. The MYRIAD[1] project has underscored the critical need for a systemic multi-hazard and multi-risk framework, which integrates hazard dependencies and interactions. This approach recognizes that the co-occurrence of multiple hazards can amplify overall risk, leading to unforeseen challenges across borders. For instance, an extended heatwave during the summer months, might lead to drought conditions. This situation becomes a hazard when it affects human health (leading to heat stress, dehydration, and heatstroke), agriculture (causing crop failures), and water supplies (resulting in shortages). As the heatwave persists, the dry conditions can significantly increase the risk of wildfires. This multi-hazard scenario has occurred in countries like Greece, Portugal, and Spain, where severe heatwaves have coincided with devastating wildfires complicating response strategies and multiplying impacts. Therefore, a dedicated study that specifically addresses multi-hazard risk assessment from an EU-wide perspective

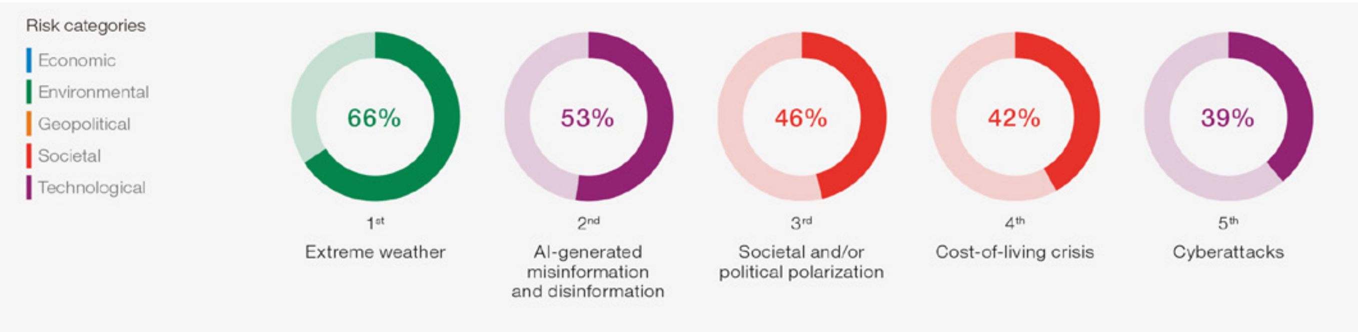
1 https://www.myriadproject.eu/

is essential. Such a study would not only highlight the complexities inherent in multi-hazard scenarios but also pave the way for developing harmonized methods for risk assessment. By embracing a holistic view, we can ensure that policies and mitigation strategies are robust, comprehensive, and aptly suited to the multifaceted nature of risks.

Way forward

Among the risks currently not covered in this report, AI and Cyberattacks are considered among the top 5 risks most likely to present a material crisis on a global scale in 2024. **Figure 56** following extreme weather events associated with the warming phase of the El Niño-Southern Oscillation cycle projected to intensify and persist this year.

Figure 56: Current Risk Landscape



Source: World Economic Forum Global Risks- Perception Survey 2023-2024

The rapid spread of advanced, versatile AI technologies is expected to significantly transform economies and societies in the next decade, bringing both positive outcomes and serious risks. These technologies will enhance productivity and lead to innovations in various fields like healthcare and education, but they also pose significant societal challenges. AI's impact will be further intensified by its interaction with other emerging technologies like quantum computing and synthetic biology, potentially leading to amplified negative effects. Risks can emerge even without deliberate misuse, especially with AI systems that improve themselves and gain more control over the physical environment, causing major shifts in socio-economic structures. Concerns about AI include misinformation, job displacement, criminal use, bias, and its integration into critical decision-making and weaponry. The rapid development and reliance on AI have outpaced regulatory measures, leading to risks in political, economic, and global security domains.

Cyber threats can easily transcend borders, impacting critical infrastructure, financial systems, and personal data security in multiple countries simultaneously. The main risks to the EU related to cyber threats include a high incidence of cloud provider attacks, cryptocurrency mining, malware, and ransomware. The severity of these cyber-breaches varies across countries, with differing rates of attacks on cloud services and encounters with various forms of cyber-crime.

In addressing these risks and their cross-border implications, the EU could focus on:

- Developing harmonized regulations and ethical guidelines for AI and other emerging technologies.
- Strengthening cross-border collaboration in cybersecurity to manage and mitigate cyber threats.
- Investing in research and development to understand and monitor the long-term impacts of these technologies.

- Enhancing public awareness and preparedness regarding the potential risks associated with these technologies.

The European Union's AI Act represents a ground-breaking legislative initiative, being the first significant global law focused on AI. It enforces rigorous control over versatile AI models, setting strict regulatory standards. The EU has established comprehensive policies and legislation related to cybersecurity, aiming to strengthen the overall security of its member states in the digital domain. A key component of the EU's cybersecurity framework is the Network and Information Security Directive (NIS2 Directive)[2], which was a revamp of the EU's first-ever cybersecurity legislation adopted in 2016. Its primary goal is to further develop cybersecurity capabilities across the EU, addressing the growing number and sophistication of digital threats. This directive places specific obligations on critical industries such as banking, energy, telecommunications, and transport to enhance their network defences and invest in cybersecurity. Public administrations are also included under this directive.

Concluding remarks

Anticipating cross-border and future risks is critical in today's rapidly evolving global landscape, where the systemic nature of these risks often leads to far-reaching societal impacts. The interconnectedness of modern systems means that risks in one area can quickly cascade into other sectors, leading to complex challenges that require holistic and innovative solutions. This is where the role of research, science, and data play an essential role.

Research and science provide the foundational knowledge and innovative methods to identify and assess potential risks before they manifest. This proactive stance is essential for developing effective strategies to mitigate or prevent the adverse effects of these risks. Moreover, data acts as a critical asset in this process, offering the empirical evidence needed to inform decision-making. By harnessing the power of big data and advanced analytics, it is possible to gain deeper insights into risk patterns and trends, enabling a more robust and informed response. This combination of foresight, scientific inquiry, and data-driven analysis is key to safeguarding our society against the challenges of tomorrow, fostering a resilient and adaptive environment in the face of ever-evolving global threats.

2 NIS2 Directive https://digital-strategy.ec.europa.eu/en/policies/nis2-directive

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List of abbreviations and definitions

AI	Artificial Intelligence
AMR	Anti Microbial Resistance
APSFR	Areas of Potential Significant Flood Risk
ARGOS	Accident Reporting and Guidance Operational System
ARIA	Analysis, Research and Information on Accidents
ASTEC	Accident Source Term Evaluation Code
BWR	Boiling Water Reactor
CANDU	Canada deuterium uranium
CBRN	Chemical, Biological, Radiological and Nuclear
CDI	Combined Drought Indicator
CEMS	Copernicus Emergency Management Service
CH	Cadre Harmonisé
CORE	The Comprehensive Resilience Ecosystem
DAPHNE	Diagnosis And Prognosis of Hazards in Nuclear Emergencies
DCRM	Dynamic Conflict Risk Model (DCRM)
DG	Directorate General
DG ECHO	European Civil Protection and Humanitarian Aid Operations
DRM	Disaster Risk Management
DRMKC	Disaster Risk Management Knowledge Centre
EC	European Commission
ECB	European Central Bank
ECML	European Crisis Management Laboratory
ECDC	European Centre for Disease Prevention and Control
EDO	European Drought Observatory
EDORA	EDO for Resilience and Adaptation project
EEA	European Environment Agency
EEAS	European External Action Service
EFFIS	European Forest Fires Information System
EFSCM	European Food Security Crisis preparedness and response Mechanism
EMM	European Media Monitoring

EMS	European Macroseismic Scale
ERCC	Emergency Response Coordination Centre
EU	European Union
EUCRA	European Climate Risk Assessment
EUSF	European Union Solidarity Found
FAO	Food Agriculture Organization
FRMP	Flood Risk Management Plan
GCRI	Global Conflict Risk Index
GDP	Gross domestic product
GDACS	Global Disaster Alert and Coordination System
GEM	Global Earthquake Model
GHSL	Global Human Settlement Layer
GRFC	Global Report on Food Crises
HERCA	Head of European Radiological Protection competent Authorities
HIAD	Hydrogen Accidents and Incidents Database
HILP	High Impact Low Probability
HWA	HERCA-WERNA approach
IPC	Integrated Food Security Phase Classification
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Centre
JRODOS	Java based Real-time On-line DecisiOn Support
LOCA	Loss-Of-Coolant Accident
MAAP	Modular Accident Analysis Program
MACCS	MELCOR Accident Consequence Code System
MELCOR	Methods for Estimation of Leakages and Consequences of Releases
PRA	Probabilistic Risk Analysis
PWR	Pressure Water Reactor
RDH	Risk Data Hub
SAMG	Severe Accident Management Guidelines
SDG	Sustainable Development Goals
SOFI	State of Food Security and Nutrition Report
UCDP	Uppsala Conflict Data Program

UCPKN	Union Civil Protection Knowledge Network
UCPM	Union Civil Protection Mechanism
UN	United Nations
UN-DRR	United Nations Office for Disasters Risk Reduction
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
UNICEF	United Nations Children’s Fund
UN-OCHA	United Nations Office for the Coordination of Humanitarian Affairs
UNU-EHS	United Nations University - Environment and Human Security
USGS	United States Geological Survey
VVER	Water-Water Energy (VVER)
WENRA	Association of Regulators of Western Europe
WFP	World Food Program
WHO	World Health Organization

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EUSBSR – EU Strategy for the Baltic Sea Region:

The European Union Strategy for the Baltic Sea Region (EUSBSR) is the first Macro-regional Strategy in Europe. The Strategy was approved by the European Council in 2009 following a communication from the European Commission. The Strategy is divided into three objectives, which represent the three key challenges of the Strategy: saving the sea, connecting the region and increasing prosperity. Each objective relates to a wide range of policies and has an impact on the other objectives. Member states involved in the EUSBSR are Sweden, Denmark, Estonia, Finland, Germany, Latvia, Lithuania and Poland. The EUSBSR implementation is coordinated in close contact with the European Commission and all relevant stakeholders. EUSBSR, as all Macro-regional Strategies, is based on effective and more coordinated use of existing funding sources, and the promotion of synergies and complementarities.[1]

EUSDR – EU Strategy for the Danube Region:

Many regions throughout the Danube Region are particularly subject to high flood risks. In 2009, the European Council formally asked the European Commission to prepare an EU Strategy for the Danube Region (EUSDR). "The importance of the Danube Basin for the EU cannot be underestimated. Our policies and the investments we are making in the Basin through the EU's cohesion policy in particular have an impact on the livelihoods of 20 million citizens" (Commissioner Hübner). States involved in the EUSBSR are Austria, Bulgaria, Croatia, Czech Republic, Germany, Hungary, Romania, Slovakia, Slovenia, Bosnia and Herzegovina, Montenegro, Serbia, Moldova and Ukraine. [2] EUSDR-related activities have helped shaping national activities by adopting a transnational approach (e.g. in the case of national programmes against natural disasters in several countries).

EUSAIR – EU Strategy for the Adriatic and Ionian Region:

The EU Strategy for the Adriatic and Ionian Region (EUSAIR) is a macro-regional strategy adopted by the European Commission and endorsed by the European Council in 2014. The Strategy was jointly developed by the Commission and the Adriatic-Ionian Region countries and stakeholders, which agreed to work together on the areas of common interest for the benefit of each country and the whole region. The EUSAIR covers eight countries: four EU Member States (Croatia, Greece, Italy, Slovenia) and four non-EU countries (Albania, Bosnia and Herzegovina, Montenegro, Serbia)[3] and one of the highlighted focuses in the 2018 EUSAIR forum in Catania was resilience to natural disasters.

EUSALP – EU Strategy for the Alpine Region:

The Alpine region represents a living and working space for the resident population and an attractive tourist destination for millions of guests every year. The Alps are the water tower of Europe. The region is particularly vulnerable to the adverse impacts of climate change as recognised by the EU Strategy on adaptation to climate change. One of the objectives is to *improve risk management and to better manage climate change, including major natural risks prevention.*[4] The focus will be to conduct an

1 https://www.balticsea-region-strategy.eu/
2 https://www.danube-region.eu/
3 https://www.adriatic-ionian.eu/
4 https://www.alpine-region.eu/

adequate comprehensive risk assessment and to implement a disaster risk management policy, as well as on conducting a comprehensive vulnerability assessment of the affected sectors and systems *and to develop a regional strategy on adapting to climate change. Enhancing cooperation, establishing efficient management systems and joint regional responses in this area will make the Region more resilient to such changes. Due to the fact that the territory is a hotspot of climate change, it can serve as a reference area in Europe in terms of observation and management of its effects.*

CBRN Decision Support Systems

The general task of a decision support system (DSS) for off-site nuclear emergency management is to provide consistent and comprehensive information at local, regional and national levels, during all phases of a real event and while preparing for a possible future event. Getting prepared requires the creation of plans through which communities intend to reduce vulnerability to and decrease the impact of future accidents. It also includes the creation of accident scenarios and background material for training and exercising the personnel and stakeholders that would be involved. In case of a real event, the system will house all relevant information on the release and the environmental contamination, and it will forecast health, agricultural, economic impacts with and without the application of countermeasures. It can also assist decision makers in evaluating different measures against a range of quantitative and qualitative criteria. A further objective of such a system was and is the promotion of a common emergency management frame aiming to move away from national solutions.

Launched initially with the support of EU funds, the two DSS presented hereunder have managed to build independent but connected communities to continuously improve its functionalities based on a collective effort. Nowadays these two DSS do not need any further support from EC since they have identified a sustainable development process based on collaboration.

ARGOS

ARGOS[5] is a decision support system for the emergency organization to make the best possible decisions in case of incidents involving atmospheric dispersion of hazardous CBRN-materials. ARGOS is useful throughout the entire disaster life cycle:

- During the Preparedness phase for planning, dimensioning and training - including evaluation of various 'What-if' scenarios
- During the Response phase by calculating prognoses about how the situation will evolve; what can be the consequences of the dispersion; what the proper emergency or evacuation zones are; etc.
- During the Recovery phase; what will be the effect of applying possible countermeasures; etc.
- In the Evaluation phase to study what could have been done better and how could the situation have evolved?

Currently, ARGOS supports emergency management organizations in 13 countries (Bosnia-Herzegovina, Denmark, Estonia, Ireland, Lithuania, Macedonia, Montenegro, Norway, Poland, Sweden, Serbia) covering more than 400 million people worldwide.

5 https://pdc-argos.com/

JRodos

JRodos[6] is a decision support system for off-site emergency management following releases of radioactive material into the environment. It contains detailed simulation models for predicting and analysing the resulting contamination, health and economic consequences. JRodos is a non-commercial system with an active user community that influences system extensions and development trends. The default data outfit is for use in Central Europe. A world-wide data base and the supported coupling to a set of globally applicable meteorological weather forecast data allows general application for any point on the globe. The JRodos system is applied by its users in emergency centres or at national or local level as a support and training tool for emergency management including long-term rehabilitation and pre-planning, thus contributing to the improvement and harmonisation of many issues in these fields.

The RODOS User Group "RUG" promotes the use of the system. During the annual meetings, the developers present new features and trends, users present their particular applications of the system, and suggested modifications or extensions are discussed and ranked by the participants.

It is worth noting that within the JRodos User Group all improvements and new features become available for the whole community, even if initiated and paid for by the interest of individual users or groups. The system design supports national language customisation and offers tools to realise user preferences. Many users, for example, want to limit the visible amount of calculation results and to modify the presentation styles of calculation results and background maps.

FP7 and H2020 Research projects

Over the last decades EU has invested a lot in developing common methodologies and tools for risk assessment and risk treatment. A full picture of the achievements on Forest Fire and on the way forward can be found at the digital version of the FOREST FIRES: Sparking firesmart policies in the EU, 2019[7].

Additional information on other research programs in different domains can be found at the DRMKC Projects Explorer[8].

HOLISTIC

The HOLISTIC project, co-financed by the European Union through the 2007-2013 IPA Adriatic cross-border cooperation programme, is a successful example of pan-European partnership between eight Adriatic countries to reduce the number and impact of forest fires, and to promote fire prevention among rural communities. The project has permitted the implementation of direct and indirect long-, medium- and short-term measures, through joint initiatives and pilot actions, which have improved fire prevention policies, fire regulations and response-coordination mechanisms across the region.

SPITFIRE

The SPITFIRE project has contributed to improving information exchange on meteorology and forest fire risk in the border area between Spain and Portugal through the identification, design and implementation of data interchange protocols and the development of a cross-border service on weather and fire

risk forecasting (SPITFIRE platform). Besides the immediate positive effects of SPITFIRE for Spain and

6 https://resy5.iket.kit.edu/JRODOS/
7 https://drmkc.jrc.ec.europa.eu/knowledge/Gaps-Explorer
8 https://drmkc.jrc.ec.europa.eu/knowledge/Projects-Explorer

Portugal, this approach can be extended to the following borders: Spain–France, France–Italy, Italy–Austria, Italy–Slovenia, Slovenia–Croatia, Slovenia–Austria, Austria–Hungary, Hungary–Romania, Romania–Bulgaria and Bulgaria–Greece.

FUTUREVOLC

The main objectives of FUTUREVOLC were to establish an integrated volcanological monitoring system through European collaboration, develop new methods to evaluate volcanic crises, increase scientific understanding of magmatic processes and improve delivery of relevant information to civil protection and authorities. FutureVolc project is funded by the FP7 Environment Programme of the European Commission and aims to address the topic "Long-term monitoring experiment in geologically active regions of Europe prone to natural hazards: the Supersite concept"

For volcano monitoring in Iceland FutureVolc has had a major impact. The large array of new sensors and systems made a huge difference in early warning capabilities and rapid interpretation of data during the most voluminous eruption for more than 200 years and the first caldera collapse in Iceland in modern times. The project integrated different disciplinary communities and helped to develop a common language and understanding. It has developed a common database with data from many disciplinary areas that needed to be integrated for effective real time response, in particular to ash-laden eruptions. FutureVolc has also pointed the way for multi-disciplinary collaboration and integrated approaches to volcanic crises of the future.[9]

AlpArray

AlpArray is a European initiative to advance our understanding of orogenesis and its relationship to mantle dynamics, plate reorganizations, surface processes and seismic hazard in the Alps-Apennines-Carpathians-Dinarides orogenic system. The initiative integrates present-day Earth observables with high-resolution geophysical imaging of 3D structure and physical properties of the lithosphere and of the upper mantle, with focus on a high-end seismological array. [10]

STIPP

STIPP was a project funded by the European Territorial Cooperation Operational Programme France-Spain-Andorra 2007-2013, which aimed at improving risk prevention in the Pyrenees by creating a Pyrenean Information Centre on Risks (PICR) making available for mountain professionals and public a cross-border information system in all languages of the Pyrenees.

Based on close collaboration between mountain professionals and authorities responsible for prevention and risk management in the Pyrenees, the aim of the project was to create an Information Center for Risk Prevention, providing in particular:

- A real-time distribution to mountain users of the latest information on the status of risks in the massif, improved by field data collection made by mountain professionals (guides, shepherds, park rangers, refuge keepers ...)
- A coordinated meteorological and snow information on both massif sides, enhanced by the increase of in-situ measured values
- An emergency call system, including satellite geo-localisation, giving access to emergency services in

9 https://futurevolc.hi.is/
10 http://www.alparray.ethz.ch/en/home/

areas out of GSM coverage.

- An assistance to wounded and sick people before the arrival of rescuers, with equipment for tele-medical care in refuges. [11]

The project included training sessions for mountain users, and the dissemination of the service on the entire Pyrenean massif.

SISSIE

The SISSIE project was established by the Alpine regions of Carinthia and Friuli Venezia Giuli in order to exchange data in real time and deliver information quickly in response to a disaster. The SISSIE platform allows both regions to provide mutual assistance in the field and to coordinate rescue operations across the border. The project brought together experts in a variety of fields, including flood control, air pollution, chemical hazards and mountain rescue. [12]

EPISECC

The project EPISECC is aiming at developing a concept of a common "European Information Space". This information space is dedicated to become the key element in a future integrated pan-European crisis and disaster response capacity. Besides the development of a common Taxonomy and an ontology model, aimed at addressing the Semantic Interoperability issue, EPISECC will focus on the establishment of Interoperability at Physical (i.e. network) and Syntactical (i.e. automated information exchange) levels. One of the main purposes of the EPISECC approach, is to allow analysis of interoperability at all levels.

INTERREG (Romania, Hungary)

The following activities were implemented within the project:

- organising common trainings, exchanges of experience and good practice.
- Organising an information campaign, especially in schools and city halls, on emergency interventions.
- Editing and distributing informative materials.
- Establishing and endowment of the integrated cross-border monitoring centre.

The main output of the project is to improve the degree of prevention and management of cross-border risks, as well as to provide efficient intervention services. By setting up and operating the centre and equipping volunteer teams with reliable equipment, the project will facilitate the management of cross-border risks, improve the infrastructure, equipment and human potential serving emergency response teams in Satu Mare and Szabolcs-Szatmár-Bereg counties.

11 http://www.medes.fr/en/our-activities-1/e-health-and-epidemiology/e-health/stipp-project.html
12 https://ec.europa.eu/regional_policy/en/projects/austria/cross-border-cooperation-improving-disaster-response

Annex II – Case studies

Table 7. Case studies of events with significant cross-border impacts on networks providing essential services

N.	Events	Infrastructure(s) involved	Countries involved	Initial triggering hazard/ threat and initial conditions	Direct damage and failure to CI	Systemic damage and failure	Second order damage to another CI (cascading)	Source of the case study and brief description of recovery intervention (when available)
1	Increasing storms severity/ frequencies due to climate change	Rotterdam Port and shipping lanes	The Netherlands and all countries shipping to and receiving goods from the port	Climate Change related hazards (storm, flooding, rainfalls)	Navigation system interruption	Extreme weather has recently often impacted shipping requiring the closure of the port. Long lasting disruption (more than one week) can lead to blockage of goods to the hinterland and to neighbouring EU countries.	Disruptions in the transport chains at the port can have costly ramifications impacting crucial supply chains for example raw materials for the German steel industry.	Case study in EU_ INTACT Project. The project examines the current status of the EWE and CI hazards in detail, the risk analysis, analysis of future risks, and an assessment of measures and strategies to alleviate these risks.
2	1981- 2011	Transport system; Dam System and Hydroelectric Plant	France, Italy	Floods, landslides, avalanche's, flows (of mud and debris), collapses (falling of blocks)	Roads crossing the Alps have been affected several times by avalanches and various types of landslides.	Apart from the functional damage due to the interruption of major transport networks connecting Northern to Southern Europe, particularly warrying are scenarios affecting dams that may have very dramatic impacts on downstream settlements.	Access to public buildings or open to the public; access to Industrial plants / manufacturing / tourism; access to facilities related to the operation of essential services or the civil protection activities. Water and electricity supply lines	Case studies in the PICRIT project. The analysis of the impacts resulting from the damage to the road infrastructure has been performed using the guidelines of the INSPIRE Data Specification on Production and Industrial Facilities' - 2012. Simulated application of intervention protocols foreseen in the event of structural collapse of the dam.
3	2002	Transport system	Germany, Czech Republic, Austria and Poland	Elbe river flood	Railway line and station in Dresden	Widespread damage to transport systems, in particular to the railway network, famous are the images of the train station in Dresden completely flooded	-	The International Commission for the Protection of the River Elbe, established in 1990 including since 2009, the Czech Republic, Germany; Poland, Austria, the European Union, the river basin Commissions for the Danube, Rhine and Oder as well as several NGOs that participate as observers.

4	August 2003	Transport system	France, Portugal, the Netherlands, Spain, Italy, Germany, the United Kingdom, Switzerland, Ireland, Sweden	Heat wave	Rails buckling; Degradation of signalling systems of railway system; Deformations of road surfaces; Break of London underground trains	Delays and failure of European transport systems	-	Speed restrictions for trains have been imposed since then when the temperature was above 30 °C; the French government has implemented (with The Heat Wave Plan) a number of preventative measures including effective alerting systems.
5	23 September 2003	Power System	Scandinavian Countries	5 transmission lines and 4 generation units out of service before the incident	-	Water supply, Transportation, Communication, Hospitals	Loss of generation, damage to isolator, busbar fault, transmission lines disconnection, power swings and voltage collapse. A total of 4700 MW of load was lost in Sweden (1.6 million people affected) and 1850 MW in Denmark (2.4 million people affected). Duration of the disruption: 5h	The technical report on the event highlighted the need for tightening procedures for improved for communication between operators.
6	28 September 2003	Power System	Italy and Switzerland	Tree flashovers; High power transfers toward Italy. Loss of synchronism of Italy with the rest of UCTE, instantaneous isolation of Italy from the rest of UTCE, thermal plants tripped due to low voltage, complete blackout.	Tripped power lines by trees flashover, high voltage line damaged	Water supply, Transportation, Communication, Hospitals	Reported damages: 640 Mln Euro, aborted liver transplant, 4 deaths. People without service: 57 mln; Lost Load: 2400 MW; Duration: 5-9 h, in some Southern regions up to 48 hours.	To contain the incident Italy was isolated from the rest of Europe, this separation caused strong instability and after few minutes the peninsula was without power. Improved shared situational awareness mechanisms and instruments between the two countries were highlighted as key risk mitigation measure. The failure of the three lines of defence of the Italian national strategy has been scrutinized and addressed.

7	2004	Gas pipeline	Belgium and France	-	Leakage and explosion	-	A transit gas pipeline exploded causing 24 fatalities and more than 120 injuries in Belgium. Damages: 100 mln Euro.	-
8	2005 - 2006	Power system; Wide areas of farmland, Bridges	Bulgaria, Turkey and Greece	Maritsa river flood	Supply interruption, connection interruption	Energy procurement	Reduced dam reservoir levels; hydroelectric power generation loss; agricultural land loss	Case descriptions in - UNECE - Convention on the Protection and Use of Transboundary Watercourses and International Lakes. *Transboundary flood risk management Experiences from the UNECE region, 2009.* Improvement in measures for flood prevention and reduction of flood impacts. Until 2003, there was no communication between neighbouring countries about floods. As a first step for cooperation, a hydrological model was jointly developed.
9	4 November 2006	Power System	Europe	The incident started from a planned routine interruption in Northern Germany to allow the passage of a large cruise ship in the North Sea. A combination of events caused overload that led to automatic protection measures of the system with cascading impacts across EU countries.	-	Water supply, Transportation, Communication, Hospitals	People without service: 45 mln; Lost load: 14500 MW; Duration: 2 h	

10	2006	Transport system	Austria, Czech Republic, Slovakia	Morava river flood, Danube river flood	Railway line	Damages from the 2006 flood were estimated to be € 35 million. The source and the largest stretch of the river are in Czech territory. It forms a (small) part of the Czech-Slovak border and of the Slovak-Austrian border. On the latter, the Morava joins the Danube. The main tributary to the Morava is the river Dyje. The Morava River is dangerous due to both floods caused by regional rainfall and flash floods, so several flood risk management problems need to be solved at the same time.	AUSTRIA. Three dikes broke on the March/Morava flood protection dam. The main line from Vienna to Prague and some roads were damaged/destroyed. Infrastructure losses total approximately €40 million (rail line and road.	Case descriptions in - UNECE - Convention on the Protection and Use of Transboundary Watercourses and International Lakes. *Transboundary flood risk management Experiences from the UNECE region, 2009.* See Also CEFRAME Project Central Europe, running from 2010 - 2013. https://www.ceframe.eu/
11	17-19 January 2007	Transport system	The United Kingdom, Norway, Ireland, France, Belgium, the Netherlands, Denmark, Sweden, Austria, Germany, Czech Republic, Slovakia, Slovenia, Switzerland, Poland	Winter storm	Abandonment of the container ship MSC Napoli in the English Channel; Roof damage of the railway stations in London and Amsterdam; Structural damage of the railway station in Berlin; Fall of trees onto rail tracks	In the European major airports, flights were cancelled or delayed; Ferry services were cancelled; Major motorways and bridges were closed; Long queues developed around blackspots	-	Speed restrictions in railway systems; Warning systems

12	20 March 2010	Transport system	All EU Member States and countries	Eruption of the Eyjafjallajökull volcano (Iceland)	-	Airspace of many countries were closed; 104.000 flights were cancelled; passengers unable to reach their destination	-	Restrictions in the air traffic for precautionary reasons. Follow up studies to assess the actual risk of ashes on plains' engine.
13	8 August 2011	Power System	Arizona, California and Mexico	High temperature and load level; Some generation and transmission maintenance outages	-	Water supply, Transportation, Communication, Hospitals	Loss of transmission line, cascading outages, system operating at its limit, violated the transmission operations and facilities design, collapse of the system. PEOPLE WITHOUT SERVICE: 8,1 mln; LOST LOAD: 7835 MW; DURATION: 6-12 h	The event was initiated by the loss of a transmission line, which caused cascading outages, since the system was not being operated in a secure N-1 state. The failure was produced primarily from weaknesses in operation planning and real-time situational awareness. Entities responsible for the transmission system could not maintain the reliable operation nor prevent cascading outages.
14	June 2013	Transport system	Austria, Bulgaria, Croatia, Germany, Hungary, Romania, Serbia, Slovakia	Danube river floods	Damage to roads and bridges	Large scale disruption to the transportation system across the countries	-	Disaster alarms and timely flood warnings; flood protection measures (i.e. flood protection walls or sandbags, Removal and disposal of debris and biomass from drainage channels); timely evacuation of the most exposed

15	28 October 2013	Transport system	Germany, the United Kingdom, the Netherlands, Denmark, France, Sweden, Estonia, Russia	Cyclone/Storm	Loss of several shipping containers; Roof damage to the railway stations in Denmark; Fallen trees and damage to the catenary of tram services in South Holland; in London, Tube lines were affected because of debris on the tracks	Sailing, ferry, tramway and air services were cancelled or delayed; Major ports, roads, bridges and railways were closed;	-	Warning systems for delays; People evacuation; Preventative closure of railway stations
16	August 2017	Transport	Germany but with repercussion across the Rhine-Alpine railway corridor	Not exactly a natural hazard, but soil conditions probably worsened by the combination of a very hot summer and heavy rains	Damage to a segment of the existing railway near the city of Randstatt that is part of the Rhine-Alpine corridor from Genova (IT) to Rotterdam (NL)	The incident occurred in the railway but the consequences were on the multi-modal shipping and inland transport of goods. The disruption in indirect damage in the added value totalled 2 billion according to an official study that was conducted.		The reputational damage to the railway system was very large with negative consequences on climate change mitigation policies. It also showed the difficulties in providing alternative routes across countries in case of major incidents.
17	October 3 2020	Transport system and power	Alex storm hit Europe between October 2-7 with different names (Brigitte in Central Europe, Aiden in the UK and Ireland)	Storm	In particular across the Roya Valley at the border between France and Italy, transportation networks connecting the two countries were cut and severely damaged.	14 bridges on the Roya river were severely damaged. The railway has been cut and substitutive bus have been organised. All lifelines suffered damage, with 800 households affected by power cuts days after the disaster whilst more than 15.000 the same days.	The tourist sector has been affected, in particular the lodges in the upper part that could not be accessed due to the damage to trails. Several villages were isolated for days.	The trainline was re-established 7 months after the event. Damage was assessed to be as high as 1.5 billion Euros according to the Prefecture in Nice. In the Italian side of the Cuneo Province 18.5 Million Euros were assigned by the national government for the recovery.

18	July 2021	Transport system, power system, network and information systems and manufacturing	Western Europe (Belgium, Luxembourg, Germany, Netherlands, Austria, Switzerland)	Severe flooding caused by strong storms	At least 183 people have died. Entire villages were severely damaged. Dozens of highways and roads closed due to debris and floodwater.	Widespread disruption to logistics and manufacturing operations. Dozens of areas remained without power, telephone, or cell phone networks.	Manufacturing sector with delivery delays and supply shortages. Several companies in the most severely affected industrial areas have been inundated by floodwater that caused extensive damage to machinery, production facilities, and warehouses.	The EEA Report (2014) outlines a series of recommendations to support companies in identifying of sub-tier suppliers and alternative sources for the most critical components; investing in technological solutions to map out and providing better access to supplier networks.
19	14 August 2003	Power System	North America	Tree flashovers; High temperature and load level; generators and 5 capacitor banks out of service	-	100 deaths and $6 billion losses were reported as a consequence. Water supply, Transportation, Communication, Hospitals were severely affected	The blackout triggered by initial outages in Northern Ohio spread to the whole region. Systemic lack of coordinated real-time security assessment, information exchange and control led to the collapse. People without service: 50 mln; Lost load: 61800 MW; Duration: 16–72 h in USA and up to 192 h in Canada	Full restoration took several days.

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