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Report

Systemic and Complex Risk Governance for Europe's Preparedness and Sustainability

Advancing the Understanding of Environmental Risk Drivers and Transformative Governance Responses in Europe

A report commissioned by the European Environment Agency (EEA)

Work carried out in collaboration with the Ecologic Institute

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Institute for European Environmental Policy

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CONTENTS

1. EXECUTIVE SUMMARY

The European Union is at a pivotal moment in its sustainability and strategic trajectory. Competitiveness, resilience, preparedness, security and innovation are now central priorities in the EU's evolving policy agenda, as reflected in the 2026 EU work programme (EC, 2025), the Competitiveness Compass (EC, 2025a), the forthcoming European Climate Resilience and Risk Management Framework, and the EU Preparedness Union Strategy (2025). These initiatives can be understood as responses to a rapidly changing global context often described as a polycrisis, in which climate change, biodiversity loss, geopolitical instability, economic shocks, health risks and social inequalities interact and can potentially amplify one another.

This renewed strategic context has important implications for sustainability transitions in Europe. Environmental risks are no longer adequately understood as isolated, sector-specific or linear challenges. They are systemic: interconnected across societal systems, capable of generating cascading and compounding impacts, and in some cases potentially irreversible. Risks linked to the triple planetary crisis of climate change, biodiversity and nature loss, and pollution affect Europe through the configuration of its energy, food, financial, industrial and ecological systems. At the same time, these systems also shape the ways in which risks emerge, spread and intensify.

The aim of this report is to inform Europe's evolving policy agenda by showing how environmental risks interact, compound and affect societal systems across Europe, and by illustrating how transformative responses can help navigate systemic and complex risks. The project was structured around three tasks: harmonising a database of key environmental risk drivers identified in targeted literature; developing and applying a qualitative "risk constellations" approach across four systems — energy and industrial transformation, economy and financial systems, food systems, and nature and ecosystems; and operationalising governance-in-complexity principles through six case studies.

The report demonstrates that systemic environmental risks are not confined to individual policy domains. Instead, they unfold across interconnected systems, creating dependencies and feedback effects that are difficult to address through siloed governance. Across the analysis, water, land, ecosystem services and infrastructure repeatedly emerge as shared pathways through which risks propagate across sectors. These findings suggest that Europe's sustainability, security and prosperity increasingly depend on the capacity to recognise, govern and transform these interconnections.

This has direct implications for current EU priorities. Competitiveness, resilience and preparedness cannot be treated as separate agendas. Competitiveness increasingly depends on whether critical systems can remain functional under environmental, economic and geopolitical pressure. Resilience depends not only on strengthening individual sectors, but also on reducing structural vulnerabilities across systems. Preparedness depends on whether governance arrangements, institutional capacities and responsibilities are in place before risks escalate. In this sense, systemic environmental risk governance is no longer a peripheral environmental concern; it is becoming a central condition for effective EU governance.

The report identifies three core governance priorities. First, environmental dependencies should be addressed more explicitly in industrial, energy, financial and food-system policies to reduce structural vulnerabilities. Second, cross-system adaptive capacity and institutional coordination need to be strengthened, alongside investment in longer-term system reconfiguration. Third, anticipatory governance capacities should be reinforced through practical tools and methods that help policymakers and experts understand, discuss and manage systemic and complex risks before they escalate.

Methodologically, the project demonstrates the value of collaborative qualitative approaches for making systemic risk more visible and actionable. The database of environmental risk drivers, the risk constellations, the system network diagrams and the operationalisation of governance-in-complexity principles provide a practical way to explore complexity at a manageable scale without losing sight of wider system dynamics. The methodology and associated resources, including the risk playing cards in Annex 6, offer a platform for context-specific workshops, expert dialogue and the co-production of policy-relevant system insights.

A key finding is that systemic risk governance requires approaches that simplify complexity without distorting it. The project identified a “complexity ceiling”: once risks become highly interconnected, it becomes increasingly difficult for experts and institutions to maintain a clear overview of the wider system. This does not imply that complexity cannot be governed. Rather, it shows that governance requires tools and processes that allow experts and policymakers to engage with interdependencies at an appropriate scale, while remaining attentive to the broader systems in which those risks are embedded.

The report also highlights practical governance implications. Across the risk constellation exercises, experts repeatedly returned to questions of uncertainty, rates of change, tipping points, foresight, coordination and the timing of intervention. These insights underline that effective systemic risk governance depends not only on better information, but also on stronger institutional capacity, clearer cross-sector coordination and a greater ability to act under uncertainty. Preparedness for systemic environmental risk therefore requires clearer arrangements for monitoring, shared ownership and anticipatory action, especially where responsibilities cut across sectors, governance levels and policy mandates.

Building on this, the report operationalises the governance-in-complexity principles presented by the EEA (EEA, 2024c). This provides a standardised yet flexible framework through which policymakers can assess governance dynamics under conditions of complexity, identify governance gaps and prioritise interventions suited to interconnected and uncertain challenges. The case studies demonstrate that governance responses are most credible when they are forward-looking, cross-sectoral, context-specific and capable of combining anticipation, participation, learning and care in practice.

Overall, the report argues that Europe's response to systemic environmental risk must become more integrated, anticipatory and transformative. This requires not only improved methods for mapping and discussing complex risks, but also governance arrangements that are fit for complexity: able to work across systems, navigate uncertainty, reduce structural vulnerability and support long-term sustainability transitions.

2. INTRODUCTION

The European Union (EU) stands at a pivotal moment in its sustainability trajectory. Concepts such as competitiveness, resilience, preparedness, security, innovation and industrial transformation are critical for the future of the EU. Recently the European Commission 2026 Work Programme outlines a series of actions to help build a more sovereign and independent Europe. The Work Programme focuses on boosting competitiveness, innovation, and strategic sovereignty in energy, digital, and industry, while protecting citizens' livelihoods, social cohesion, and democratic values. Europe will strengthen defence, security, migration management, and climate resilience, ensuring sustainable growth and ecosystem protection. This Work Programme is accompanied by a variety of documents which reinforce and guide these goals.

First, is the Commission's 'competitiveness compass,' which provides a roadmap to enhance the EU competitiveness. There are three main objectives to boost EU competitiveness: 1) closing the innovation gap by supporting startups and enhancing uptake of artificial intelligence; 2) decarbonising our economy by facilitating the transition to move toward clean, affordable energy; and 3) reduce dependencies and strengthen supply chains by forming global partnerships to secure essential resources.

Second, the EU Adaptation Strategy (2021) aims to help the EU become more resilient through smarter, faster and more systemic adaptation. The Strategy emphasises the importance of developing solutions to reduce climate risks, enhance protection, and secure water resources, as well as addressing climate impacts across all sectors by integrating climate resilience into policy instruments and measures. Building from the EU Adaptation Strategy, the Commission is currently developing a new integrated framework for European climate resilience and risk management. The framework aims to provide a balanced policy package that safeguards Europe's security and prosperity, boosting its competitiveness, protects health and well-being and enhances resilience to systemic risk. As of the publication of this report, this framework has finished its consultation period in February 2026 and is set for adoption in the fourth quarter of 2026.

Finally, regarding preparedness, the European Preparedness Strategy (2025) is a central document in enhancing the ability for Europe's Member States to respond more rapidly to increasingly complex crises. The preparedness strategy outlines the need for an integrated all-hazards approach that is bolstered by climate risk assessments. The Strategy implements an efficient whole-of-government approach which aims to move beyond siloed thinking and departments, to ensure coordinated responses across national governments. It also implements a whole-of-society approach which enhances population preparedness and encourages the public to adopt practical measures that involve businesses, civil society, and individuals to foster citizen self-sufficiency and strengthen security. Furthermore, it includes 30 explicit key actions and a detailed action plan to develop a ‘preparedness by design' culture between 2025-2027.

Building from this, Europe’s ability to meet its 2030 and 2050 sustainability goals is under growing pressure (European Environment Agency (EEA), 2025a). The 2025 edition of the European Environment Agency’s (EEA) State and Outlook of the Environment Report (SOER) signalled the urgent need for fundamental transformations across production and consumption systems (EEA, 2025a). This assessment is reinforced by the EEA’s Monitoring report on progress towards the 8th Environmental Action Programme objectives 2025, which provides the most up-to-date evidence base and shows that many sustainability targets are ‘likely off track’ or ‘off track’ for achievement by 2030 (EEA, 2025d).

Delivering upon the goals of competitiveness, resilience and security requires an appreciation of systemic and complex risks. Europe’s sustainability transitions are unfolding during what has been termed a global ‘polycrisis’: a convergence of multiple, interconnected crises including climate change, biodiversity loss, geopolitical instability, health emergencies, inflationary shocks, and social inequalities (EC, 2025). Rather than containing risks within isolated challenges, the polycrisis generates systemic risks, which are deeply interdependent threats that can cascade across sectors and borders, thus overwhelming conventional governance and policy response mechanisms (JRC, 2025d). These interconnected crises challenge traditional problem-solving (EEA, 2024c) and require a more integrated understanding of risks and the ways in which they interact.

The urgency of this challenge is underscored by the EEA’s 2024 EU Climate Risk Assessment (EUCRA) (EEA 2024a), which provides the first EU-wide analysis of current and future climate-related risks. The EUCRA report highlights that climate risks are no longer isolated environmental events but have become systemic in scope, threatening infrastructure, health systems, ecosystems, economies, and social stability simultaneously (EEA 2024a). The EUCRA report warns that the EU is inadequately prepared to manage many of these interlinked and escalating risks, particularly considering widening adaptation gaps and existing governance failures (EEA 2024a). Accordingly, the report takes a broader perspective, situating its analysis within the context of the triple planetary crisis and addressing risks related not only to climate change, but also to environmental degradation and pollution.

The findings in the EUCRA report reinforce the need for an integrated risk governance approach capable of anticipating, managing, and reducing cross-cutting vulnerabilities. The EEA's findings are further substantiated by those of recent global assessment reports by international bodies such as The European Strategy and Policy Analysis System (ESPAS), The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), Organisation for Economic Co-operation and Development (OECD) (OECD, 2024), United Nations Environment Programme (UNEP) (UNEP, 2021; 2024).

Against this backdrop, there is an urgent need for robust knowledge and practical frameworks to help EU institutions anticipate, assess, and respond to systemic and complex environmental risks. While many existing assessments identify sectoral environmental risks, fewer analyses examine how environmental drivers interact across social, economic, political, and technological systems in ways that create compounding or cascading effects across governance systems. In its report Governance in complexity - Sustainability governance under highly uncertain and complex conditions (EEA, 2024c), the EEA explores an approach to sustainability governance that is designed to respond to challenges marked by uncertainty and complexity. The key principles underpinning this approach to transformative governance include experimentation, systems thinking, participation, precaution, anticipation, and care.

The governance in complexity principles align with the EU Preparedness Strategy, which is explicitly built around the need for integrated approaches, including all-hazards, whole-of-government, and whole-of-society frameworks. Furthermore, the principles of governance in complexity emphasise the importance of experimentation and innovation, which are explicitly recognised in the EU Work Programme and are essential to responding effectively to complex and interconnected risks. The report is also intended to inform the development of the EU's integrated framework for European Climate Resilience and Risk Management, a key reference point for EU researchers, policymakers, and practitioners. This underlines the need for credible, accessible, and forward-looking insights and methodologies to support action in the face of uncertainty and complexity.

Before setting out the aim and objectives, it is important to clarify what constitutes a systemic risk in the context of environmental change. Box 1 presents the working definition used in the project.

Box 1: Understanding/working definition of systemic and complex risks.

Understanding/Working Definitions:

Systemic and complex risks - are risks that arise within and across highly interconnected systems, where disturbances in one element can cascade through feedback loops, amplify vulnerabilities, and generate disproportionate, unpredictable, and often transboundary impacts. Systemic risks differ from conventional risks because they are not confined to isolated events or single sectors; instead, they are embedded in dynamic, nonlinear, and adaptive networks of social, technological, environmental, and economic systems. In this sense, systemic and complex risks represent the entanglement of hazards, vulnerabilities, and exposures in coupled human-environmental systems, where failures are non-linear, cascading, and often irreversible. They form the foundation of today's polycrisis, in which multiple systemic risks actualise and interact simultaneously.

Key features include:

Complexity - Multiple interacting drivers and feedback loops make cause–effect relationships opaque, with potential for sudden regime shifts or tipping points.

Cascading and Spillover Effects - Local shocks can propagate across sectors and regions, leading to systemic disruption of critical functions such as finance, food, health, or energy.

Transboundary Nature - Risks cross political, spatial, and sectoral boundaries, creating global interdependence (e.g. pandemics, climate change, supply chain failures).

Deep Uncertainty and Ambiguity - Outcomes are unpredictable, knowledge contested, and interpretations of risks divergent, making governance and decision-making especially difficult.

Systemic Stakes - They threaten the stability and resilience of essential societal and planetary systems, not just their individual components.

Source : EEA (2025), based on : EEA (2024c), Gambhir et al. (2025), Jehn (2025), Lawrence et al. (2025), Liu & Renn (2025), Richardson (2025) and Sillmann et al. (2022).

2.1 Aim

This report aims to advance the understanding of systemic and complex risks stemming from the triple planetary crisis by delivering targeted knowledge on risk drivers, systemic and compounding interactions and governance responses that can inform Europe's evolving resilience agenda.

2.2 Objectives

The overarching objective of this report is to support the EEA in advancing knowledge on systemic and complex environmental risks and how risk governance can strengthen Europe's sustainability and resilience. To achieve this, the project has:

- Identified and characterised key environmental risks arising from climate change, biodiversity loss, pollution, and land/resource degradation.
- Illustrated how the interactions between risks across critical societal systems such as food, energy, economy, and ecosystems can be identified.
- Reflected on how these risks may impact the EU's ability to achieve policy priorities including competitiveness, resilience, social fairness, and long-term sustainability.
- Identified real-world applications of governance frameworks responding to systemic risks and analysed case studies at different scales.

2.3 Workflow

Figure 1 presents a detailed overview of the project workflow, outlining the main tasks and key steps undertaken.

Figure 1: Overview of the project workflow and key outputs and methodological steps.

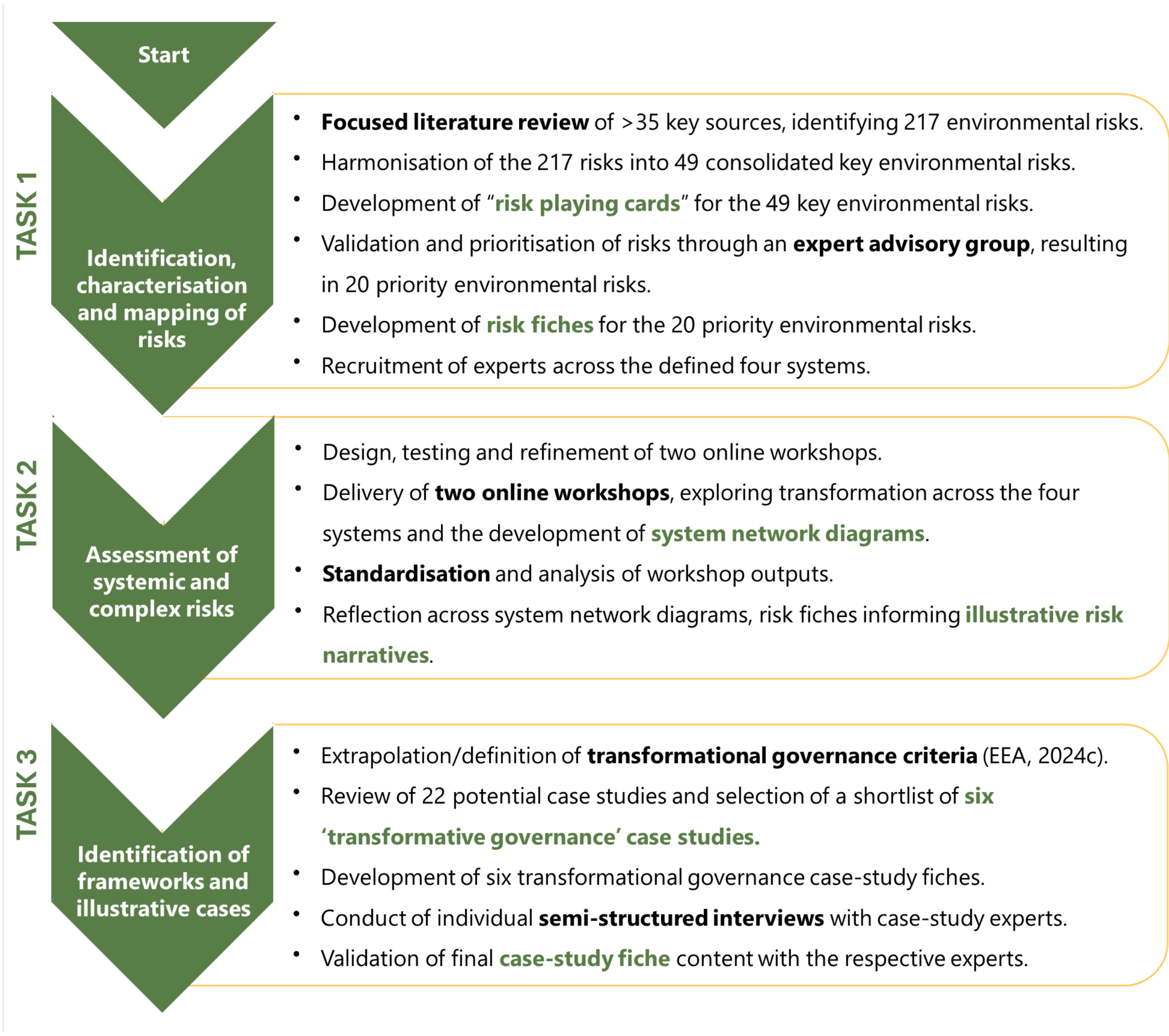

Figure 1: Author

3. TASK 1 - CHARACTERISATION OF SYSTEMIC RISKS STEMMING FROM ENVIRONMENTAL CHANGE

3.1 Conceptual Framing – The Four Systems

The project was divided into three core tasks as defined in the workflow diagram in Figure 1. Conceptually, this project's work is structured around four interconnected systems, each representing a key sectoral/policy area in Europe. These four systems include:

- Resilient and Competitive Economic and Financial Systems,
- Energy Transitions and Industrial Transformation.
- Resilient Ecosystems and Nature Protection, Climate Resilience and Restoration
- Secure and Sustainable Food Systems.

The analysis of risks associated with these four interconnected systems was central to the objectives of this project. First, they represent key sectoral interests and disciplinary areas that are critical to the EU agenda (EEA, 2024a), thereby ensuring that major policy-relevant areas are adequately represented. Second, establishing them enabled both the project team and participating experts to structure inputs and discussions around specific systems from the outset, before examining broader interactions and cross-sectoral implications. This approach helped experts navigate some of the inherent complexities associated with discussing systemic risk, allowing them to begin from subject areas with which they were most familiar.

Building on this, it is important to recognise that these risks often span all four systems, and that the boundaries between systems are not fixed. Accordingly, while the report is broadly structured around these four systems, the workshops were designed to encourage discussion between experts from different systems and to capture input on the interconnections between them. By design, this project focused on those 4 systems only, however, it is acknowledged that the original system framing may not fully reflect certain risk pathways, especially those relating to social and public health.

Finally, it is important to note that the triple planetary crisis served as a key conceptual framing of the project as both a source of environmental risks for systems (OECD, 2025) and perceiving integrated approaches to interconnected nature of risk (Iwasuk et al. 2025).

The first objective of the project was to identify and characterise key environmental risks arising from climate change, biodiversity loss, pollution, and land/resource degradation. The identification and characterisation of these key risks was conducted through a focused targeted literature review.

3.2 Literature Review

Purpose and Scope of the Literature Review

The focused targeted literature review aimed to identify, map, and characterise potential systemic, complex and cascading risks stemming from environmental risk drivers that affect European society and territory. This includes risks that manifest in Europe but have their origin elsewhere. The focus was on risks arising from climate and environmental change, including climate change, environmental degradation, biodiversity loss and pollution, and how these risks interact across systems. In line with the 8th Environment Action Programme, the review adopted a long-term perspective to 2050, recognising that risks linked to climate change, environmental degradation, biodiversity loss and pollution unfold across multiple time horizons and can undermine the EU's broader objective of enabling people to live well within planetary boundaries. This review did not consider risks that arise solely from non-environmental drivers, such as cyber threats, artificial intelligence–related risks, technological or geopolitical risks. This does not imply that such risks are unimportant; on the contrary, many systemic risks emerge through interactions between environmental and non-environmental drivers. Rather, the analytical focus here was placed on risks in which environmental pressures act as primary or contributing driver, and where impacts propagate across sectors, geographies or time horizons.

Defining a Shared Understanding, Framing and Clarity

The initial phase of the focused targeted literature review involved establishing a shared understanding of key terms, especially risk and risk drivers. Clarifying these concepts was essential to ensure consistency across the review and comparability between different sources. Box 2 presents the definitions of the key terms Risk, Driver, Hazard, Exposure and Vulnerability that was used in the inception phase of the project.

Box 2: Key risk-related definitions used at the inception phase of the project

Key risk-related definitions

Risk - *"The* ***potential for adverse consequences for human or ecological system(s)*** *(...). In the context of climate change, risks can arise from potential impacts of climate change as well as human responses to climate change. Relevant adverse consequences include those on lives, livelihoods, health and well-being, economic, social and cultural assets and investments, infrastructure, services (including ecosystem services), ecosystems and species. In the context of climate change impacts, risks result from dynamic interactions between* ***climate-related hazards*** *with the* ***exposure*** *and* ***vulnerability*** *of the affected human or ecological system to the hazards. (...)"*

Driver - *"Any natural or human-induced factor that directly or indirectly causes a change in a system"*

Hazard - *"The potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources".*

Exposure - *"The presence of people; livelihoods; species or ecosystems; environmental functions, services, resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected."*

Vulnerability - *"The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt."*

Source: IPCC, (2023)

Utilising these definitions as a base for the initial scan of literature revealed significant variation in how risks are formulated and described across different assessments and institutions. For example:

- The IPCC (IPCC, 2023) and the European Climate Risk Assessment (EEA, 2024a) commonly formulate risks using a structured "risk to [system or endpoint] from [risk driver]", formulation (e.g. risk to biodiversity and carbon sinks from increased frequency and intensity of wildfires).

- The Joint Research Centre (JRC) publications "Analysis of risks Europe is facing" (JRC, 2025a) and "Cross-border and emerging risks in Europe" (JRC, 2024), often describe what are defined in this project as drivers (e.g. wildfires, biodiversity loss) rather than risks in a strictly analytical sense or define risks in terms of impacted systems or outcomes, such as risks to food security.
- Finally, reports from organisations such as the OECD apply other risk framings, reflecting different analytical traditions and purposes.

This diversity in risk definitions and framings poses a challenge, as it limits the ability to systematically organise, compare, structure and synthesise risks identified across the literature. To ensure conceptual clarity and consistency, risks in this project were formulated using a structured risk logic aligned with the IPCC and EUCRA formulation. This formulation was selected, in part, because it provides a coherent basis for synthesising risks across sectors and systems, in a comparable manner. In this formulation, **primary environmental risk drivers** associated with the triple planetary crisis (e.g. climate change, biodiversity loss, environmental degradation and pollution) give rise to **specific risk drivers**, such as droughts, floods, heat stress or pollinator loss. These risk drivers correspond broadly to what the IPCC framework refers to as hazards, namely the physical or ecological processes through which environmental change manifests. In combination with exposure and vulnerability, these risk drivers create **risks to defined endpoints**, such as societal systems, ecosystems or human health. Throughout the project, risks were therefore consistently framed as "**risk to [system or endpoint] from [risk driver]**", ensuring that the impacted system and the underlying environmental process were clearly distinguished. In the "risk to" component, the analysis focuses primarily on the four systems that structure this project (resilient and competitive economic and financial systems; energy transitions and industrial transformation; resilient ecosystems; and secure and sustainable food systems). This system-based framing helped ensure that risks were not considered in isolation, but rather in terms of their cross-sectoral interactions and cascading nature.

The literature review also highlighted that human health was frequently identified as a key endpoint affected by environmental change. While health is not one of the four systems that this report focuses on, given the prominence of health impacts across the reviewed sources, risks to human health from environmental risk drivers were included in the selection of risk fiches for the purpose of comprehensiveness.

Purpose and Scope of the Literature Review

Building on the agreed risk framing and system boundaries, the next step of the focused targeted literature review consisted of a systematic screening of 35+ key references (see Box 3). The starting point for the literature scan was a set of core reports identified by the EEA, which primarily included major European and global environmental and risk assessment reports. These reports, which were selected based on their policy relevance, scientific credibility, and coverage of systemic environmental risks relevant to the four systems addressed in this study, served as the initial evidence base for the analysis. The review was conceived as a "review of reviews", focusing on authoritative synthesis reports that have compiled and assessed evidence on environmental and systemic risks. This approach allowed the review to efficiently capture the state of knowledge across multiple sectors and environmental domains. The resulting list of sources should therefore be understood as a comprehensive but non-exhaustive set of key references, selected for their relevance, authority and coverage of systemic environmental risks affecting Europe.

Attention was given to authoritative reference reports, including the European Climate Risk Assessment (EUCRA) (EEA, 2024a) and assessments of risks to Europe produced by the JRC (JRC 2024, 2025a and 2025b) and EEA, alongside key publications from international organisations and research bodies addressing systemic and cross-border risks affecting Europe (See Box 3)

Box 3: Breakdown of the key literature analysed in the focused targeted literature review

Core Synthesis Reports:

- EEA (2024). European climate risk assessment. https://data.europa.eu/doi/10.2800/8671471
- JRC (2025). Analysis of Risks Europe is Facing: An Analysis of Current and Emerging Risks. https://doi.org/10.2760/0176850
- JRC (2024). Cross-border and emerging risks in Europe: Overview of state of science, knowledge and capacity https://doi.org/10.2760/184302
- JRC (2025). Earth System Tipping Points are a threat to Europe. https://publications.jrc.ec.europa.eu/repository/handle/JRC140827

- World Economic Forum. (2025). The Global Risks Report 2025. https://www.weforum.org/publications/global-risks-report-2025/
- OECD (2024). Managing Emerging Critical Risks: Case Studies and Cross-Country Synthesis Report. https://doi.org/10.1787/1f9858ea-en
- United Nations Environment Programme. (2024). Navigating New Horizons: A global foresight report on planetary health and human wellbeing. https://wedocs.unep.org/xmlui/handle/20.500.11822/45890
- University of Exeter. (2023). Global Tipping Points: Report 2023. https://global-tipping-points.org
- University of Exeter (2025). Planetary Solvency – finding our balance with nature
- United Nations Environment Programme. (2021). Making Peace with Nature: A Scientific Blueprint to Tackle the Climate, Biodiversity and Pollution Emergencies. https://www.unep.org/resources/making-peace-nature
- UNDRR (2024) Policy brief: Nature for Resilience

System specific / thematic reports:

- Green Finance Institute. (2023). Greening Finance for Nature: Unlocking the Potential of Green Finance for Nature-Positive Outcomes. https://www.greenfinanceinstitute.co.uk/greening-finance-for-nature/
- JRC (2023). Risks and vulnerabilities in the EU food supply chain. https://doi.org/10.2760/171825
- EEA (2025). Protecting and restoring Europe's wild pollinators and their habitats. https://www.EEAeuropa.eu/en/analysis/publications/protecting-and-restoring-europes-wild-pollinators-and-their-habitats
- EEA & JRC (2025). Zero pollution monitoring and outlook 2025 (No. 13/2024). https://data.europa.eu/doi/10.2800/6470682
- EEA (2023) The importance of restoring nature in Europe, https://www.EEAeuropa.eu/en/analysis/publications/the-importance-of-restoring-nature-in-europe
- EEA (2022) Air quality in Europe 2022, https://doi.org/10.2800/488115
- EEA (2025) Renewables, electrification and flexibility - For a competitive EU energy system transformation by

2030, https://www.EEAeuropa.eu/en/analysis/publications/renewables-electrification-and-flexibility-for-a-competitive-eu-energy-system
- EEA (2024), Europe's state of water 2024, https://www.EEAeuropa.eu/en/analysis/publications/europes-state-of-water-2024
- JRC (2022), Floods and firms: Vulnerabilities and resilience to natural disasters in Europe, https://publications.jrc.ec.europa.eu/repository/handle/JRC132125
- ECB (2024), Economic and financial impacts of nature degradation and biodiversity loss, https://www.ecb.europa.eu/press/economic-bulletin/articles/2024/html/ecb.ebart202406_02~ae87ac450e.en.html
- ECB (2023), Living in a world of disappearing nature, Living in a World of Disappearing Nature: Physical Risk and the Implications for Financial Stability by Simone Boldrini, Andrej Ceglar, Chiara Lelli, Laura Parisi, Irene Heemskerk: SSRN
- Network for Greening the Financial System. (2024). Nature-related Financial Risks: A Conceptual Framework to Guide Action by Central Banks and Supervisors https://www.ngfs.net/en/publications-reports/nature-related-financial-risks-conceptual-framework
- JRC (2025), The EU economy's dependency on nature.https://publications.jrc.ec.europa.eu/repository/handle/JRC140003
- JRC (2024), European SMEs' exposure to ecosystems and natural hazards: A first exploration. https://publications.jrc.ec.europa.eu/repository/handle/JRC136901
- EEA (2025), Imagining a sustainable Europe in 2050. https://www.EEAeuropa.eu/en/analysis/publications/imagining-a-sustainable-europe-in-2050
- EEA (2022), Rethinking agriculture, https://www.EEAeuropa.eu/en/analysis/publications/rethinking-agriculture

Supplementary academic literature:

- Aall et. al. (2025), Overlooked climate risks in the ongoing renewable energy transitions, https://doi.org/10.1016/j.energy.2025.137986

- Ferreira et. al. (2022), Soil degradation in the European Mediterranean region: Processes, status and consequences, https://doi.org/10.1016/j.scitotenv.2021.150106
- Seshadri, A. K., Gambhir, A., & Debnath, R. (2025), Navigating systemic risks in low-carbon energy transitions in an era of global polycrisis. https://doi.org/10.1017/sus.2025.7
- Wescombe et. al. (2025), It's Time to Consider Global Catastrophic Food Failures, https://doi.org/10.2139/ssrn.5116973
- Wunderling et. al. (2024), Climate tipping point interactions and cascades: A review., https://doi.org/10.5194/esd-15-41-2024
- La Notte et. al. (2025), The assessment of nature-related risks: From ecosystem services vulnerability to economic exposure and financial disclosures, https://doi.org/10.1016/j.ecolecon.2025.108636
- Sánchez-García, P. A., Galaz, V., Rocha, J. C., & Barbour, F. (2025), Climate change, nature degradation, and financial stability: A review of domino-effects between finance, climate, and the biosphere. https://doi.org/10.5751/ES-16130-300236

Risk Database and Categorisation

A total of 217 individual "risk to [system or endpoint] from [risk driver]" were identified by scanning the literature and recorded in a dedicated risk database. These entries reflect instances in which a source mentioned or described a risk that could be captured in this form; they therefore do not represent 217 fully distinct underlying risks. Some entries were identical or near identical across sources, while others reflected different formulations of a similar underlying risk. The database was designed to enable structured comparison and synthesis across sources. To support this, each recorded risk entry was coded according to a set of analytical categories, including:

- A risk description, that was reformulated using the structured risk framing of "risk to [system or endpoint] from [risk driver]"
- The affected system(s), linked to one or more of the four key systems defined for the project.
- The environmental driver(s) associated with the risk.

Importantly, the environmental risk drivers were classified using a two-level structure: Level 1 captured the primary environmental risk drivers, including climate change, biodiversity loss, environmental degradation and pollution. Level

2 captured more specific risk drivers, which represent the environmental processes through which these broader drivers manifest (e.g. droughts, floods, heat stress or pollinator loss).

The coding was conducted by one researcher using this common structure to support consistency across entries. The categorisation allowed risks to be traced back not only to the primary environmental risk drivers associated with the triple planetary crisis, but also to more specific processes through which these pressures translate into risks to systems. It thereby facilitated the identification of patterns, overlaps and clusters across the literature. Following the initial extraction, the subcategories of environmental risk drivers identified across the literature were reviewed, clustered, and reformulated to improve consistency and comparability across sources. This step was necessary given the wide variation in terminology and levels of specificity used in different assessments. The initial mapping and categorisation of the 217 identified risks and associated drivers were conducted by the project researcher responsible for the literature review and subsequently discussed with a second researcher and reflected upon with the wider project team. These exchanges helped refine the interpretation of risk formulations and driver classifications and ensured a shared understanding of the analytical approach. Closely related or conceptually overlapping risk drivers were consolidated under standardised categories. For example, descriptions such as "water scarcity" and "reduction of low flows in rivers" were harmonised and reformulated under the broader category of "water stress."

This harmonisation process reduced duplication addressed semantic differences between sources and enabled a more systematic comparison of risks across systems and environmental risk drivers. At the same time, the process involved expert judgement, which helped shape the final clustering. This harmonisation supported subsequent analytical steps, including the identification of cross-cutting risk drivers and the clustering of risks with similar underlying environmental pressures.

3.3 Harmonisation and Consolidation

Initial Mapping and Prioritisation of Key Environmental Risk Drivers

The harmonisation and clustering of environmental risk drivers (See section 3.2.4) enabled a first analysis of the compiled dataset of 217 specific environmental risk drivers. Given the large number and diversity of risks identified through the literature review, this step was necessary to reduce and consolidate the findings into a more manageable pool of specific environmental risk drivers for use in the participatory workshops. It also made it feasible to assess the relative frequency with which specific risks, affected systems, and specific environmental risk drivers appeared across the reviewed literature. This preliminary analysis provided an overview of which types of risks (from which driver to which system) are most often addressed in existing assessments, and where concentrations or gaps in the literature may exist. The frequency of occurrence does not in itself indicate the magnitude or severity of a risk. It also does not necessarily reflect evidentiary independence, as some risks may recur across reports because institutions draw on the same underlying evidence base or cite similar assessments. This step nonetheless offered an initial evidence base to inform subsequent analytical stages and to support a more structured synthesis of systemic and complex risks. An example of this preliminary analysis is visible in Figure 2. Figure 2 shows a partial preview of a "heatmap" table highlighting frequency of occurrence of identified risks in the analysed literature.

Figure 2: Partial preview of a "heatmap" table highlighting the frequency of occurrence of identified risks in the analysed literature.

	ENER energy transitions	FOOD food systems	ECON economic and financial systems	ECOSYS resiliant ecosystems	OTHER other systems	Total
biodiversity loss	**1**	**14**	**14**	**5**	**6**	**40**
biodiversity loss (general)		3	11	3	4	21
ecosystem health	1	1				2
genetic diversity loss		1				1
habitat loss		1	1	1	2	5
loss of ecosystem services			1			1
pollinator loss		8	1	1		10
climate change	**32**	**36**	**56**	**35**	**19**	**178**
climate change (general)	2	3	14	8	5	32
algal blooms				1	1	2
cascading and compouding climate impacts	1					1
changing weather patterns		2	1			3
cold waves	1		1			2
drought	3	3	3	3		12
extreme weather events	5	8	7	1	2	23
flooding	5	2	7		1	15
forest disturbances	1	1	1	1		4
heat stress	4	1	4	2	2	13
ocean acidification		1	1	1		3
soil erosion		1		1		2
species distribution shifts		1		2	1	4

Figure 2: Author

Note: Frequency of occurrence should be interpreted as a proxy for how visible or discussed a risk is in the reviewed literature, not as a direct measure of its importance. Risks that appear less frequently may be underexplored, emerging or difficult to quantify, rather than necessarily being of lower relevance or priority.

Expert Workshop for Risk Driver Prioritisation

As a next step, an online workshop was organised with a focus group of experts to support the prioritisation of key environmental drivers contributing to systemic risks. In total, seven external experts as well as members of the EEA project team were invited to participate in an online focus group workshop. The group brought together expertise relevant to systemic risk, transformation, and the four systems considered in the project, while also reflecting a range of disciplinary and institutional backgrounds, including academia, applied research, and the science-policy interface. Given the small size of the group, the workshop was designed to support in-depth deliberation and exchange rather than to provide a representative sample of views. As such, the outcomes should be understood as informed expert input to the prioritisation process. The external experts included:

- Professor and researcher leader in innovation, sustainable transitions, economic and geography.
- Researcher in the science-policy interface focusing on urban transformation and global change.
- Expert in systemic risk.
- European biodiversity expert.
- Professor and inter/transdisciplinary researcher on just sustainability transitions with a focus on food systems.
- Professor and national food system expert with expertise in Nature Capital loss.

The focus group workshop attempted a prioritisation of environmental risk drivers identified through the focused targeted literature review. In the first step, participants were presented with a set of playing cards representing environmental drivers that contribute to multiple systemic risks (e.g. loss of ecosystem services, air pollution, water stress, soil degradation). Each card indicated both systems affected (Risk to…) and the risk driver (Risk from…). The playing cards formed a fundamental component of the project and were instrumental in translating the specific environmental risk drivers identified through the literature review into concise, easily digestible items that could be used by researchers in an online setting. Figure 3 contains an example of the playing card with a breakdown of its layout. The complete deck of risk playing cards developed following the prioritisation process is provided in **ANNEX 6**.

Figure 3: An example demonstrating the layout of the risk playing cards

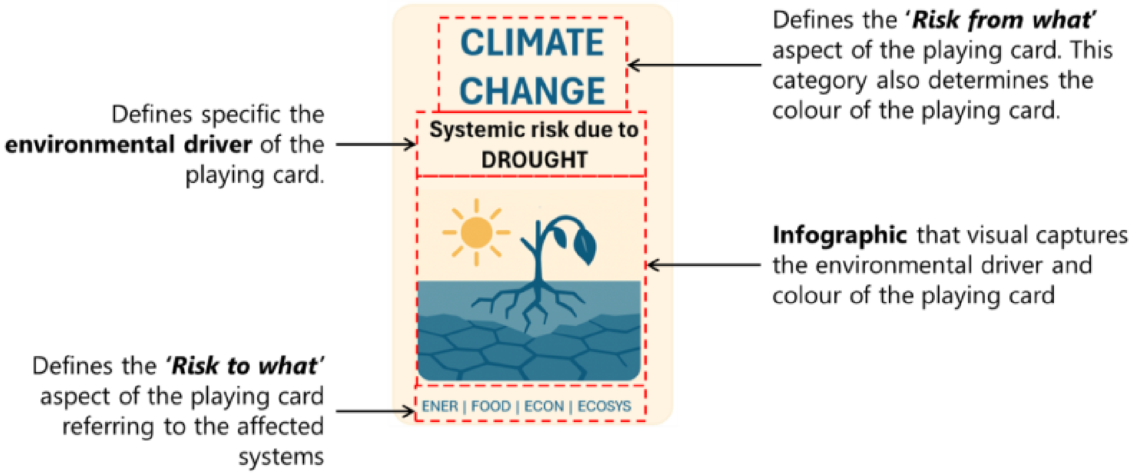

Figure 3: Author

In the focus group workshop, the experts were asked to consider "*In your expert view, which of these risk drivers most significantly hamper Europe's vision of "living well within the limits of our planet*"? Working "alone together" - in parallel and in individual spaces on a virtual board participants were invited to:

- Select up to 10 environmental risk drivers they considered the most significant or systemic and assign them to a "high priority" category; and
- Select up to 5 drivers of relatively lower significance and assign them to a "low priority" category.

The aggregated results were then presented to the participants in a group setting, highlighting: 1) environmental risk drivers that received high levels of agreement across experts as a priority environmental driver; 2) the drivers that were assigned to have lower priority; and finally, 3) areas where expert assessments diverged.

The presentation of these findings was followed by a group discussion. During the discussion, the experts were invited to explain the rationale behind their prioritisation choices, reflect on differing perspectives, and discuss underlying assumptions. Where relevant, participants jointly explored whether certain drivers should be merged, reframed or more clearly distinguished, particularly in cases where overlaps or ambiguities had emerged during the exercise.

This discussion provided important qualitative insights to complement the quantitative aggregation of priorities and informed subsequent steps in the identification and refinement of priority systemic risks.

There was a high degree of convergence around generic environmental risk drivers contributing to systemic risks in Europe. Climate change (general) and biodiversity loss (general) emerged as the most consistently prioritised drivers, reflecting their pervasive impacts across multiple systems. Experts also highlighted the importance of non-linear and compound dynamics, notably climate tipping points and large-scale biodiversity loss affecting provision of ecosystem services. Drivers related to environmental degradation (such as deforestation and soil degradation), pollution (especially air and chemical pollution), and resource overexploitation were also repeatedly identified as high priority, albeit with greater variation in expert judgement.

There were several conceptual and methodological challenges associated with prioritising environmental risk drivers, which should be understood as limitations of the prioritisation exercise. Participants widely agreed that it was difficult to assign low priority to any driver, given that most were considered critical in at least some contexts, scales or systems. A recurring theme concerned the hierarchical nature of risk drivers, with more general or overarching categories (such as climate change, biodiversity loss or the triple planetary crisis). While these general categories were frequently prioritised, experts questioned whether their inclusion always supported meaningful prioritisation, as they can obscure underlying causal mechanisms and reduce analytical specificity. In addition, the framing question used in the workshop, which asked participants to consider which environmental risk drivers most hamper Europe's vision of "living well within the limits of our planet", may itself have influenced the prioritisation exercise. While this framing was useful for anchoring the discussion in Europe's long-term sustainability vision, it may also have encouraged participants to give greater weight to broad, systemic and transformative concerns, potentially at the expense of more immediate or shorter-term risks.

Moreover, there were tensions between general and specific formulations of drivers, particularly where broader categories appeared to dominate over more granular ones, even when the latter captured important processes. The discussion also revealed differing views on how to handle uncertainty, especially in relation to climate tipping points: some experts prioritised tipping point risks due to their potentially severe impacts, while others were hesitant to select tipping points because of scientific uncertainty. This highlights a further limitation, in that risks characterised by high uncertainty may have been treated differently by participants depending on their interpretation of uncertainty as either a reason for concern or a reason for caution. Overall, the discussion underscored the value of combining frequency-based prioritisation with qualitative expert reflection, and it informed subsequent decisions to refine drivers to better capture systemic and cascading risk dynamics.

From Environmental Risk Drivers to the Database of System-specific Risks

The environmental risk drivers prioritised through the expert workshop were subsequently refined and operationalised for use in a series of system-specific expert workshops, corresponding to the four systems the project has been structured around (see section 3.1). The methodology and results of these workshops are described in detail in chapter 4.

As part of each of these system-specific workshops, experts were invited to identify and prioritise key systemic risks relevant to the respective system, building on the set of prioritised environmental risk drivers (See section 4.1, Activity 2).

The results of the system-level prioritisation were then compared and triangulated with findings from the literature review. An iterative synthesis process was applied to identify the final set of 20 priority risks to be developed into risk fiches. The final set was therefore not composed simply of the 20 highest-ranked risks, but of a selected set designed to combine expert prioritisation with evidence from the literature while also ensuring balanced coverage across systems and driver categories. This process combined multiple considerations, including:

- The degree to which risks were prioritised by experts as particularly systemic or consequential for the respective system;
- The strength and consistency of evidence in the literature, including the frequency with which risks appeared across key assessments (see Figure 2); and
- The intention to ensure a balanced representation across the main categories of environmental risk drivers (climate change, biodiversity loss, environmental degradation and pollution), and the four systems addressed by the project.

Where expert judgement and literature review findings did not align, decisions were made through qualitative synthesis, taking into account the systemic relevance of the risk, the breadth and consistency of the evidence base, and the need to maintain balanced coverage across systems and driver categories. This approach ensured that the final selection of risk fiches reflects both expert judgement and the state of the evidence, while avoiding overconcentration on any single driver category or system. As a result, the final 20 risk fiches should be understood as an illustrative set of priority risks selected for in-depth analysis, rather than as a strict ranking of the "highest scoring" (when it comes to e.g. literature coverage or expert elicitation) risks. The selection should also not be understood as (and was not intended to be) an exhaustive inventory of critical systemic environmental risks facing Europe.

Overview of the Prioritised Risks and Associated Risk Fiches

Table 1 below presents the selected risks, indicating for each **the primary system affected** and **the primary environmental driver**, while recognising that many of the risks have cross-system impacts and are driven by multiple, interacting environmental pressures. While human health was not one of the four original systems, health-related risks were included in the final list because health impacts emerged consistently across the reviewed literature as a key way in which environmental change affects European society.

Table 1: Selected systemic environmental risks for in-depth analysis, listed in order of the primary system affected and indicating the primary environmental driver.

ID	Systemic Risk	Primary System Affected	Primary Environmental Driver
1	Risk to ecosystems, and human systems including food and energy security, health, and economic stability from the Atlantic meridional overturning circulation (AMOC) collapse	MULTI	AMOC collapse
2	Risk to economy and financial systems from loss of ecosystem services	ECON	Loss of ecosystem services
18	Risk to economy and financial systems from changing weather patterns, water stress and drought	ECON	Changing weather patterns, water stress and droughts
19	Risk to economy from extreme weather events incl. flooding	ECON	Extreme weather events
3	Risk to food systems from soil degradation	FOOD	Soil degradation
7	Risk to food systems from extreme weather events (incl. drought, water stress and heat stress)	FOOD	Extreme weather events

8	Risk to food systems from pollinator loss	FOOD	Pollinator loss
13	Risk to food systems from pollution (general, antibiotics, soil, water, chemicals)	FOOD	Pollution
16	Risk to marine food systems from overfishing and invasive alien species	FOOD	Overfishing and invasive alien species
4	Risk to ecosystems from intensive agriculture and soil degradation	ECOSYS	intensive agriculture and soil degradation
6	Risk to resilient ecosystems, nature protection, climate resilience and restoration from hot and dry weather (heat stress, drought, wildfire)	ECOSYS	Heat stress, drought, wildfire
9	Risk to ecosystems from pollution and eutrophication	ECOSYS	Pollution and eutrophication
17	Risk to resilient ecosystems, nature protection, climate resilience and restoration from biodiversity loss	ECOSYS	Biodiversity loss
5	Risk to energy transitions and industrial transformation from extreme weather events including flooding	ENER	Extreme weather events
11	Risk to energy transitions and industrial transformation from heat stress, water stress and drought	ENER	Heat stress, water stress and drought
20	Risk to energy transitions and industrial transformation from soil degradation and loss of ecosystem services	ENER	Soil degradation and loss of ecosystem services
15	Risk to wellbeing, health and mental health from biodiversity loss / loss of nature	OTHER/ HEALTH	Biodiversity loss / loss of nature
10	Risk to human health from climate change	OTHER/ HEALTH	Climate change
12	Risk to health from air pollution	OTHER/ HEALTH	Air pollution
14	Risk to health, economy, wellbeing from chemical pollution	HEALTH, ECON	Chemical pollution

Table 1: Author

Each of the 20 selected systemic risks was documented using a standardised risk fiche format to ensure consistency, transparency and comparability across risks. The categories included in the risk fiche format were selected namely because they represent the key characteristics commonly used to describe and assess risks in major environmental and risk assessments. Drawing on established approaches from previous assessments (e.g. IPCC, EUCRA and JRC risk analyses), these categories capture the main dimensions required to understand systemic risks, including their drivers, affected systems, pathways, magnitude, likelihood, uncertainty, temporal dynamics and geographical scope.

Each fiche covers the following elements:

- **Risk description:** risk ID, risk name and a brief narrative description explaining why the risk matters, what is at stake, for whom, and why it warrants policy and societal attention, including why it is considered systemic (complexity, cross-sectoral and transboundary dynamics, cascading or compounding effects).
- **Systems affected:** description of the main systems impacted, reflecting the project's system-based framing.
- **Main drivers:** primary environmental driver, other relevant environmental drivers, as well as a description of non-environmental drivers exacerbating the risk (e.g. social, technological, economic, environmental, political and values-related factors).
- **Unequal exposure and impacts:** findings from literature highlighting social, spatial and sectoral inequalities in exposure and impacts.
- **Pathways:** description of direct and indirect pathways through which drivers translate into impacts across systems (based on literature).
- **Magnitude and likelihood:** magnitude of risk impacts and likelihood of risk occurrence, as reported in reviewed literature.
- **Uncertainty:** summary of confidence levels reported in the literature and key sources of uncertainty as described in the literature, where available.
- **Timescale:** indication of risk onset, time horizon, duration and, where possible, observed or projected trends, as reported in literature.
- **Geographical scope:** description of geographic scale, relevant contexts and specific areas where impacts are particularly pronounced, as reported in literature.

- **Interlinkages:** documentation of links to other systemic risks, including shared drivers, systems and proximity of risk pathways. While shared drivers and shared systems were clustered directly by project team members, the clustering of pathways was done with assistance of generative AI (using the OpenAI model GPT-5.2 Thinking) and the AI clustering carefully reviewed for accuracy (see Box 4 for details).

To populate the risk fiches, information was drawn from the sources consulted in the initial focused targeted literature review, complemented by additional literature where gaps were identified, using a combination of targeted keyword searches and expert recommendations. The information collected for each risk was compiled in a structured database maintained in a spreadsheet (see **ANNEX 1A**), which allowed for the systematic organisation and comparison of evidence across risks. The compiled information was subsequently exported and presented using a standardised fiche template (see Figure 4).

To support the efficient identification of relevant information within the consulted literature, the Google NotebookLM AI tool was also used as an advanced search aid. For each risk fiche, the relevant literature sources were uploaded to a dedicated notebook and queried to help locate sections addressing specific analytical elements, such as STEEPV drivers (see EEA, 2019 for drivers of change), unequal impacts and other relevant dimensions. NotebookLM's responses point to specific passages in the uploaded sources, which can then be reviewed in their full original context. These cited sections were subsequently checked directly in the source publications, and the information included in the fiches was extracted and validated against the original texts. NotebookLM was therefore used to assist in locating relevant information, but all information included in the risk fiches was verified against the original sources.

Box 4: Using generative AI to find similar causal pathways driving systemic risks.

Using generative AI to find similar causal pathways driving systemic risks

As a result of the literature review for each systemic risk, the project team identified one or more causal pathways that connected the risk driver to the risk impact. In total, just over 100 risk pathways were identified. These pathways contained complex, multi-step causal chains. Here are five examples of causal pathways:

- Air pollution (ozone from industry and transport) → excessive concentration of ground level ozone causes damage to plants → reduces growth rates → lower crop yields (EUR 2 billion in damage to food crops per year from ozone)
- Intense rainfall → waterlogged soils and inundation of fields/infrastructure → reduction in harvestable area, potential disrupted logistics → loss of production/ yields
- Lack of accessible, high quality natural environments → loss of space for recreation, relaxation, social interaction → decreased mental health (psycho-physiological stress and mental fatigue, chronic diseases)
- Plastic pollution → direct impacts on marine life and indirect impacts via the food chain (in European seas; for instance, 93% of fulmar birds assessed in the North-East Atlantic Ocean had ingested some plastic)
- Heatwave → crop heat stress and accelerated evapotranspiration → reduced crop yields, heat stress in livestock and increased spoilage during transport/storage → lower production/increased food prices

Recent advances in generative AI make it possible to fairly quickly identify relationship patterns across complex data sets such as the list of 100+ causal pathways.

We selected the model GPT-5.2-Thinking and worked with it via OpenAI's chat interface. We used a multiple-step process of working with the AI, then conducted a human review to adjust the results and ensure their validity:

Step 1. Designing the approach - We first worked with the model to develop a suitable approach, describing the aim, the data set and important aspects that needed to be considered. After iterating through the options, the model helped design the following steps and helped draft suitable prompts. Samples from the data set were used in this step.

Step 2. Preparing the data - The data was prepared to hide unwanted semantic information from the model. The model was given only the pathway, without any knowledge of the risk name, risk driver or risk impact, as the name and the two endpoints would generate strong semantic signals that could interfere with a pathway-focused clustering. A data set was prepared that had only the causal pathways and a random ID number. In the subsequent prompts, the model was told the ID was random and should be ignored.

Step 3. Cluster "discovery heats" - Over multiple separate sessions, the model was given a subset of the risk pathways and asked to cluster them and provide a pathway cluster name of the form "Step → Step → Step" (length arbitrary). In one session, the entire set of pathways was provided to the model. The model was given rich information describing what the data described and was asked to provide nuanced output regarding the strength of connections.

Step 4. Cluster consolidation "tournament" - In a new session, the model was given only the pathway cluster names that had been generated in Step 3 discovery heats. The model was provided no background context for this task; it was asked simply to group the items provided. Again, the output was of the form of the form "Step → Step" (length arbitrary).

Step 5. Human review of pathway cluster names and number of clusters - the resulting pathway cluster names were carefully reviewed by project staff, as they would be an essential input and have an important effect on the final results.

Step 6. Grouping pathways by pathway cluster - In this step, the model was asked to assign the 100+ pathways to the pathway clusters that were generated via Steps 3 - 5. Again, the model was asked to provide nuanced information about the strength of the match, including flagging where matches were of lower confidence.

Step 7. Human review of final result - The ***entire*** clustering (all 100+ pathways, now clustered by the AI) were carefully reviewed by project staff. This review was more readily undertaken at that stage, as subject-matter experts could more easily determine whether clustered pathways were related and identify outliers.

Step 8. Integration into the risk fiches - Via the random ID generated in Step 2, the AI-supported pathway clustering could be integrated back into the full data set on systemic risks; this enabled all risk fiches to point to the other risk fiches in the set that shared a related pathway.

All 20 risk fiches (populated templates) developed using this framework are provided in **ANNEX 1.**

Figure 4: Risk Fiche Template used to populate risk fiches

Risk ID: RiskID

Risk name

Systems affected:

Brief narrative description (incl. why systemic - Complexity; Cascading & spillover effects; Transboundary nature; Deep uncertainty & ambiguity; Systemic stakes;) (see tab helpful_ref)

Drivers:

Primary environmental driver:	Primary environmental driver (subcategory):	Other environmental drivers:
Non-environmental drivers (STE(E)PV):		

Pathways:

Direct pathways:	Indirect pathways:

Unequal exposure and impacts (risk inequalities):

Unequal exposure and impacts (risk inequalities)

Magnitude, likelihood and uncertainty:

Magnitude (limited; critical/substantial; catastrophic):	Magnitude basis:
Likelihood (unlikely; about as likely as not (33-66%); likely)	Likelihood basis:
Confidence levels (high / medium / low) and sources of uncertainty:	

Timing:

Onset: Time horizon: Duration: Trend:

Geography:

Geographic scale: Geographic contexts:

Interlinkages:

Interlinkages to other systemic risks (IDs): Interlinkages: Interlinkages between drivers: Cascading & compounding mechanism(s):

Examples / case studies:

References:

Figure 4: Author

4. TASK 2 - ASSESSMENT OF SYSTEMIC AND COMPLEX RISKS OF FOUR KEY SYSTEMS AND THEIR CASCADING AND COMPOUNDING EFFECTS

4.1 Methodology

Task 2 used online expert workshops to examine the systemic interactions, cascading effects, and compounding dynamics of environmental risks across four key societal systems: food, energy, economy, and ecosystems. Two workshops were organised to support collaborative mapping of risk interconnections, drivers, and amplifiers. As outlined in the introduction, the objectives of the online workshop were twofold. First, the aim of the workshop was to validate the selected environmental risks and illustrate how the interactions between risks across critical societal systems such as food, energy, economy, and ecosystems can be identified. Second, to reflect on how these risks may impact the EU's ability to achieve policy priorities including competitiveness and security, resilience, and preparedness. The workshops took place in November 2025 using a combination of webinars to record and transcribe the discussions and the interactive white board software MIRO to host the activities. A total of 22 experts and 8 facilitators were involved across the two workshops. The 22 experts were selected based on their expertise and knowledge relating to one or more of the four systems and/or their understanding of systemic risks. The experts represented a variety of think tanks, research institutions and EU institutions.

Each of the two workshops brought together experts from two systems: Workshop 1 included experts representing (a) the Resilient and Competitive Economic and Financial Systems and (b) the Energy Transitions and Industrial Transformation System. Workshop 2 included experts representing (a) Resilient Ecosystems, Nature Protection, Climate Resilience and Restoration System and (b) the Secure and Sustainable Food System. This arrangement reflected the project's time constraints and was also intended to encourage exchange between experts working in thematic domains with a greater degree of overlap in knowledge and expertise. Figure 5 below displays a visual workflow of the online workshops in the context of the project workflow.

Figure 5: Visual workflow of the online workshop and the five activities

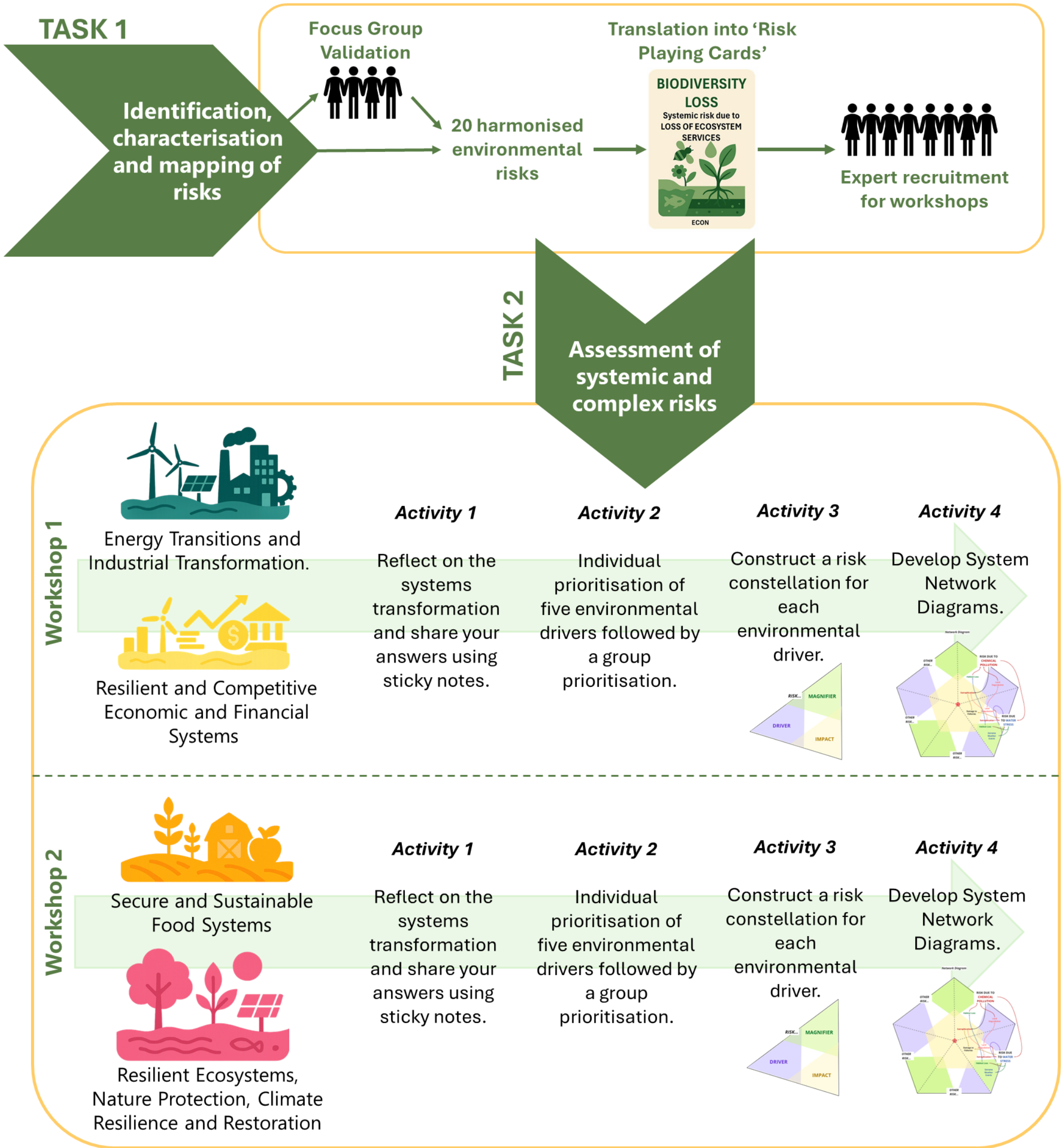

Figure 5: Author

Workshop 1

- Resilient and Competitive Economic and Financial Systems,
- Energy Transitions and Industrial Transformation.

Workshop 2

- Resilient Ecosystems, Nature Protection, Climate Resilience and Restoration.
- Secure and Sustainable Food Systems.

The two workshops employed an original qualitative methodological approach. The approach utilises a structured, game-based facilitation to help navigate inherent complexity and to support discussion of environmental risk drivers and their implications across the four systems. The approach utilises a novel deck of risk playing cards created specifically for online workshops. The risk playing cards encapsulate the environmental risks defined in section 3.3.1 and 3.3.2 and form the basis for the workshop activities. The full deck of playing cards produced for the workshops have been provided in **ANNEX 6**. Five examples have been included in Figure 6 below. It is important to note that within the online workshop, the activities and approach were tested with a maximum of six experts. Finally, the approach is consistent with other qualitative methodological approaches designed to explore the complexity of risk. By way of example, the approach shares similarities and differences with the Joint Research Centre's Polycrisis Exploration Workshop Toolkit (JRC, 2025d).

Figure 6: Five examples from the deck of risk playing cards used in the online workshop.

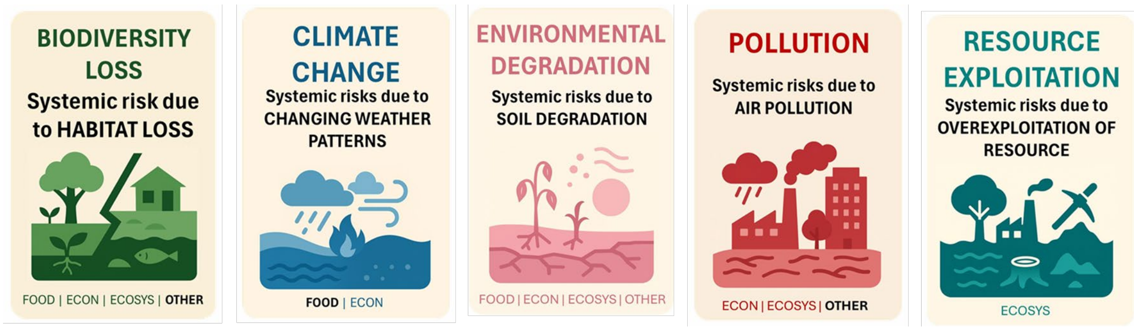

Figure 6: Author

The workshops were divided into 5 activities that build upon the validation of the prioritisation of the 20 environmental risk playing cards defined in section 3.3.2. The workshops were hosted via Microsoft Teams webinar, and the experts joined a meeting room with the host. The initial meeting room served as the space to introduce the participants to each other, outline the agenda and reiterate the goal of the workshop. Following this introduction, the experts were divided into their predefined breakout rooms. Each workshop organised two breakout rooms, one per system. Each breakout room followed the same five activities and sequencing.

Activity 1 'System's transformation goals, trends and challenges' – Experts were asked to define what "transformation" of the considered system means by identifying e.g. policy goals, normative visions, trends, enablers, challenges, with the aim of establishing a shared understanding and common framing for subsequent discussions.

Objective: Establishing a shared understanding of the system and its transformation path.

Outcome: Emerging picture, documented through notes on MIRO boards (see e.g. figure 7).

Figure 7: Example from the Energy Transition and Industrial Transformation system MIRO Board.

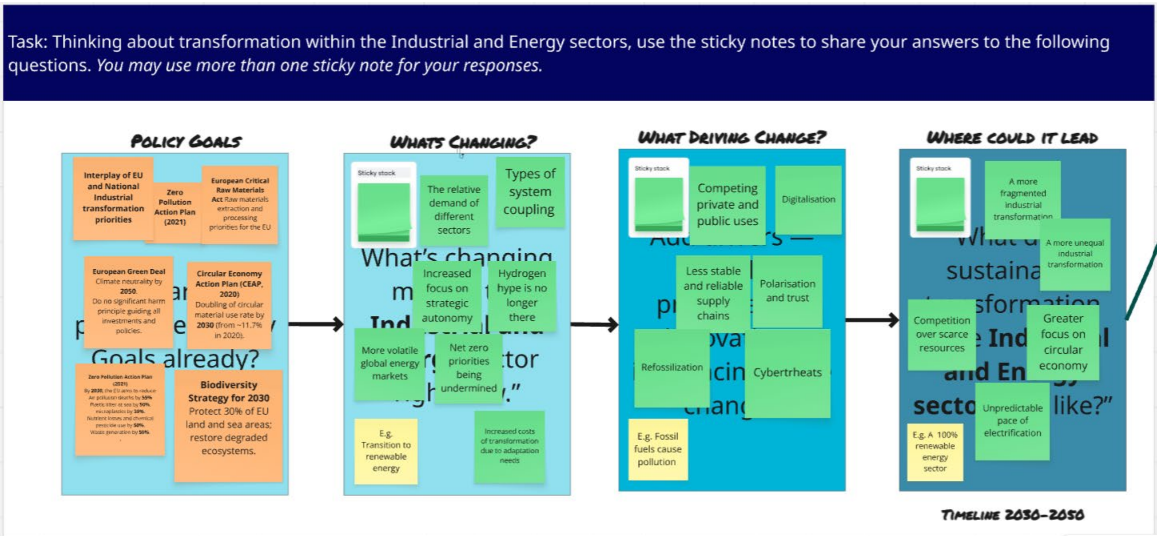

Figure 7: Author (Screenshot from MIRO Board)

Activity 2 'Prioritising specific environmental risk drivers' – The experts were provided with the full deck of risk cards and asked to individually prioritise the top 5 or 6 (depending on the number of experts in the workshop) key environmental risk drivers affecting their respective system and its transformation (e.g. figure 7). The individual priorities were then discussed collectively and consolidated into a group-level prioritisation, limiting the selection to up to 6 risks (e.g. figure 8)

Objective: Individually and as a group select up to 6 environmental risks per system.

Outcomes: List of selected priority risks for each system documented through MIRO boards. (e.g. see figure 8 and 9).

Figure 8: Example of an individual expert's prioritisation of risks from the Resilient Ecosystems, Nature Protection, Climate Resilience and Restoration system MIRO Board.

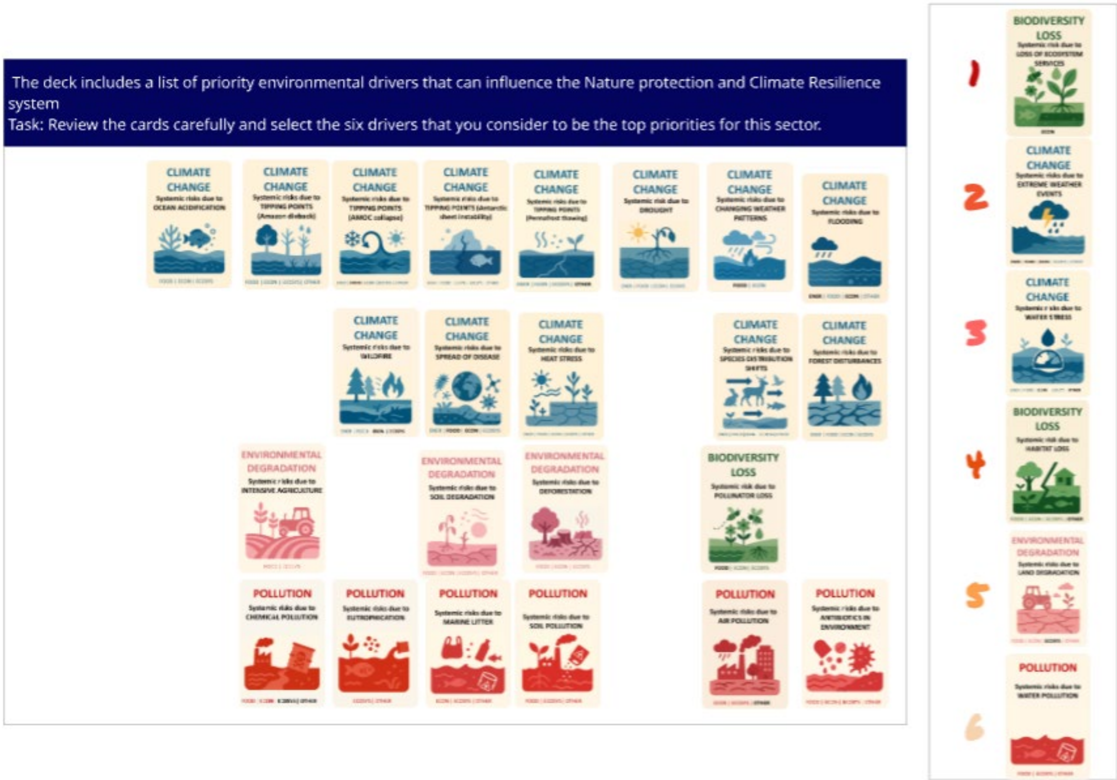

Figure 8: Author (Screenshot from MIRO Board)

Figure 9: Example of the group's prioritisation of environmental risks from the Secure and Sustainable Food systems MIRO Board.

Figure 9: Author (Screenshot from MIRO Board)

Activity 3 'Establishing risk constellations' – Each expert was allocated one environmental risk driver prioritised by Activity 2 and invited to construct and present the resulting risk constellations for that environmental driver. The constellation is composed of the categories: non-environmental drivers, magnifiers and impacts (see section 4.3.1). To facilitate the creation of the risk constellations, experts were provided with the full deck of playing cards, a list of potential drivers and magnifiers identified earlier in section 3.2.3 and a stack of digital post it notes.

Objective: Characterise each of the selected environmental risk drivers through the development of the risk constellations.

Outcomes: Risk constellation map developed for each individual environmental risk driver. See figure 10 as an example of a MIRO screenshot for activity 3 (for only one of the 5 risks).

Figure 10: Example of risk constellation developed by an expert in the Resilient Ecosystems, Nature Protection, Climate Resilience and Restoration MIRO Board.

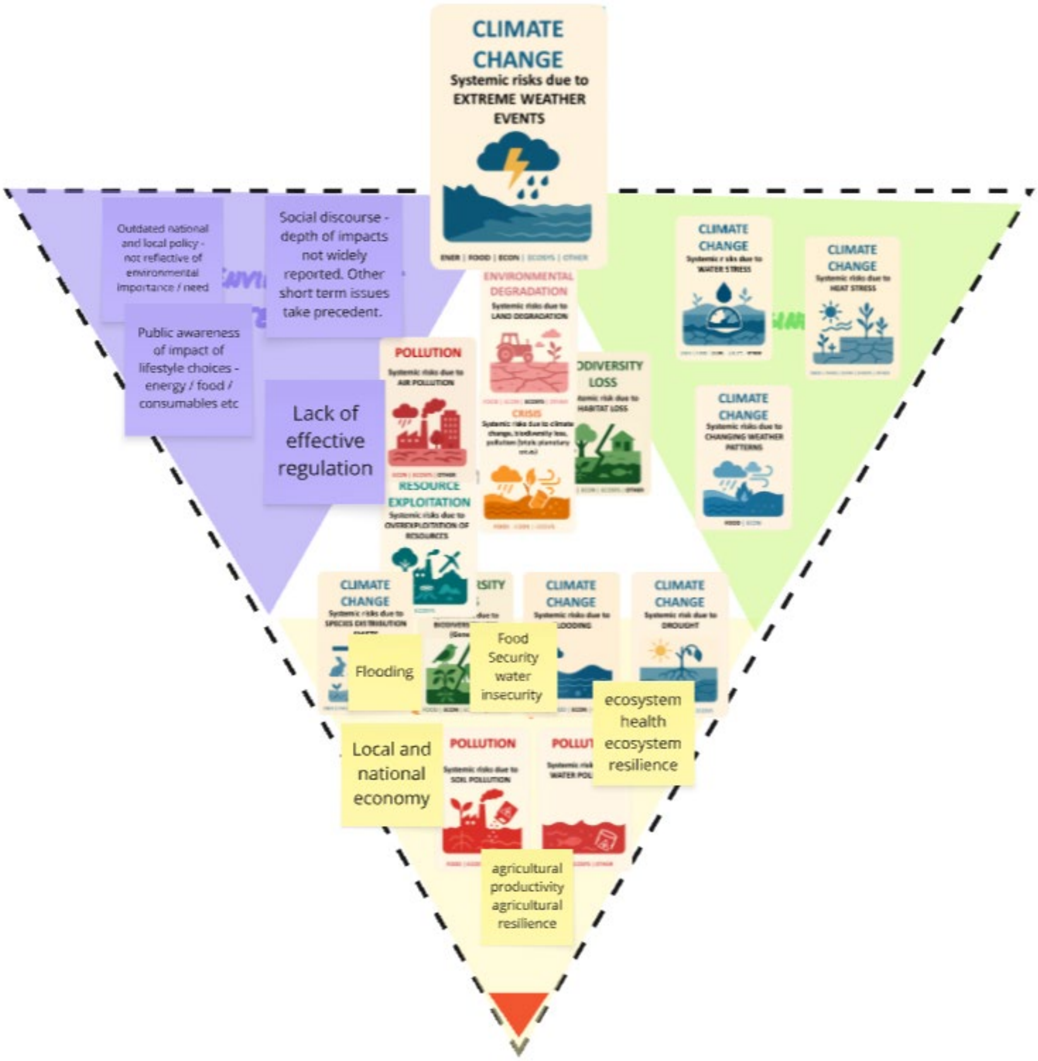

Figure 10: Author (Screenshot from MIRO Board)

Activity 4 'Exploring risk pathways' – This activity explored the collection of risk constellations that were developed in activity 3 as a combined system network diagram. Participants then identified and discussed interconnections, compounding and cascading patterns across different elements of the network diagram and the other systems.

Objective: Identify cascading and compounding dynamics across different risk constellations with that system.

Outcomes: System network diagrams. See figure 11 as an example of a system network diagram from the workshops.

Figure 11: Example of the system network diagram developed within the Resilient Ecosystems, Nature Protection, Climate Resilience and Restoration MIRO Board.

Figure 11: Author (Screenshot from MIRO Board)

Activity 5 'Implications for EU strategic priorities' – The experts then discussed the implications of the findings and discussions against the EU strategic priorities, with particular focus on resilience, competitiveness, and security. Sections 4.3 present a curated set of results from the two workshops beginning with a summary of what the experts' perceived transformation for their sector would look like by the year 2050.

4.2 Critical reflection of the Workshop Outcomes

Activities 1, 3, 4 and 5 required significant post-workshop interpretation, analysis, and standardisation by the project team. The process ensured that the results could be demonstrated within the context of this report as well as to surface narratives and discussion points. The workshop and the workshop-based evidence do have inherent limitations. The results of the workshop reflect the judgement of a select group of experts rather than empirical modelling. **As a result, the outcomes of the workshop should be considered exploratory rather than predictive due to the findings potentially being influenced by group dynamics and framing.**

4.3 System Transformational Goals, Trends and Challenges, and Prioritisation of Environmental risks

Outcome for System 1 - Energy Transition & Industrial Transformation

Transformation trends, challenges and outcomes (as identified by workshop participants)

Trends

The transition of the energy system towards net-zero carbon goals and the related industrial transformation ambitions are increasingly shaped by considerations regarding strategic autonomy, from across member states and at the EU level overall. There is a trend towards the replacement of fossil fuels through electrification of end-use sectors, accompanying the rise in renewable energy production. This trend is particularly evident in chemical, automotive, and steel sectors, by way of example through the increased uptake of electric cars. Finally, high energy prices in Europe are threatening to weaken competitiveness, driving energy-intensive businesses to close, thus creating economic security vulnerabilities.

Challenges

First, there is greater volatility of global energy markets which causes a high degree of uncertainty across the system. This is driven by a combination of factors such as climate change as well as geopolitical tensions. Building on this, the participants referred to the traditional 'baseload power system', designed to provide a continuous and reliable electricity supply to meet minimum constant demand on the grid, largely independent of weather conditions or time of day. However, the energy sector is increasingly shifting away from a system centred on baseload generation towards one with a greater share of variable renewable energy sources, which in turn requires much greater system flexibility. This shift creates new risks for power system reliability, but also new opportunities for distributed resilience.

Second, risks in the energy sector are shaped by a wide range of interacting environmental risk drivers, such as changing weather patterns and water stress, as well as non-environmental drivers, including war and the need to reinforce energy security in times of conflict. These factors emerged from the workshops as critical interacting drivers. In addition, although cyber threats were not included in the original scope of the literature review, they were identified as an important emerging concern. Experts highlighted that the increasing digitalisation of the energy sector inherently heightens cyber risk, making national energy systems increasingly attractive and vulnerable targets.

Furthermore, participants observed an increased emphasis on the circular economy alongside a broader range of developments, including supply chain reconfiguration, cybersecurity as part of infrastructural resilience, energy system electrification, socio-technical transitions, and greater interoperability across European energy networks.

Potential 'Outcomes'

- A shift to renewables with greater flexibility and the potential growth of nuclear and/or gas.
- Greater fragmentation in the energy system and/or unequal industrial transformation.
- Fossil fuel lock-in.
- More interoperability across energy networks in Europe leading to energy shortages.
- Vulnerable infrastructure and societies that are over-reliant on technology making them susceptible to cyberattacks, shutdowns and manipulation.
- Redirection of financial resources and abandonment of the Just Transition.

Following Activity 1, which aimed to establish a shared understanding of the system, and its transformation path, the experts prioritised the key environmental risk drivers for the energy transition & industrial transformation.

Prioritisation of Key Risks for Energy Transition & Industrial Transformation

Figure 12 illustrates the five top risks for energy transition and industrial transformation. This is also accompanied by a prioritisation matrix in which the risks were categorised according to their likelihood, magnitude and uncertainty within the 2030–2050 timescale.

Figure 12: Five prioritised Risks for Energy transition and Industrial Transformation System

Figure 12: Author

- *Risk from* Climate Change – Systemic risk due to tipping points (AMOC Collapse).
- *Risk from* Biodiversity Loss - Systemic risk due to loss of ecosystem services.
- *Risk from* Climate Change – Systemic risk due to water stress.
- *Risk from* Climate Change – Systemic risk due to extreme weather events.
- *Risk from* Environmental Degradation – Systemic risk due to soil degradation

Following the prioritisation of these five environmental risk drivers, Figure 12 shows the perceived likelihood, magnitude, and uncertainty of those environmental risk drivers.

Figure 13: Environmental Driver Likelihood, Magnitude and Uncertainty matrix for the Energy transition and Industrial Transformation System.

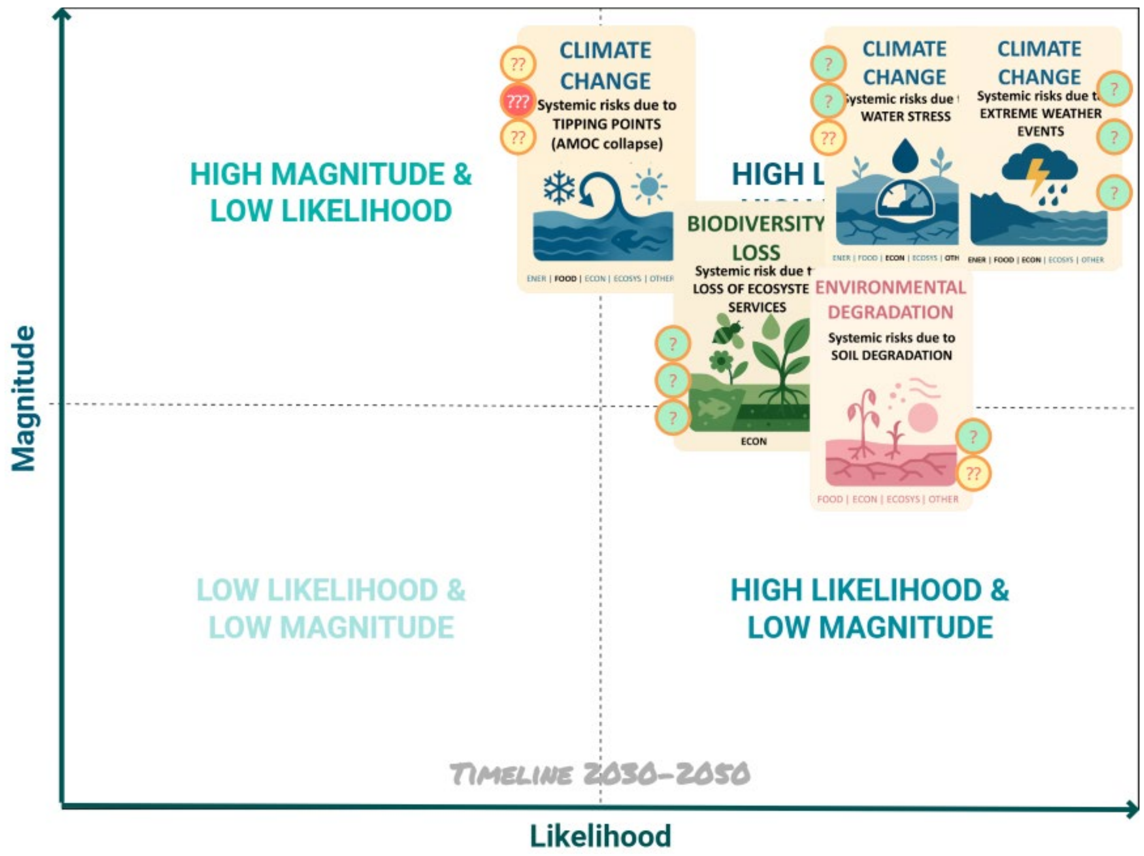

Figure 13: Author (Screenshot from MIRO Board)

Outcome for System 2 - Competitive Economic and Financial System.

Transformation trends, challenges and outcomes (as identified by workshop participants)

Trends

There is a broader trend within the financial sector of retreating from net-zero commitments, associated with increased market volatility and reduced regulatory certainty. Continued fossil fuel subsidies may not align with growing Environmental Social Governance (ESG) driven demand for sustainable investment, including from pension funds, while increased defence and security spending may divert political and financial attention away from net-zero goals. These developments coexist with a growing range of taxonomies and classification systems that seek to define what sustainability means, as well as ongoing efforts to embed sustainability risks into mainstream financial risk management. Taken together, these trends highlight systemic inconsistencies that affect transition pathways.

Challenges

There are currently several significant challenges facing the economic and financial system. First, the system is under increasing pressure from non-environmental risk drivers, particularly geopolitical shifts and tensions, which directly affect investment conditions, trade relations, energy prices, and broader economic stability. These pressures are unfolding alongside a shift from voluntary to mandatory sustainability-related reporting requirements, which is likely to reshape how companies and investors assess, disclose, and manage sustainability-related risks. This challenge is compounded by the coexistence of multiple, and at times competing, definitions of 'sustainability', which can create uncertainty and hinder consistent implementation.

A further challenge lies in the growing range of interacting pressures affecting the sector. These include rising external dependencies that are increasingly difficult to manage, uneven uptake of renewable energy technologies, pushback against net-zero goals, heightened market volatility, and reduced regulatory certainty. Together, these developments make it more difficult for economic and financial actors to plan, invest, and respond strategically over the long term. They are further shaped by slow progress in innovation, shifting EU budget priorities, increasing polarisation in policy debates, and the growing frequency of climate-related disasters. Taken together, these factors heighten uncertainty, weaken the predictability of transition pathways, and make it more difficult for financial actors to assess risk and allocate capital effectively. While developments such as the increasing use of nature-based approaches may create new opportunities, they also add to the complexity of the transition landscape and may challenge existing financial and governance frameworks.

Finally, it is important to recognise that finance itself acts as a transmission channel for systemic risk and may function either as an amplifier of instability or as a stabilising force. Through mechanisms such as insurance markets, credit conditions, asset valuations, and investment flows, risks can spread across sectors and geographies, with important implications for resilience and transition pathways.

Potential 'Outcomes'

- A potential reduction of financial subsidies for sustainability.
- A more resilient industrial base, more affordable energy, and stronger strategic sovereignty.

- A "cradle-to-cradle" circular economy that enhances resource efficiency across the industrial and energy sectors and limits waste.
- A secure and competitive EU.

Following Activity 1, which aimed to establish a shared understanding of the system and its transformation pathway, experts prioritised the key environmental risk drivers affecting the Resilient and Competitive Economic and Financial System.

Prioritisation of Key Risks for Competitive Economic and Financial Systems.

The five most significant risks to the transformation of the economic and financial systems (which are displayed in Figure 14) are:

- *Risk from Climate Change – Systemic risk due to tipping points (AMOC Collapse).*
- *Risk from Climate Change – Systemic risk due to changing weather patterns*
- *Risk from Biodiversity Loss – Systemic risk due to loss of ecosystem services.*
- *Risk from Climate Change– Systemic risk due to water stress.*
- *Risk from Pollution – Systemic risk due to chemical pollution.*

Figure 14: Five prioritised risks for Resilient & Competitive Economic and Financial Systems.

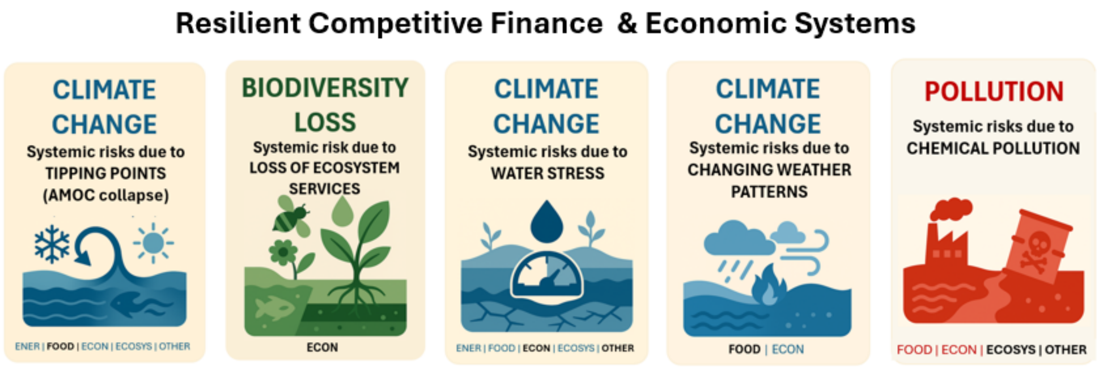

Figure 14: Author

Building on this, Figure 15 highlights the perceived likelihood, magnitude and uncertainty of these environmental risk drivers.

Figure 15: Environmental driver likelihood, magnitude and uncertainty matrix for competitive economic and financial systems.

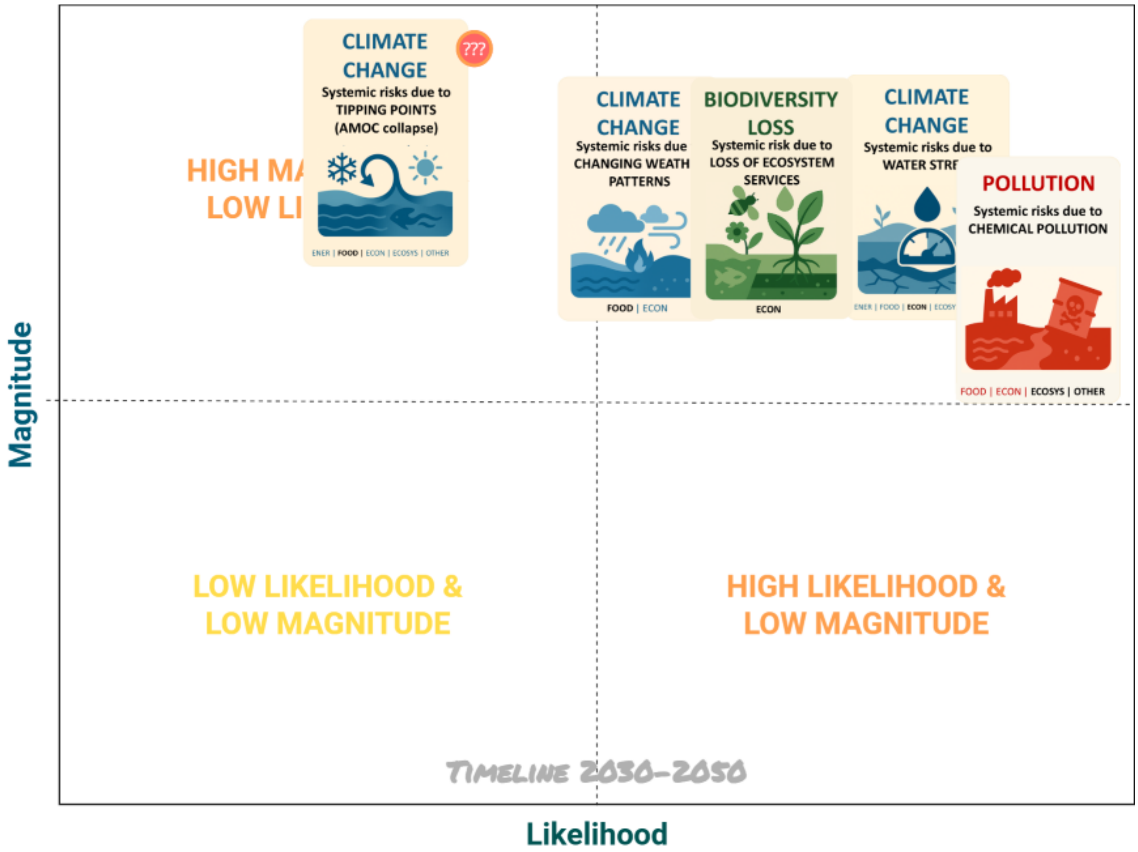

Figure 15: Author (Screenshot from MIRO Board)

Outcome for System 3 - Secure & Sustainable Food Systems.

Transformation trends, challenges and outcomes (as identified by workshop participants)

Trends

In the food system, there is a growing emphasis on adaptation, as climate change increasingly drives yield variability and undermines food security across the EU. Alongside this, preparedness is becoming more prominent on municipal agendas, in part encouraging greater interest in local food systems as a means of strengthening resilience. Another overarching trend is the accelerating, though uneven, digitalisation of the food system. Additional trends include protein diversification and a broader social shift towards diets and agricultural systems that rely less on animal-based products.

Finally, the transition towards a secure and sustainable food system is also being shaped by growing interest from investors and capital holders. This includes increased attention to systemic forms of financing, such as municipal bonds that support preventative healthcare through improved nutrition, as well as rising impact-investor interest in food systems resilience.

Challenges

The food system faces a set of interrelated challenges arising from both longstanding structural vulnerabilities and emerging transitions. A first challenge concerns persistent structural inequalities, including unequal access to food and unequal exposure to food insecurity. These are compounded by import dependencies in an increasingly volatile global context, where geopolitical tensions and environmental disruptions can damage supply chains and undermine the stability of food provision.

A second challenge relates to the growing difficulty of maintaining economically and environmentally sustainable food production. Rising production costs, linked in part to the energy transition and fertiliser price volatility, are placing additional pressure on producers. At the same time, climate change-driven water scarcity is forcing changes in crop choices and, in some cases, the geographic location of production. Together, these pressures challenge the viability, predictability, and resilience of the food system.

A further challenge lies in the uneven capacity of the sector to respond to rapid technological change. Developments in artificial intelligence, robotics, sensors, and wider digitalisation may create important opportunities, but they also raise challenges relating to access, affordability, implementation capacity, and the risk of uneven uptake across actors and regions.

Finally, the food system faces mounting ecological and climate-related pressures. Soil degradation, the loss of ecosystem services, and growing evidence of climate-related damage are already prompting a range of adaptation responses. However, these pressures are accompanied by wider challenges, including the risk that resilience becomes a justification for maintaining business-as-usual practices; the increasing frequency and intensity of heatwaves, droughts, and floods; continued concentration of the food system around a limited number of crops, producers, and traders; and growing expectations that farmers contribute to wider security and resilience objectives. Together, these dynamics make it more difficult to achieve a food system that is both secure and sustainable.

Potential 'Outcomes'

- Integrated, AI-enabled precision agriculture as a core feature of the food system.
- Reduced demand for animal-based products and subsequently less land use/fertiliser use etc.
- Climate-resilient crop portfolios adapted to hot/dry conditions.
- Diversified farming systems with restored soils and pollinator habitats.

Following Activity 1, which aimed to establish a shared understanding of the system, and the transformation path of the secure and sustainable food system, experts prioritised key environmental risk drivers.

Prioritisation of Key Risks for Secure & Sustainable Food Systems.

The six risks prioritised by experts for the secure and sustainable food system (displayed in Figure 16) are as follows:

- *Risk from* Environmental Degradation – Systemic risk due to soil degradation.
- *Risk from* Climate Change - Systemic risk due to drought.
- *Risk from* Biodiversity Loss – Systemic risk due to loss of ecosystem services.
- *Risk from* Climate Change – Systemic risk due to tipping points (AMOC Collapse).
- *Risk from* Climate Change – Systemic risk due to heat stress.
- *Risk from* Climate Change – Systemic risk due to extreme weather.

Figure 16: Six prioritised risks for secure & sustainable food systems

Figure 16: Author

Figure 17 displays the perceived likelihood, magnitude and uncertainty of the selected environmental risk drivers.

Figure 17: Environmental driver likelihood, magnitude and uncertainty matrix for secure & sustainable food systems.

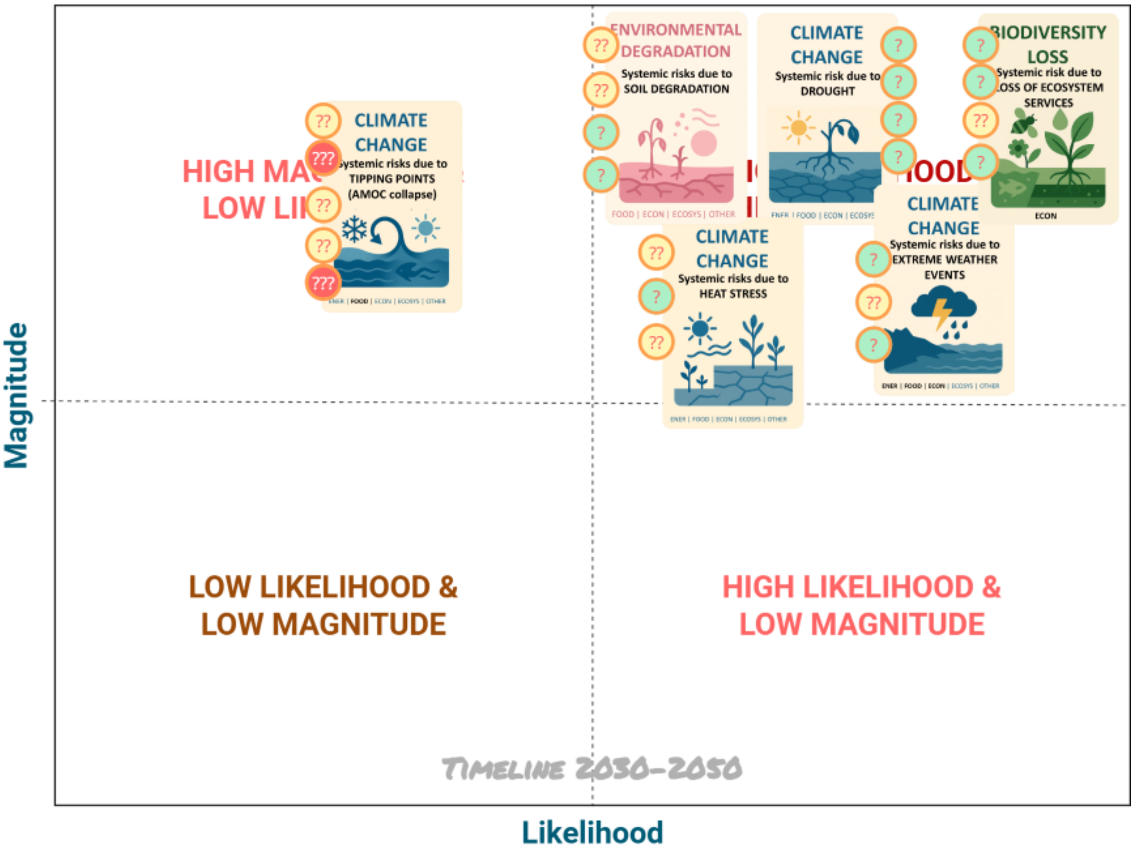

Figure 17: Author (Screenshot from MIRO Board)

Outcome for System 4 - Resilient Ecosystems, Nature Protection, Climate Resilience and Restoration.

Transformation trends, challenges and outcomes (as identified by workshop participants)

Trends

In the area of resilient ecosystems, nature protection, climate resilience, and restoration, a number of important trends are becoming increasingly visible as the impacts of climate change grow more apparent and more costly. The rising severity and frequency of environmental risks, including pollution, wildfires, and floods, are affecting both ecosystems and communities, thereby increasing public awareness of environmental degradation and disaster-related risks. This, in turn, is influencing policy attention and shaping mitigation and adaptation efforts across multiple governance levels.

Nature-based solutions are also receiving growing attention, contributing to a shift in research and policy towards more integrated and cross-cutting approaches. This includes increasing interest in indicators and interventions that reflect interconnections across systems, such as sponge landscapes. At the same time, concerns remain about the persistence of short-termism in political agendas, whereby decision-making and policy development continue to prioritise immediate gains over longer-term resilience, protection, and restoration objectives.

Challenges

A key challenge concerns the persistent funding gap for nature restoration and ecosystem protection, as grants and public funding may not keep pace with the scale of investment required. This shortfall can delay restoration efforts, increase ecosystem vulnerability, and contribute to the continued decline of critical ecosystem services on which other systems depend.

A second challenge relates to the implementation of the EU's Nature Restoration Regulation, which is expected to play a central role in shaping transformation in this area. While the Regulation is expected to strengthen efforts to link water retention measures with other drivers of resilience, including biodiversity, its effective implementation will require coordination across sectors, governance levels, and policy objectives. This challenge is becoming more acute in a context shaped by the increasing frequency of damaging events, growing public awareness, and the development of the new Climate Resilience Framework, with its emphasis on resilience by design and greater harmonisation in data and risk assessment. At the same time, climate mitigation policies may also generate unintended negative impacts on ecosystems, including through land-use change, wind energy infrastructure, and bioenergy deployment. Managing these trade-offs therefore represents a significant governance challenge.

Potential 'Outcomes'

- Diversified funding streams to achieve nature protection and restoration, including co-funding and co-delivery mechanisms, which encourages broader buy-in across industries and stakeholders.
- Expansion of the delivery of green finance, supported by policies mobilising private investment.
- Greater focus on community / local led interventions.

Prioritisation of Key Risks for Resilient Ecosystems, Nature Protection, Climate Resilience and Restoration.

The six most significant risks to the transformation of the economic and financial systems (displayed in Figure 18) prioritised by experts are as follows:

- *Risk from* Climate Change – Systemic risk due to tipping points (AMOC Collapse).
- *Risk from* Biodiversity Loss – Systemic risk due to habitat loss.
- *Risk from* Biodiversity Loss – Systemic risk due to loss of ecosystem services.
- *Risk from* Environmental Degradation – Systemic risk due to intensive agriculture.
- *Risk from* Climate Change– Systemic risk due to extreme weather.
- *Risk from* Pollution – Systemic risk due to chemical pollution.

Figure 18: Six prioritised risks for resilient ecosystem, nature protection, climate resilience and restoration.

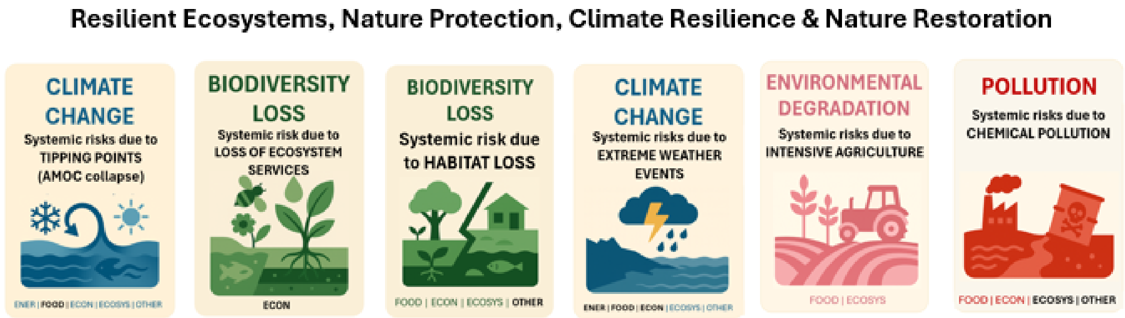

Figure 18: Author

Figure 19 displays the expert's perceived likelihood, magnitude and uncertainty of these environmental risk drivers.

Figure 19: Environmental driver likelihood, magnitude and uncertainty matrix for resilient ecosystems, nature protection, climate resilience and restoration.

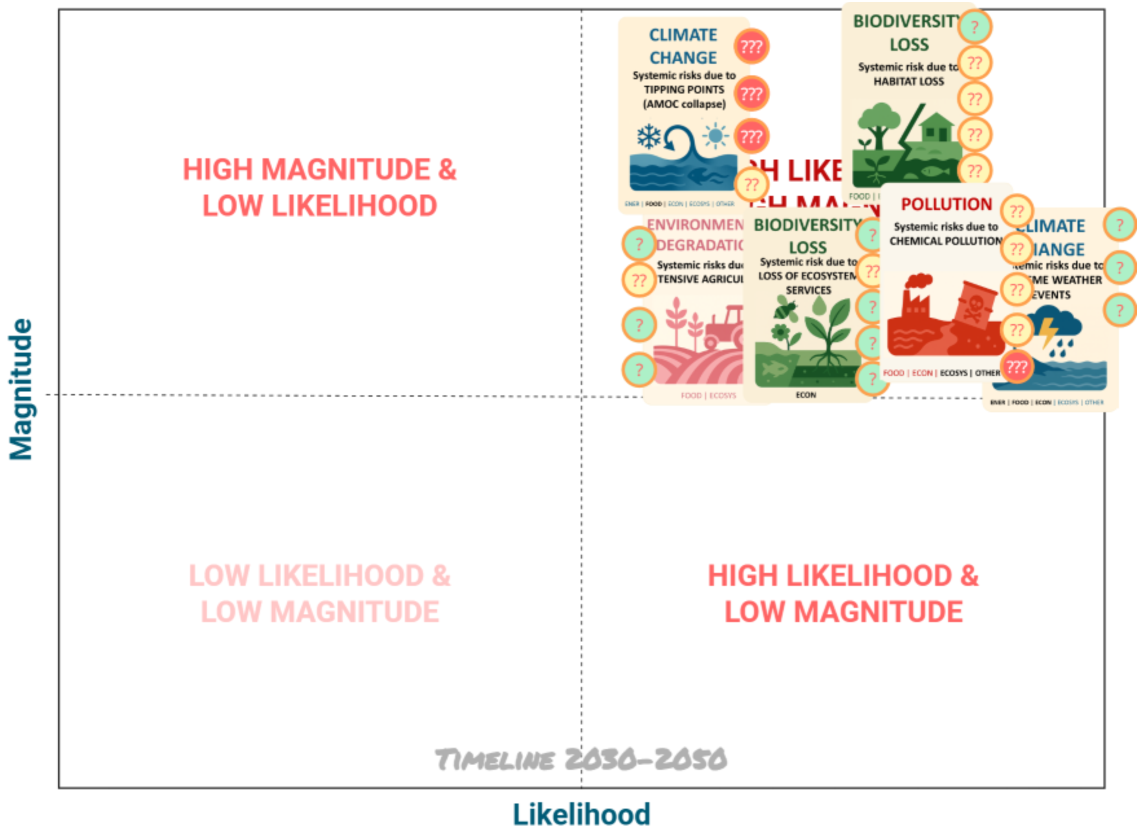

Figure 19: Author

Environmental Risk Drivers Across the Four Systems, Cross-cutting Findings

This section explores the similarities and differences from the prioritisation of the environmental risk drivers across each of the four systems. First, the risks from climate change are the most common environmental risk drivers with 12 out of 22 within that risk category. Next, 5 out of 22 drivers were extracted from risks from biodiversity loss. Finally, 3 out of 22 of the environmental risk drivers were from environmental degradation and 2 out of 22 from risk from pollution.

The high frequency with which environmental risk drivers linked to climate change appear may be attributable to several factors. First, it may reflect the composition of the 35+ key resources that informed the risk prioritisation process (see Section 3.2.2, Box 3). These resources may have placed greater emphasis on climate change-related environmental risk drivers, thereby introducing a degree of bias into the research methodology. Alternatively, this emphasis may also reflect the balance of expertise represented among the selected experts in both the advisory group and the online workshops. While these experts were chosen for their expertise in one of the four systems defined in the research, many also worked in cross-cutting roles involving systems thinking. As a result, they may have placed greater, even if unintended, emphasis on environmental risk drivers associated with climate change. Finally, the prominence of climate change-related environmental risk drivers may also reflect the hierarchical nature of the risks, which is explored later in this section.

Building on this, 'systemic risk due to tipping points, including a potential AMOC collapse', was identified as a priority environmental driver across all four systems. However, it was considered less likely to materialise within the 2030–2050 timeframe covered by the analysis. The focus on the risk from climate change – 'systemic risk due to tipping points, including a potential AMOC collapse' may have been a result of framing of the questions in the workshops. Specifically, activity 1 of the workshop encouraged the experts to consider the transformational trends, challenges and potential outcomes of the system they were exploring. The focus on the long-term transformative outcomes of these systems potentially influenced the outcomes and may have encouraged the experts across all the systems to prioritise 'tipping points AMOC collapse' as an environmental driver to discuss in the following workshop activities.

Furthermore, a high level of uncertainty exists around this environmental risk driver, emphasising that while it is critical across sectors, the timeline and scale of its impacts remain extremely unclear. In fact, across all the systems risk from climate change – 'systemic risk due to tipping points AMOC collapse' was the only environmental driver which was categorised as having a high degree of uncertainty. With the exception of the Resilient ecosystem, nature protection, climate resilience and restoration system breakout group, 'Risk from Climate Change – systemic risk due to extreme weather' was also defined as highly uncertain.

Similarly, all four systems identified 'Risk from Biodiversity Loss – systemic risk due to loss of ecosystem services' as a prioritised key environmental driver. However, unlike risk from AMOC collapse, systemic risk due to a loss of ecosystem services is associated with strong to medium certainty, causing significant issues in the proposed timeframe between 2030-2050, with high magnitude and high likelihood of occurrence.

Experts across the four systems highlighted a consensus around environmental risk drivers associated with climate change and extreme weather, particularly those related to water. Across the four systems, the following risks were prioritised:

- *Risk from* Climate Change – systemic risk due to drought.
- *Risk from* Climate Change – systemic risk due to extreme weather.
- *Risk from* Climate Change – systemic risk due to heat stress.
- *Risk from* Climate Change – systemic risk due to water stress.

While analytically distinct as defined by the literature review, these risks are causally interconnected and frequently co-occur. Climate change acts as an upstream driver, generating multiple, closely related categories of risk that are relevant across sectors. Experts further emphasised that water functions as a transmission pathway, transporting pollution and linking sectors and ecosystems, thereby amplifying and propagating impacts across domains.

Finally, it is important to note that the environmental risk drivers are inherently connected, and one environmental driver is considered to precede or encapsulate others, a factor which was highlighted earlier in the research. The finding supported the results from the initial advisory group workshop in which some playing cards often function as “umbrella” or “trump” categories that encompass more specific drivers (sees section 3.3). By way of example, ‘Risk from Biodiversity Loss – systemic risk due to loss of ecosystem services’ could also include ‘Risk from Biodiversity Loss – systemic risk due to habitat loss.’ These also affect some of the decisions made by the participants in the workshops. The role of some risks preceding others may have had implications on the way the experts prioritised some risks and may imply the need for more research into the hierarchical nature of some of the environmental risks.

4.4 Co-creating Risk Constellations

What is a Risk Constellation?

Following the prioritisation of environmental risk drivers within each system, experts were then asked to develop a “risk constellation” for a specific environmental driver. The concept of a risk constellation was developed within the project as a metaphor to help address the inherent complexity involved in discussing risk and the interactions between multiple drivers, both internally and in dialogue with experts. Rather than treating risks as isolated or linear phenomena, the metaphor frames them as interconnected elements within a wider configuration, where relationships, dependencies, and relative positions matter. A risk constellation allows experts to perceive and articulate risk at a scale that is most meaningful to their own expertise, while retaining an understanding that each risk or driver remains embedded within a larger, more complex system of interacting risks. This approach can be used as both an analytical and facilitation tool. First, the idea of risk constellations supports analytical clarity by allowing experts to map out the different magnifiers, drivers and impacts associated with a risk at a scale that they are most comfortable enabling discussion of specific risks without losing sight of the broader context in which the risk sits. As a result, within this project the experts were asked to define the different magnifiers, drivers (both climatic and non-climate) and potential impacts associated with that specific environmental driver, which has been captured in Figure 20.

Figure 20: The structure of the risk constellation that informed the systemic risks

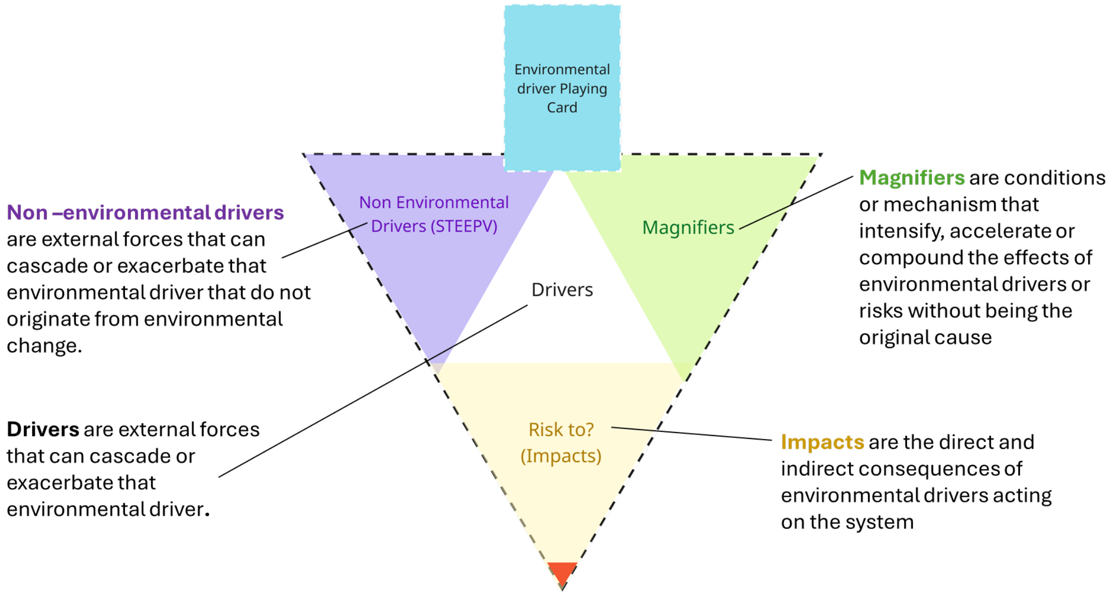

Figure 20: Author

Each risk constellation was developed by an individual expert. As a result, the individual expert-created constellations varied significantly between the systems and between the different experts. To counteract these differences in the workshop, the experts were asked to briefly present the risk constellation that they had created to ensure that all workshop participants understood each risk constellation before preceding to the system network diagram in activity 4. Second, given the differences in the structure and content of the risk constellations, after the workshop each constellation underwent a standardisation process to allow the researchers to systematically analyse and present the connections between them. The standardisation process converted the contents of each risk constellation into text. It is important to note that no changes were made to the content of the risk constellations during this standardisation process. An example of this standardisation process has been provided in Figure 21.

Figure 21: An example of the standardisation process used to unify the differences in the individual risk constellations.

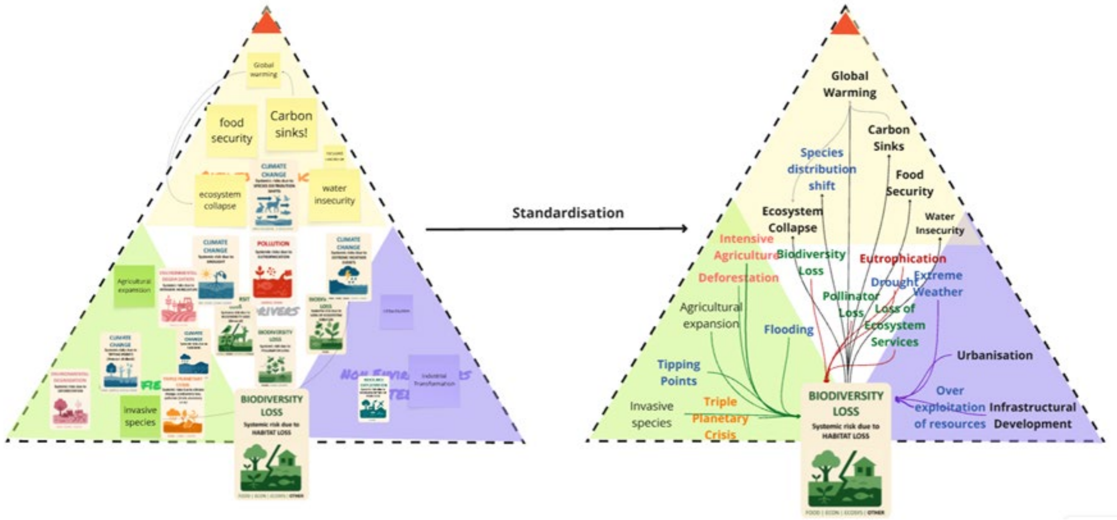

Figure 21: Author

The individual standardised risk constellations were subsequently integrated into a unified diagram (referred to as the 'system network diagram'). These network diagrams contain a large amount of information which does not translate to an A4 report format. Examples of the system network diagrams have been included in **ANNEX 2.**

4.5 Co-creating Risk Constellations Cascading and Compounding Risks Across the Four Systems

This section discusses the interconnections between the different elements of risk constellations within the four systems, visualised as network diagrams and further elaborated as narratives. These diagrams were co-created with experts during the workshops. However, while their content remained unchanged from the workshop outputs, their presentation was standardised across all system network diagrams through the use of consistent text and arrow formats.

Each diagram illustrates the input from the workshops, mapping magnifiers, drivers, and potential impacts identified by the experts within the risk constellations. Priority environmental risk drivers are arranged around the perimeter, with environmental risk drivers (white & black), non-environmental or STEEPV drivers (purple) and magnifiers (green) moving inward, and the associated impacts (yellow) positioned at the centre. This structure highlights how the prioritised drivers ultimately lead to impacts.

Overlaid on the diagrams are coloured arrows that match the colours above, with environmental risk drivers (white & black), non-climatic drivers (purple) and magnifiers (green) moving inward, and the associated impacts (yellow). With one addition in pink. The pink arrows are used to highlight specific connections within the network diagram between the same magnifiers, drivers and impacts from different risk constellations. Experts can follow different connections through these network system diagrams to explore potentially cascading and compounding connections. The complete system network diagrams are complex and have not been included in the main text of the report. These diagrams can be found in **ANNEX 2** and downloaded as A3 diagrams which can be explored in greater detail. Instead, the report highlights seven narratives pointing to cascading and / or compounding interactions. These narratives are designed to highlight some of the key systemic risk pathways that can be distilled from the network diagrams. It is important to note that these diagrams should not be considered as a 'complete' picture of all the direct, indirect pathways between every risk. Rather, they are illustrative of selected pathways, rather than comprehensive system representations or predictive models. The narratives provide a snapshot of the complexity of risks that affect that system. We acknowledge that further iterations of these network diagrams would help to strengthen the detail and accuracy of the network diagrams

Narrative 1 – The Combined Impact of Extreme Weather, Water stress, and Ecosystem Degradation on Energy Transitions and Other Systems

Figure 22: Network diagram for Narrative 1

KEY

- Defines **magnifiers** or **magnifying links** between different elements of the network
- Defines **Impacts** from environmental drivers
- Defines **environmental drivers** or **driving links** between different elements of the network
- Defines links across the the risk constellations
- Defines **non-climatic drivers** or **non climatic driver links** between different elements of the network
- Highlights **environmental drivers** from environmental drivers

**Connections outside the network diagram signify explicit links between the priority drivers*

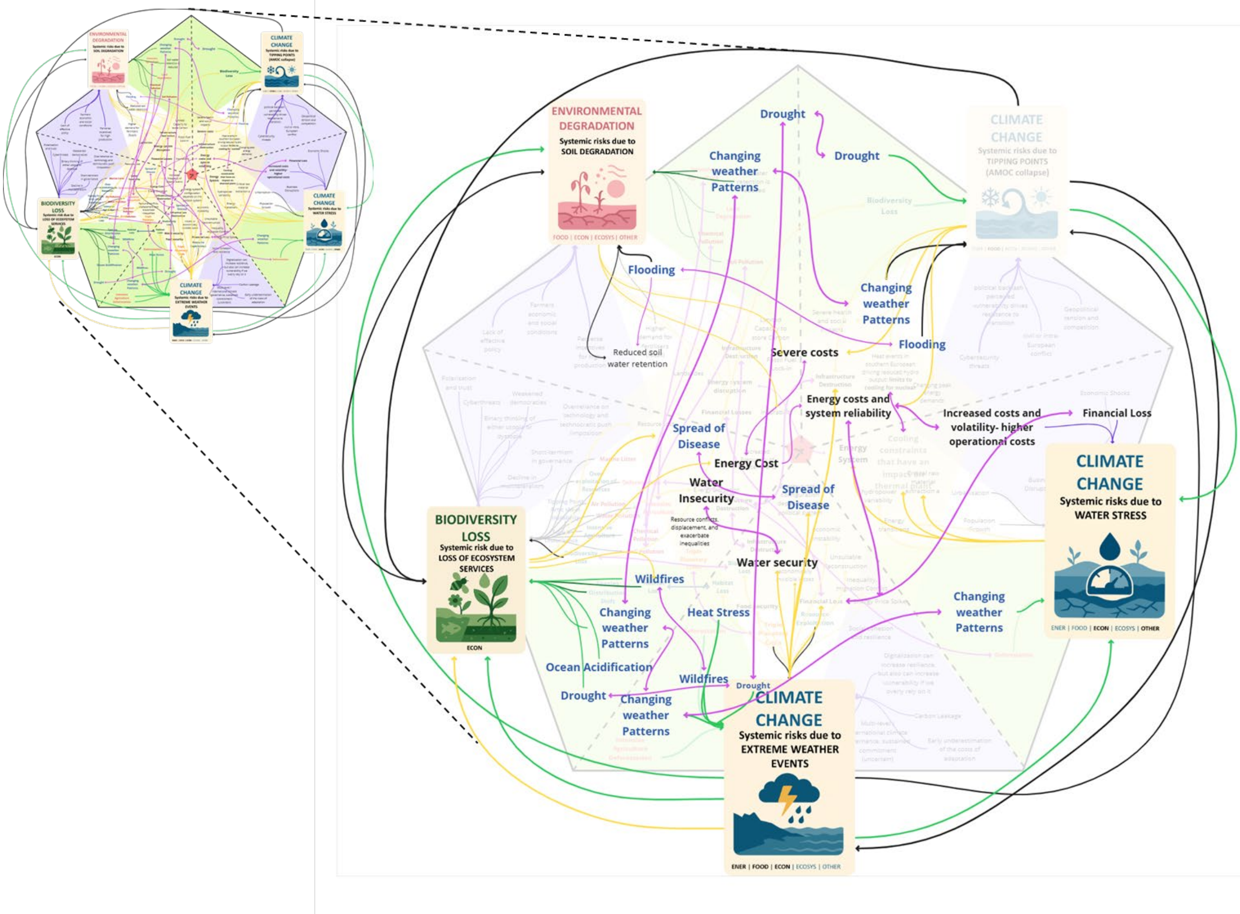

Figure 22: Author

Core message — Climate change creates compounding and cascading risks for the energy transition because extreme heat, drought, water stress and extreme weather can simultaneously disrupt energy production, increase electricity demand, raise system costs and amplify vulnerabilities across industrial, water and ecological systems. These risks are further intensified by ecosystem degradation, soil deterioration and unsustainable land use change, which reduce water retention, carbon storage and other ecosystem services that buffer climatic extremes. In line with the EEA's EUCRA (2024a), this means that climate risks to energy transitions should be understood not only as direct impacts from hazards, but as systemic risks shaped by interacting climatic and non-climatic drivers across sectors and territories.

The transition to a renewable and electrified energy system could increase exposure to climate risks because many renewable technologies depend on weather and hydrological conditions. Droughts, reduced river flows and glacial retreat threaten hydropower generation, while concurrent heatwaves and droughts can lead to electricity shortfalls, particularly in southern Europe. At the same time, rising temperatures increase cooling demand and reduce transmission efficiency and capacity, placing further strain on electricity systems and increasing the risk of price spikes and supply disruptions. Such risks should be read as interconnected and cascading, rather than as isolated sectoral impacts.

Moreover, ecosystems and land systems are not only affected by these climatic pressures but materially shape their severity. Soil degradation undermines resilience to extreme weather and climate change, while ecosystem degradation reduces the ability of landscapes to regulate water, retain soil moisture, moderate heat, store carbon and limit erosion, wildfire spread and flood impacts. In this sense, land use change, soil sealing, intensive land management and biodiversity loss act as risk multipliers: they weaken the natural buffering capacity that would otherwise dampen climatic shocks, thereby worsening drought, runoff, wildfire risk and downstream flooding, with consequences for energy, agriculture and water security.

The network diagram shows that **systemic risk due to water stress** and **systemic risk due to extreme weather events** remain key environmental risk drivers, but they can be read together with **ecosystem degradation,** and the underpinning land use change as interacting amplifiers. These drivers contribute to water insecurity, energy price spikes and persistently high energy costs, while also increasing pressure on industry, food systems and territorial cohesion. The direct pathway between water stress, water scarcity and energy production remains central, as water is a critical input for hydropower, cooling and wider industrial transformation. However, the pathway is arguably broader: degraded soils and ecosystems also reduce infiltration, groundwater recharge and landscape water retention, thereby intensifying water scarcity and increasing exposure of infrastructure and production systems to both drought and flood extremes.

This is particularly visible in the lower-left section of the system, where **extreme weather events** and **loss of ecosystem services** share multiple magnifiers, including drought, wildfires and changing weather patterns. Drought already suppresses vegetation productivity and carbon sequestration, compromises ecosystems' capacity to reduce heat impacts, and increases wildfire risk. In turn, climate change and altered land use further degrade ecosystems, intensify habitat loss and weaken adaptation capacity over time. This creates a reinforcing feedback loop: climate hazards damage ecosystems and soils; degraded ecosystems become less able to buffer heat, drought and flooding; and the resulting increase in systemic exposure feeds back into risks for energy transition, industrial activity, food production and water resources.

Taken together, a broader **energy-water-land-ecosystem** framing adds perspective to the issue. The risk is not only that climate hazards directly disrupt the energy transition, but that degraded ecosystems and unsustainable land use lock in higher vulnerability across multiple systems. This also implies that adaptation responses cannot rely only on technical or sector-specific measures. Ecosystem restoration, soil protection, wetland and floodplain restoration, agroforestry, close-to-nature forestry and other nature-based solutions are important complements because they can strengthen water retention, reduce erosion, moderate heat, lower wildfire and flood risk, and deliver co-benefits across climate adaptation, mitigation and biodiversity objectives.

Narrative 1 – Impact pathway: *Water stress and extreme weather as priority environmental drivers, interacting with ecosystem degradation and land use change → intensified drought, heat stress, wildfires and shifting weather patterns → reduced soil moisture, weaker landscape water retention and lower freshwater availability → increasing water scarcity and constraints on water-dependent energy production → weaker energy supply, greater risk of price spikes and persistently high energy costs → cascading risks to water and energy security and other interconnected systems.*

Narrative 2 – Cascading and Compounding Climate and Nature Risks to the European Economy and Financial System

Figure 23: Network diagram for Narrative 2

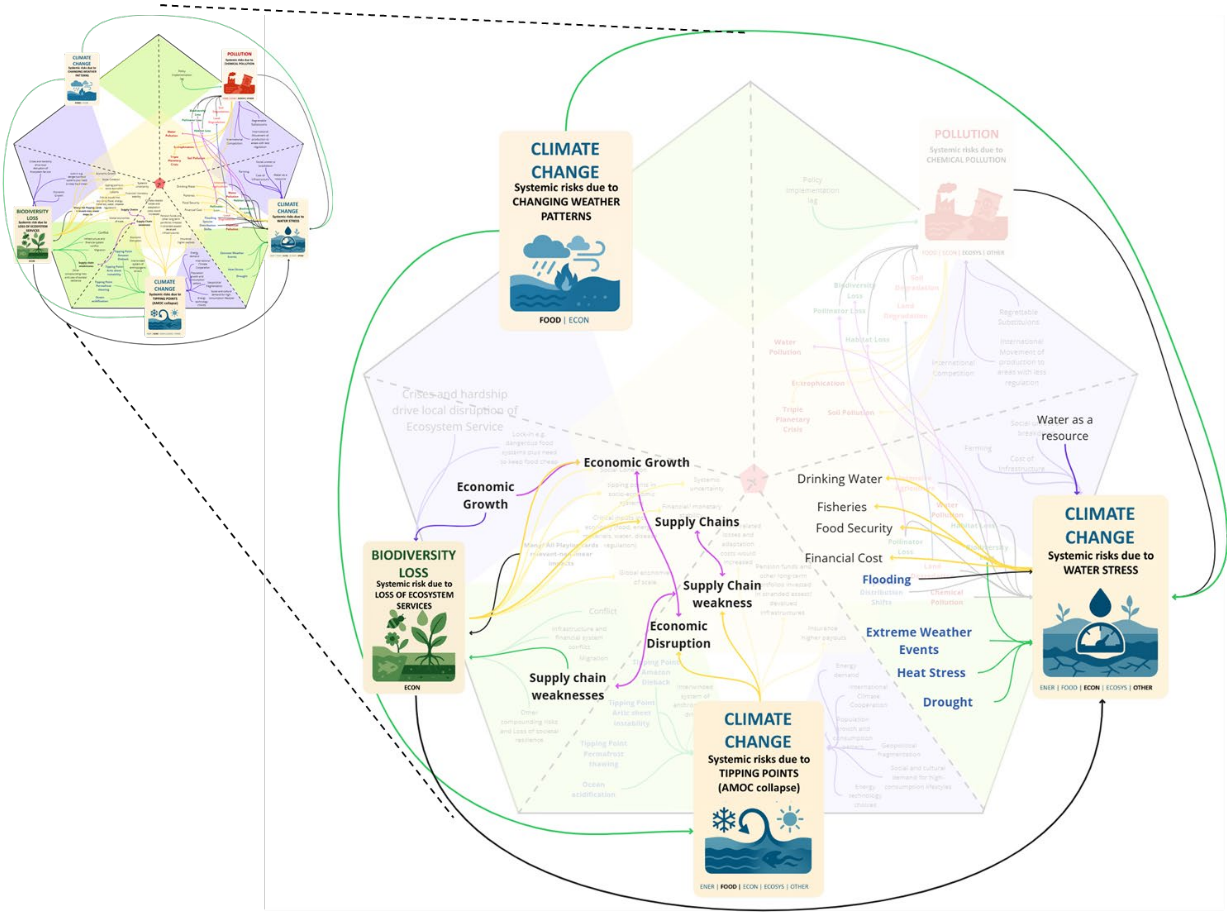

Figure 23: Author

Core message — Climate change and nature loss are not separate risk drivers. They interact through ecosystems, supply chains, infrastructure and financial exposures, creating cascading and compounding risks for the European economy and financial system.

Climate-related hazards such as drought, heat, flooding and changing weather patterns increasingly interact with biodiversity loss, ecosystem degradation and declining ecosystem services. This interaction creates a reinforcing risk dynamic: climate change damages ecosystems, while degraded ecosystems are less able to regulate water, stabilise soils, support food production, protect against floods, buffer heat and sustain economic activity. The EEA's *State of the Environment Report* (EEA, 2025a) underlines that the climate and biodiversity crises are intrinsically linked: climate change is a driver of biodiversity loss and ecosystem degradation, while ecosystem restoration can support mitigation, adaptation and resilience (EEA, 2025c).

This climate–nature interaction is particularly important because ecosystems function as resilience infrastructure. Forests, wetlands, soils, rivers, floodplains and freshwater systems regulate water availability, support pollination, maintain soil fertility, protect water quality, reduce flood impacts and contribute to carbon sequestration. When these systems deteriorate, the economy loses natural buffers against climate shocks. Drought, heat and flooding therefore become more damaging when they occur in landscapes already weakened by habitat loss, land degradation, over-abstraction or declining ecosystem condition. Conversely, repeated climate shocks further weaken ecosystems by reducing soil moisture, lowering vegetation productivity, degrading habitats and increasing exposure to fires, pests and disease.

These dynamics are already material at European scale. Europe is warming faster than the global average, increasing risks to water security, ecosystems, food systems and infrastructure. The EEA reports that altered rainfall patterns are contributing to droughts in some regions and flooding in others, affecting freshwater ecosystems and vegetation productivity, while areas impacted by drought in the EU increased between 2000 and 2022 (EEA, 2025a). Although EU water abstraction declined between 2000 and 2022, water stress continues to affect a substantial share of Europe's land and population each year, with the EEA's water indicators pointing to persistent and worsening water scarcity risks under climate change (EEA, 2024a; EEA, 2025d).

The economic significance of these pressures lies in their systemic and cross-sectoral character. Climate and nature risks rarely remain confined to the initial physical hazard. They cascade through agriculture, food systems, energy production, industry, transport, public health, trade and public finances. In agriculture, drought and ecosystem degradation reduce yields, increase irrigation needs, weaken soil fertility, and undermine pollination and pest regulation. In energy, low river flows and high-water temperatures can constrain hydropower generation and thermal plant cooling. In industry and logistics, water scarcity, heat and flooding can disrupt production, storage, processing, and inland navigation. These sectoral impacts propagate through value chains, affecting input costs, inventories, revenues, trade flows, and household purchasing power.

The EEA's European Climate Risk Assessment reinforces this systemic framing by identifying climate risks to water resources, ecosystems, food security, infrastructure, financial systems and human health, with many risks already at critical levels in parts of Europe and potentially catastrophic without urgent action (EEA, 2024a). This is why climate and nature risks should be assessed as interacting risk systems rather than as isolated environmental pressures. Vulnerability is shaped not only by hazard exposure, but also by dependence on degraded ecosystems, ageing infrastructure, unsustainable resource use and limited adaptive capacity.

ECB work strengthens the macrofinancial relevance of this framing. ECB Occasional Paper No. 380 finds that nature degradation can undermine productivity, disrupt supply chains and heighten vulnerability to shocks, thereby creating risks for both the real economy and the banking system. Applying a nature value-at-risk framework to the euro area, the ECB finds that water-related ecosystem services — including flood protection, surface-water scarcity, groundwater scarcity and water quality — are among the most material nature-related risks. Surface-water scarcity alone could expose up to 24% of euro area output to risk under a drought event with a 100-year return period (ECB, 2026a). The same analysis finds that around 72% of euro area non-financial corporations, representing nearly 75% of corporate bank lending, are highly dependent on at least one ecosystem service (ECB, 2026a).

The financial-system transmission is therefore not limited to direct physical damage. It also arises through reduced firm profitability, higher operating costs, disrupted supply chains, impaired collateral values, higher default probabilities, increased insurance losses, and rising fiscal burdens. ECB analysis finds that around 19% of euro area bank loans are exposed to surface-water scarcity, 22% to groundwater scarcity and 12% to degraded water quality, with exposures concentrated in sectors such as real estate, manufacturing, wholesale and retail trade, mining and construction (ECB, 2026a). ECB also framed water-related ecosystem risks as directly relevant to price stability and financial stability, noting that "too much water, too little water or polluted water" represent urgent ecosystem-service risks to euro area output (ECB, 2026b).

The key implication is that climate impacts and nature loss should not be treated as parallel trends. They are interacting processes that reduce resilience and increase the probability of cascading failures across sectors and territories. Southern Europe remains particularly exposed to chronic water stress and prolonged drought, but the consequences are not regionally contained. Through trade, supply chains, insurance, credit exposures and public budgets, localised ecological and climatic shocks can propagate across the European economy and financial system.

Water stress and drought should therefore be understood as compound climate–nature risk multipliers within a wider system of cascading risks. Their economic significance lies not only in direct physical impacts, but in the way they interact with ecosystem degradation, biodiversity loss, infrastructure vulnerability, sectoral dependencies and financial-sector balance sheets. Strengthening ecosystem resilience is therefore not only an environmental priority; it is a condition for economic resilience, financial stability and long-term competitiveness.

Narrative 2 - Impact pathway — *Climate change and biodiversity loss → water stress and drought, intensified by degraded ecosystems and declining ecosystem services → pressure on critical societal resources and sectors, including drinking water, food systems, fisheries, energy, transport and industry → amplification of existing vulnerabilities in supply chains, infrastructure, public finances and insurance markets → cascading risks to the European economy and financial system, reducing resilience and constraining sustainable economic growth.*

Narrative 3 – Water Resilience as Key Enabler for Economic and Financial Systems

Figure 24: Network diagram for Narrative 3

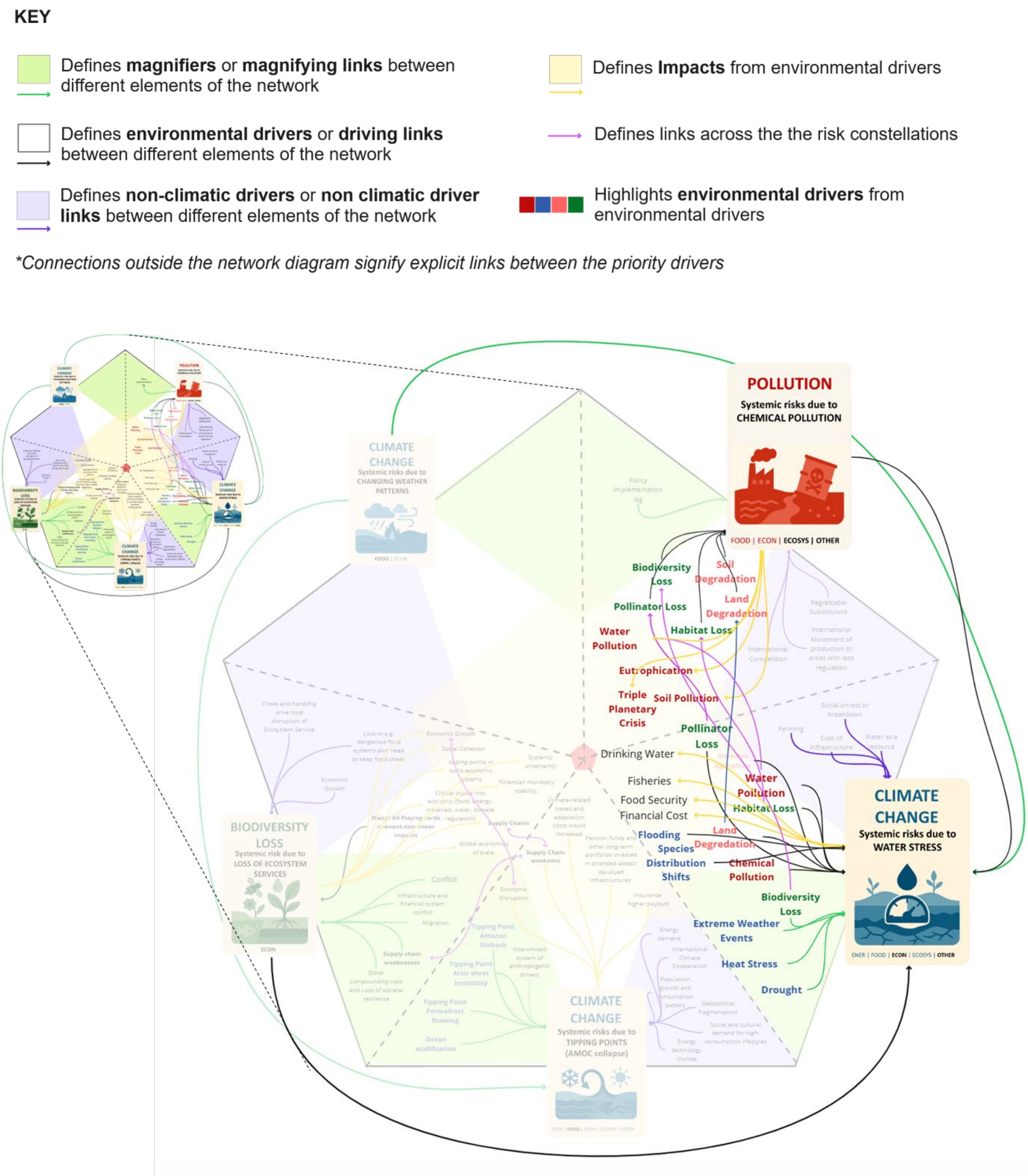

Figure 24: Author

Core message — Water resilience is not only about managing scarcity. It is about maintaining the quantity and quality of water systems under climate stress, pollution pressure and rising economic demand, so that shocks do not propagate across sectors and into the financial system.

Water is a foundational resource for households, ecosystems, agriculture, industry, energy production, transport and public health. It is also a cross-cutting transmission channel through which climate pressures and pollution interact, accumulate and spread across sectors, territories and scales. In this framing, the central issue is not only whether enough water is available, but whether water remains usable, affordable, clean and reliably accessible under worsening climate conditions.

This distinction is important because water quantity and water quality risks are closely linked. Climate change intensifies heat, drought, floods and hydrological variability. Drought and prolonged low-flow conditions reduce river flows, reservoir levels and groundwater recharge, while also lowering the dilution capacity of rivers, lakes and reservoirs. As dilution capacity declines, pollutants become more concentrated, increasing risks to aquatic ecosystems, drinking-water provision, irrigation, fisheries, industrial processes and public health. Floods can also mobilise contaminants from soils, industrial sites, waste facilities and urban systems, spreading pollution across catchments. Climate drivers therefore do not only create water scarcity; they can also aggravate chemical pollution and reduce the effective stock of water that can be safely used.

The EEA's *Europe's State of Water 2024* supports this integrated framing. It identifies three overarching challenges for European water management: protecting and restoring aquatic ecosystems, achieving the zero-pollution ambition, and adapting to water scarcity, drought and flood risks (EEA, 2024d). These challenges are interdependent. A water body affected by chemical pollution is less resilient to drought and heat. A river system affected by low flows is less able to dilute contaminants. A wetland degraded by habitat loss or pollution is less able to filter water, retain flows and buffer extremes. Water resilience therefore depends on managing climate adaptation and pollution reduction together.

The scale of the challenge is already significant. The EEA reports that water stress affects a substantial share of European territory and population each year, while only a minority of European surface waters achieve good chemical status (EEA, 2024d). The EEA-JRC *Zero Pollution Monitoring and Outlook 2025* (EEA-JRC, 2025) further shows that pollution remains a major structural pressure on ecosystems, human health and the economy, with pesticide residues detected in a large share of monitored agricultural soils and toxic substances remaining a key reason for failure to meet chemical-status objectives (EEA-JRC, 2025). These findings indicate that pollution continues to constrain both ecological resilience and economic resilience.

The economic transmission channels are extensive. Reduced water availability can disrupt public water supply, agriculture, food processing, water-intensive manufacturing, energy generation and inland navigation. At the same time, deteriorating water quality raises treatment costs, increases monitoring and compliance requirements, constrains production processes and reduces the reliability of water-dependent activities. For agriculture, the combined effect of drought and pollution can reduce yields, limit irrigation options and degrade soil and water conditions. For industry, it can increase input costs, interrupt operations or require costly substitution and treatment. For energy, low flows and high temperatures can constrain hydropower and thermal cooling, while polluted water can increase operational and environmental compliance risks. For transport, low river levels can reduce inland navigation capacity, while contamination events can disrupt storage, handling and logistics.

Pollution also creates direct and indirect economic costs. Direct costs include clean-up, waste management, treatment, monitoring, enforcement and accident response. Indirect costs arise through degraded ecosystem services, lower agricultural and fisheries productivity, reduced recreational value, public health impacts and loss of natural purification functions. These costs become more material when climate extremes intensify exposure. For example, drought can concentrate pollutants and increase treatment needs, while floods can redistribute contaminants and damage water infrastructure. The interaction between climatic drivers and pollution can therefore produce larger and more persistent impacts than either pressure would generate alone.

From a financial-system perspective, water resilience matters because these impacts can be transmitted to balance sheets. Firms facing water shortages or pollution constraints may experience lower profitability, higher operating costs, stranded or impaired assets, production interruptions and higher compliance expenditures. These pressures can increase credit risk, reduce collateral values, raise insurance claims, tighten access to finance and increase fiscal burdens related to adaptation, remediation and disaster response. Where water risks affect multiple sectors at once — agriculture, energy, industry, transport and households can become macro-financial rather than merely sectoral.

The EEA's European Climate Risk Assessment is relevant in this respect because it shows that climate risks increasingly unfold through compounding and cascading mechanisms, affecting water resources, ecosystems, food security, infrastructure, financial systems and human health simultaneously (EEA, 2024a). In the case of water resilience, the compounding mechanism is clear: climate change intensifies drought, heat and floods; drought reduces water quantity; reduced water quantity worsens water quality; pollution reduces the stock of usable water; degraded water quality undermines ecosystems and human uses; and these combined effects transmit into food systems, energy systems, transport networks, public health, public finances and financial institutions.

This is why water resilience should be framed as a key enabler of economic and financial systems. It is not simply the ability to cope with scarcity, but the ability to maintain water quantity, water quality, ecological functioning and infrastructure reliability under compound stress. Where rivers, aquifers, wetlands and water-supply systems are already degraded by pollution, habitat loss, land degradation or ageing infrastructure, they are less able to buffer drought, heat, flood and contamination events. Conversely, where water systems retain good ecological and chemical status, storage capacity and natural purification functions, they reduce the propagation of shocks across the economy.

Water resilience therefore sits at the intersection of climate adaptation, pollution prevention, ecosystem restoration, infrastructure investment and financial-risk management. It supports competitiveness by securing reliable inputs for production, reducing disruption costs and lowering the need for emergency responses. It supports financial stability by reducing credit, insurance and fiscal risks linked to water-dependent sectors. And it supports social resilience by protecting drinking water, food security, health and affordability. In this sense, water resilience is not a narrow environmental objective; it is a systemic condition for a resilient, competitive and financially stable European economy.

Narrative 3 — Impact pathway — *Climate drivers such as heat, drought, floods and hydrological variability interact with pollution, unsustainable water use, ecosystem degradation and ageing infrastructure → lower water availability reduces dilution and purification capacity, increasing pollutant concentrations and reducing usable water for households, ecosystems and economic activity → water quantity and quality risks reinforce each other, disrupting drinking water, food production, fisheries, industry, energy and transport → impacts transmit into the economy and financial system through higher treatment and compliance costs, production losses, asset impairment, rising credit and insurance risks, increased public expenditure and wider macro-financial instability.*

Narrative 4 - Compounding Risks for Food Security: Droughts, Biodiversity Loss and Environmental Degradation

Figure 25: Network diagram for Narrative 4

KEY

- Defines **magnifiers** or **magnifying links** between different elements of the network
- Defines **environmental drivers** or **driving links** between different elements of the network
- Defines **non-climatic drivers** or **non climatic driver links** between different elements of the network
- Defines **Impacts** from environmental drivers
- Defines links across the the risk constellations
- Highlights **environmental drivers** from environmental drivers

**Connections outside the network diagram signify explicit links between the priority drivers*

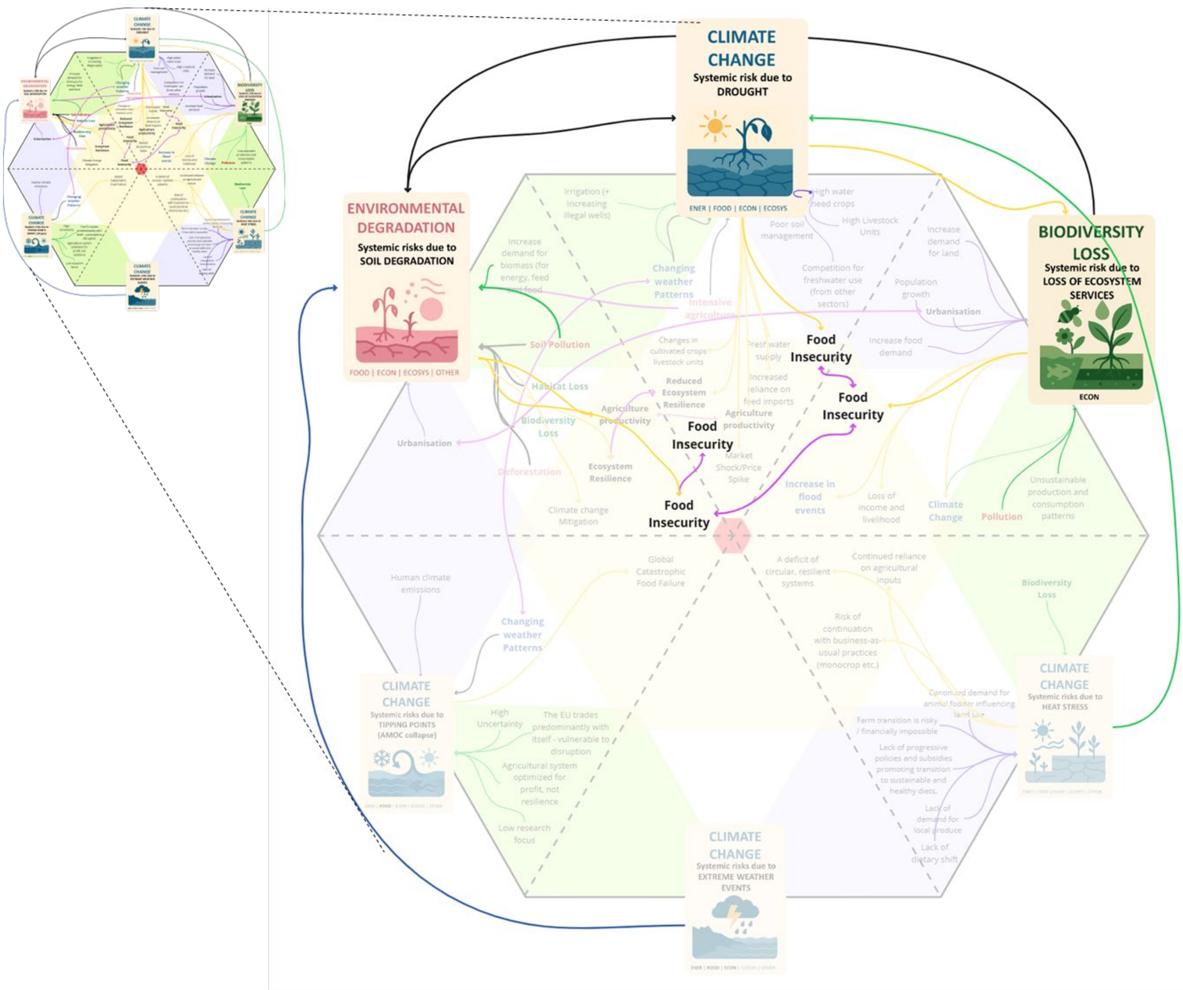

Figure 25: Author

Core message — Food security and resilience of the EU food system is increasingly threatened by compounding and cascading risks. Food security emerges as the endpoint of multiple interacting pathways, with soil degradation, drought and loss of ecosystem services acting as the most direct and structurally important hazards. Other risks, such as extreme weather, heat stress and wider climate tipping dynamics, often intensify food insecurity indirectly by worsening water scarcity, degrading ecosystems, increasing erosion, weakening pollination, disrupting production and raising prices.

Food security should not be understood as a single-sector outcome, but as the cumulative result of pressures building across soils, water, biodiversity and agricultural production systems. An interlinkage of food security across these systems is emphasised in EEA (2025f). In the network diagram, food security appeared repeatedly as the final direct or indirect impact in several pathways. It was identified as a direct impact of three priority hazards in particular — soil degradation, drought, and loss of ecosystem services — while risk drivers such as AMOC collapse, heat stress and extreme weather were more often linked through longer cascading pathways. This distinction is important: it shows that food insecurity in Europe is often produced not by one shock alone, but by the interaction of chronic environmental degradation with acute climate shocks. The interaction of environmental degradation with acute climate shocks was also emphasised recently in a European Parliament Briefing Entitled *Climate change impacts on food security in the European Union* (European Parliament, 2025).

Europe's environment is under mounting pressure from climate change, biodiversity loss, and pollution, and that nature continues to face degradation and overexploitation. The report also highlights the central role of the natural environment in securing resilience, health and prosperity. In this context, food security is best seen as a downstream resilience outcome that depends on whether ecosystems, water systems and soils can continue to support agricultural production under growing stress.

Drought is a key compounding factor because it does not act alone. EEA evidence shows that Europe is warming faster than the global average (EEA, 2025g) increasing risks to water security by exacerbating water scarcity, drought and floods (EEA 2025c). Even though water abstraction has declined, water stress still affects around 30% of Europe's land and 34% of its population, and climate change is intensifying extreme droughts and floods with knock-on effects on ecosystems, food and energy production, and human health (EEA 2025c). This means drought is both a direct production risk and a multiplier of existing weaknesses in agricultural and ecological systems.

Food-system risks intensify when drought combines with other hazards and structural vulnerabilities. Heavy rainfall after drought can generate rapid runoff and severe soil erosion, stripping topsoil and nutrients, and reducing yields. Soil degradation lowers the land's capacity to retain water during drought and increases erosion during storms. Heat and dryness increase pest and disease pressure, while high dependence on irrigation makes production especially vulnerable when water availability falls. These are classic compound mechanisms: one hazard amplifies another, and the resulting impact is greater than the sum of individual shocks.

Soil degradation is particularly significant because it both directly reduces productivity and makes the whole food system less able to absorb climatic shocks. Soil degradation is described as a complex cluster of interacting processes — including erosion, loss of soil organic carbon, compaction, salinisation, nutrient depletion and loss of soil biodiversity — that reinforce one another over time. More than 60% of soils in the EU are degraded, and 89% of agricultural land is likely affected by soil degradation processes such as erosion and carbon loss (EEA, 2025f). This means drought and extreme rainfall do not hit a neutral baseline; they hit already weakened production systems, increasing the probability of compound crop losses and longer-term declines in resilience.

Biodiversity loss and the erosion of ecosystem services are equally central because they remove the ecological buffering capacity that keeps food systems functioning under stress. The loss of ecosystem services can produce concurrent failures across pollination, water regulation, soil retention, pest control and flood protection, while pollinator decline, habitat fragmentation, pollution and landscape simplification further weaken agricultural resilience. In practice, this means drought does more damage where soils are degraded, food production is more vulnerable where pollinators and semi-natural habitats have declined, and price or supply shocks become more likely where ecosystem services have already been eroded.

This is also consistent with EEA's broader framing (by way of example see EEA 2025h and EEA, 2024e) The agency emphasises that Europe's natural systems are being destabilised by unsustainable farming, pollution, climate change and invasive species, and that restoring habitats and nature-based solutions is essential for resilience. Thus, biodiversity is not an "environmental co-benefit" separate from food security; rather, it is part of the productive infrastructure of resilient food systems. When ecosystem services decline, food security risks rise not only through lower yields, but through reduced adaptive capacity, greater exposure to future shocks and more volatile food prices.

A further vulnerability is that the current EU food system remains heavily shaped by economic incentives that prioritise short-term competitiveness over long-term resilience. As highlighted in the workshop, the system is still largely profit-driven, with competitiveness often measured in trade and economic output rather than resilience, nutritional security or ecological stability. Participants noted that subsidies and price incentives can remain misaligned, favouring carbon- and input-intensive food production rather than supporting a shift towards more resilient crops, diversified systems and lower-risk production models. This increases lock-in and makes the system more exposed to compound shocks.

There are also structural trend of simplification, intensification and concentration characterising agriculture. This matters because a more simplified system is usually less diverse, less redundant and therefore less able to cope with shocks. Specialisation in fewer crops and breeds, dependence on external inputs, and concentration in larger production units may improve efficiency under stable conditions, but they can reduce resilience under compound crises. When drought, soil degradation, pollinator loss and market disruptions occur together, highly simplified systems have fewer buffers and fewer alternatives.

This highlights why the discussion of "resilient foods" is essential. Research into crops and food sources that can perform under harsher climatic and environmental conditions — including seaweeds (FAO, 2022) and other lower-risk food groups — could strengthen food security under crisis conditions. But the benefits will only materialise if they are embedded in broader dietary, market and governance shifts. Resilience is not only about technological substitution; it also requires changes in consumption patterns, agricultural support, ecosystem restoration and risk governance.

Taken together, the evidence suggests that food security is the ultimate expression of whether Europe can manage compound environmental risk. It is threatened not only by direct yield losses from drought or degraded soils, but by reinforcing interactions among water scarcity, declining ecosystem services, biodiversity loss, pollution, pest pressure, erosion, energy costs and supply-chain disruption. In line with *Europe's environment 2025*, the challenge is therefore to move beyond siloed risk management and strengthen resilience across the entire food-water-ecosystem nexus.

Narrative 4 – Impact pathway *— Soil degradation, drought and loss of ecosystem services interact with biodiversity loss, heat stress and other climate hazards → compounded impacts on soil moisture, water availability, pollination, pest regulation, ecosystem functioning and crop productivity → reduced food production, lower food quality, and higher exposure to price and supply shocks → heightened food security risks for EU citizens, especially during crises → urgent need* *for resilient food systems that restore ecosystems, protect soils, diversify production and align incentives with long-term resilience.*

Narrative 5 - Pollution as a Systemic and Cascading Risk Driver for Nature Protection and Restoration

Figure 26: Network diagram for Narrative 5 - pollution

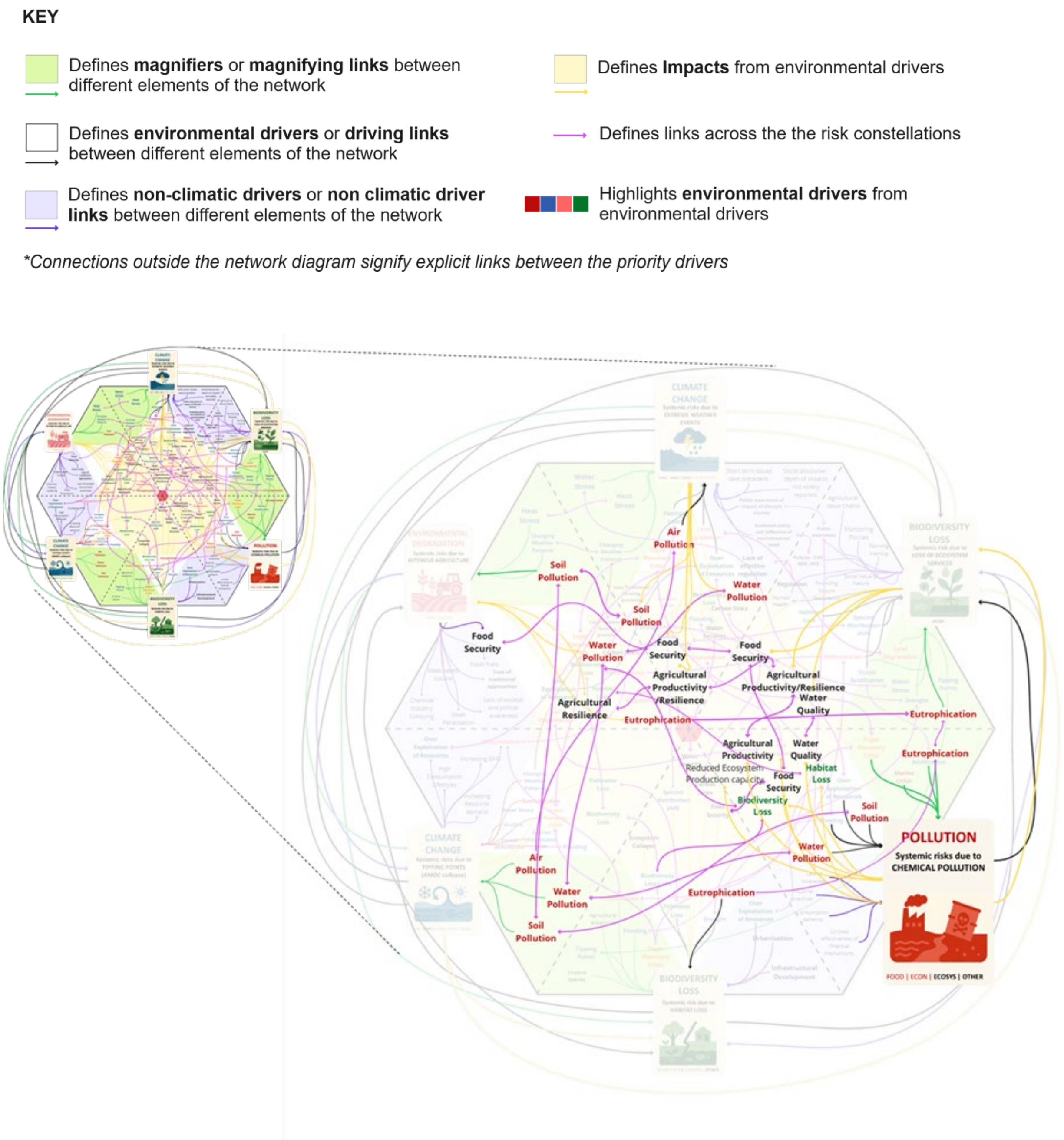

Figure 26: Author

Figure 27: Network diagram for Narrative 5 – biodiversity loss

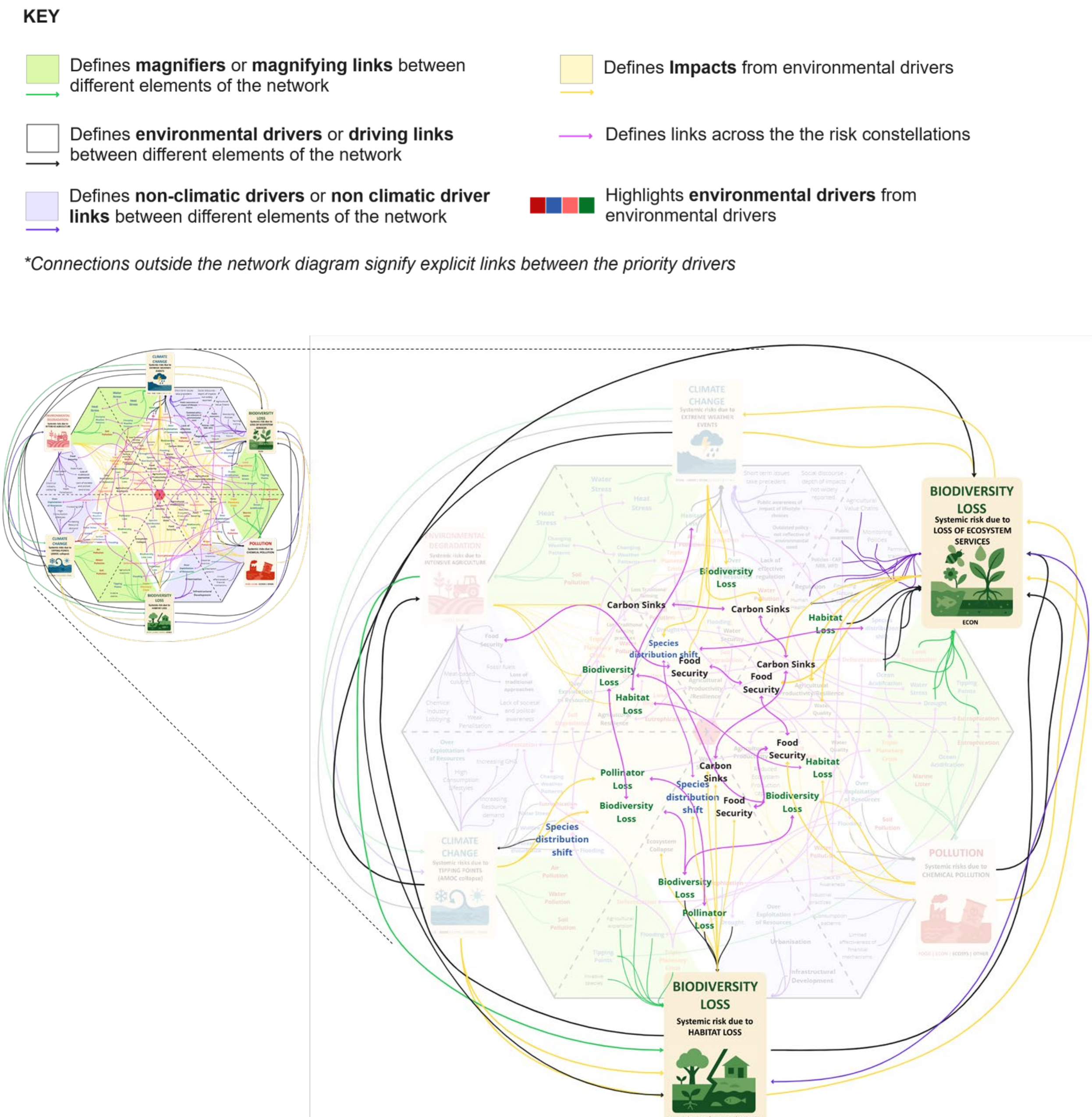

Figure 27: Author

Core Message – Chemical pollution and eutrophication are compounding systemic risks that weaken ecosystems and reduce their capacity to buffer climate, water and food shocks. They interact with biodiversity loss, habitat degradation, soil degradation, drought and intensive agriculture, creating reinforcing feedback across environmental, health and economic systems. These pressures erode ecosystem services such as water purification, soil fertility, pollination, carbon sequestration and natural pest control, with cascading effects on food security, water security and human wellbeing. Strengthening pollution prevention, resilient nature protection and ecosystem restoration is therefore essential to reduce cross-system vulnerability and long-term societal risk

Chemical pollution and eutrophication should be understood as compounding systemic risks rather than stand-alone environmental pressures. Building on the risk catalogue, pollution emerges as a risk that both originates from and intensifies other systemic pressures across ecosystems, food, water, health and the economy. Pollution moves across environmental media — from air to soil, from soil to water, and through food webs into human exposure — while also interacting with climate stress, land-use change, biodiversity loss and intensive agriculture. This is what makes it systemic: impacts do not remain contained within one sector or one medium, but accumulate, cascade and amplify across connected systems.

Several recurring compounding mechanisms stand out. Intensive agriculture is a key upstream driver because fertiliser, manure and pesticide use simultaneously increase nutrient runoff, chemical residues, air emissions and soil contamination. This produces not a single pollution outcome, but a cluster of interacting pressures: eutrophication in water bodies, toxic accumulation in soils and biota, reduced soil biodiversity, weakening of ecosystem functions, and declining food-system resilience. The same pathways also connect directly to biodiversity loss. Excessive pesticide use contributes to pollinator decline, and that the loss of pest regulation and pollination services can trigger greater dependence on chemical inputs, reinforcing the cycle of degradation.

This matters because pollution does not only damage ecosystems directly; it also accelerates habitat loss and the erosion of ecosystem services. The loss of ecosystem services and biodiversity is itself systemic, since ecological functions underpin production, food security, climate regulation and economic stability. Water purification, nutrient cycling, soil retention, pollination and carbon sequestration are all reduced when ecosystems are chronically exposed to nutrient loading, hazardous substances and land degradation. As these services deteriorate, ecosystems become less stable and less able to absorb additional shocks, increasing exposure to drought, heat, invasive species, crop loss and wider socio-economic impacts. Pollution therefore acts not only as a direct driver of harm, but also as a multiplier of biodiversity-related risks.

The compounding character of the risk becomes even stronger when climate hazards are added. The fiches indicate that droughts and low river flows increase pollutant concentrations and worsen water quality, raising the risk of eutrophication and harmful algal blooms. At the same time, more intense rainfall and flooding can increase runoff from agricultural land and wastewater systems, spreading contamination across soils and waters. Pollution, eutrophication and habitat fragmentation increase ecosystem vulnerability to drought and warming, while degraded ecosystems may lose carbon sink capacity and become less able to regulate water and temperature extremes. In this way, climate change does not merely sit alongside pollution as a parallel challenge; it amplifies pollution impacts, while pollution in turn leaves ecosystems less able to cope with heat, drought and hydrological extremes.

This compounding dynamic also explains why pollution is not only an ecosystem issue, but a cross-system resilience issue. Chemical pollution moves into food chains, drinking water, consumer products and human bodies, generating chronic health burdens and direct economic costs. The loss of ecosystem services can cascade into production shocks, asset devaluation and macroeconomic instability, while pollinator loss alone can reduce crop yields, nutritional quality and food-system resilience. Taken together, pollution, habitat loss and ecosystem service loss function as a connected risk cluster: they undermine ecological condition, reduce adaptive capacity, and transmit impacts into food security, water security, health and financial stability.

Chemical pollution, soil pollution and water pollution are not merely parallel environmental impacts: they are compounding system stressors that interact with eutrophication, biodiversity loss, habitat degradation, climate hazards and land degradation to erode ecosystem resilience over time. Their effects accumulate spatially and temporally, reduce the success of restoration efforts, and increase the probability that environmental degradation spills over into food insecurity, water insecurity, health harms and economic disruption. This is particularly important for resilient nature protection and restoration, because restoration outcomes are less likely to hold where ecosystems remain exposed to chronic pollution loads, nutrient enrichment, habitat fragmentation and chemical mixtures whose long-term effects remain uncertain.

Narrative 5 – Impact pathway *– Agricultural intensification, chemical pollution, soil pollution and water pollution act as interacting system drivers and magnifiers → nutrient loading, toxic accumulation and contamination across soils, freshwater and marine systems → eutrophication, habitat degradation, trophic disruption and biodiversity loss → declining ecosystem services, including water purification, soil fertility, pollination and natural pest control → reduced agricultural productivity, water resilience and adaptive capacity → worsening food security, water security, health outcomes and economic stability.*

4.6 An Integrated Overview Across the Narratives

This report explores five narratives across the four systems. These narratives serve as examples of how the network diagrams can be used to trace pathways through complex systems. These pathways illustrate how different environmental and non-environmental risks can interact within a system and between systems, generating compounding and cascading effects. The five narratives include:

- Narrative 1 – The combined impact of extreme weather, water stress, drought, ecosystem degradation and land use change on energy transitions.
- Narrative 2 – Cascading and compounding climate and nature risks to the European economy and financial system.
- Narrative 3 – Water resilience as key enabler for economic and financial systems.
- Narrative 4 – Compounding risks for food security, droughts, biodiversity loss and environmental degradation.
- Narrative 5 – Pollution as a systemic and cascading risk driver for nature protection and restoration

The following section briefly explores some of the similarities and differences between these narratives.

Similarities across the five narratives

First, there is a clear theme across the narratives that environmental risks rarely act alone. Every environmental risk has cascading and compounding connections with other risks. For example, the systemic risk from climate change and extreme weather creates cascading and compounding effects across different systems. *Narrative 1 – The combined impact of extreme weather, water stress, drought, ecosystem degradation and land use change on energy transitions and other systems* emphasises how extreme weather combines with drought and water stress to affect the availability of water for cooling in energy systems and damage critical infrastructure, which can result in energy price spikes. This is mirrored in *Narrative 2 – Cascading and compounding climate and nature risks to the European economy and financial system*, which highlights how water stress, combined with changing weather patterns and potential AMOC collapse, can weaken supply chains and hinder economic growth. In short, the shared environmental risk from climate change and systemic extreme weather is an example of a priority risk that affects both energy security within the Energy Transitions and Industrial Transformation system and the competitiveness and growth of the EU economy within the Resilient and Competitive Economic and Financial Systems.

Second, there is a strong focus on water and water-related environmental risks across the different systems. *Narrative 3 – Water resilience as key enabler for economic and financial systems* focuses specifically on the fact that water is not only a critical resource for society, but also a mechanism linking different drivers, impacts and magnifiers together. The importance of water is reinforced by several other narratives across the four systems, which identify water either as a critical resource or as a magnifying factor. For example, *Narrative 1 – The combined impact of extreme weather, water stress, drought, ecosystem degradation and land use change on energy transitions and other systems* highlights the role of water availability as a constraint on energy production and energy security. *Narrative 2 – Cascading and compounding climate and nature risks to the European economy and financial system* highlights how water stress drives economic and financial system risks. *Narrative 5 – Pollution as a systemic and cascading risk driver for nature protection and restoration* emphasises how water can act as an important transmitter of different types of pollution from one ecosystem to another. Understanding the availability and quality of water, as well as the dynamics of the water cycle, is therefore crucial for explaining how environmental risks interact, cascade and compound across interconnected systems.

Many of the narratives also highlight how environmental risks do not remain confined to a single sector but instead cascade across interconnected systems. For example, risks to energy systems can affect broader economic stability, while ecosystem degradation can reduce agricultural productivity and contribute to food system pressures. Finally, food security emerges repeatedly as a key outcome across several narratives, even when food systems are not the initial focus of the pathway. Climate impacts on supply chains and resources, soil degradation and drought, pollution affecting agricultural productivity, and biodiversity loss all contribute to pressures on food systems. Across these examples, food security appears as a common endpoint of multiple environmental risk pathways.

Differences across the five narratives

Several key differences also emerge across the narratives. First, each narrative begins from a different entry point within the system, including environmental risks such as extreme weather, water stress, soil degradation, pollution and biodiversity loss. While these risks operate within the same interconnected systems, they highlight different starting points for how risks can develop and propagate.

Second, the narratives emphasise different system outcomes. Some focus on risks to energy security or economic stability, while others highlight impacts on water resources, food security, ecosystem health or climate regulation. Although many of the underlying drivers overlap, each narrative prioritises a different sectoral perspective.

Third, environmental risk drivers play different roles within the pathways. In some cases, they act as primary triggers, while in others they function as magnifiers or intermediate steps within broader cascading processes. For example, *Narrative 3 – Water resilience as key enabler for economic and financial systems* highlights water as a cross-cutting connector through which multiple environmental pressures interact and propagate, while *Narrative 5 – Pollution as a systemic and cascading risk driver for nature protection and restoration* focuses more directly on pollution as a systemic driver of ecosystem degradation and wider cross-system vulnerability. The development of the network diagrams demonstrated that multiple iterations of the diagrams may be an important addition to the methodological approach. This would allow experts to reflect on what has been developed and revisit the network diagrams multiple times, resulting in a more robust and representative system network diagram.

As an additional step in developing the narratives, the systemic network diagrams were used to trace links between environmental drivers and potential governance implications. Illustrative figures are provided in **ANNEX 3**.

5. TASK 3 - IDENTIFICATION OF GOVERNANCE FRAMEWORKS AND ILLUSTRATIVE CASES THAT RESPOND TO SYSTEMIC RISKS

The last objective of the work is to identify and analyse governance frameworks and real-world case studies illustrating how transformative governance approaches can be leveraged to increase resilience to systemic risks, across different scales. To address this objective, both search and assessment criteria were defined. The full case study fiches can be found within the **ANNEX 5**. What is provided in this section is a short summary of each case study and related findings on risk governance across different risk management phases, as well as their transformative resilience ambitions (see EEA, 2024b). Figure 28 presents the workflow through which governance frameworks and transformative governance criteria were identified within the context of the project.

Figure 28: Visual workflow for the development of the case study and case study fiches.

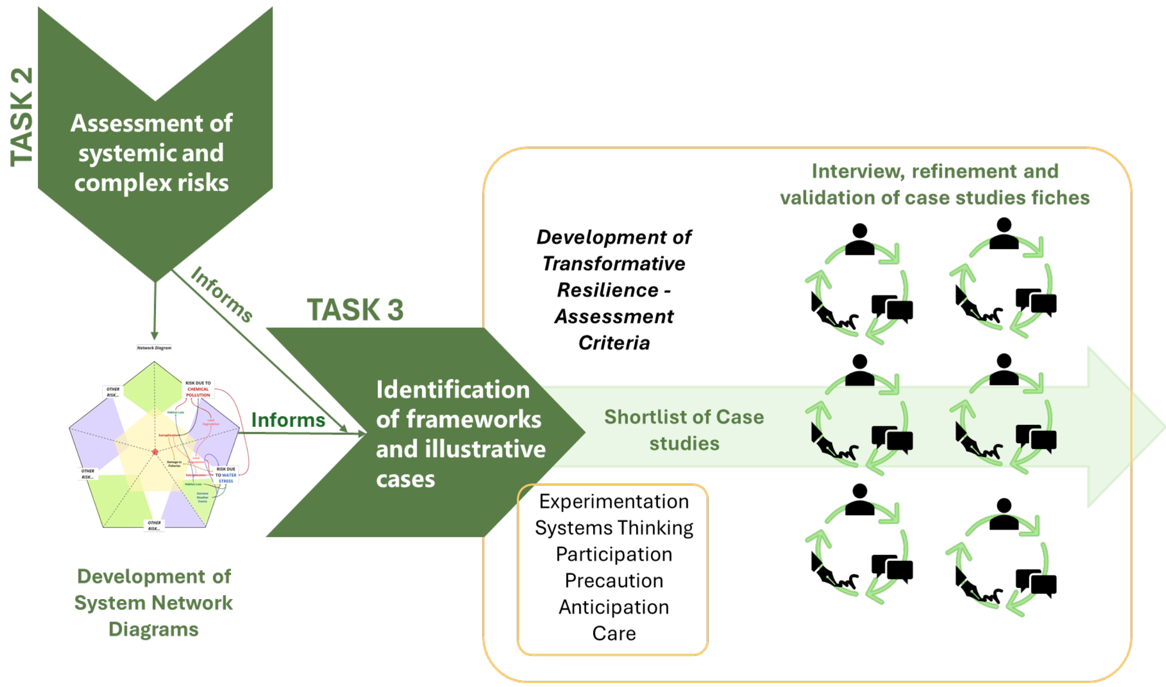

Figure 27: Author

5.1 Introduction to the assessment and selection criteria

The EEA report "*Governance in complexity: Sustainability governance under highly uncertain and complex conditions*" (EEA, 2024c) outlines the concept of governance in complexity as alternative to traditional governance models. The concept is based on our evolving understanding of sustainability. The governance in complexity approach provides a basis for dealing with complex and systemic challenges, such as those defined in section 4.5, by recognising that each of these issues has many possible framings. The report acknowledges that governance in complexity must be understood as a flexible perspective or 'frame of mind 'rather than a fixed toolkit that must be rigidly applied. Importantly, this perspective aligns strongly with the risk constellation metaphor previous defined in report (see section 4.4.1). The risk constellation metaphor allows experts to map out the different magnifiers, drivers and impacts associated with a risk at a scale that they are most comfortable with, enabling the discussion of specific risks without losing sight of the broader context.

As part of the governance in complexity perspective, the report outlined six governances in complexity principles: experimentation, systems thinking, participation, precaution, anticipation and care. The governance in complexity principles serve as a valuable starting point that can be used to assess the different case studies on their potential systemic risks. The characteristics have been outlined in Box 5 and were distilled directly from (EEA 2024c)

Box 5: Six governance principles used to analyse the transformation case studies, based on EEA's Governance in Complexity (EEA, 2024c)

Summary of Principles of Governance in Complexity

Experimentation - Transformation governance is by its nature flexible and innovative. As a result, a governance case study must have a dedicated process and resources to allow for experimentation and openness for experts to experiment.

Systems thinking - Systemic thinking refers to the understanding of interdependencies and causal pathways across disciplinary lenses. Cross-scale and cross-sector linkages should be considered, integrating diverse knowledge bases and supporting adaptive, multilevel and polycentric governance.

Participation – Participation refers to the need for broad, pluralistic, and transparent extended-peer-community participation, which is underpinned by co-design and co-creation, not only consultation.

Precaution - Precaution emphasises the need for proactive action and anticipation to prevent serious or irreversible damage and incorporates careful consideration of scientific evidence of strengths, risks, benefits, and distributional impacts.

Anticipation- Anticipation involves acting immediately based on possible futures by integrating expectations, uncertainties, and long-term impacts into decisions, aligning short-term actions with long-term goals, and informing the resources and systems (supporting capacity) needed to enable transformative change.

Care - Care involves attending to the relational, contextual, and ethical dimensions of governance, recognising the needs of humans, animals, ecosystems, and communities, and remaining responsive and adaptive amid uncertainty rather than relying solely on predefined plans.

Each of the principles introduced above was broken down into a more detailed subset of qualitative criteria for analysis. This allowed the project team to look for specific keywords, topics or references within the case study material to support the analysis of the cases. By way of example, Box 6 contains a breakdown of principle 1 - Experimentation. The full breakdown of subset of qualitative criteria can be found in **ANNEX 4.**

Box 6: An example of the subset of qualitative criteria for characteristic 1 – 'Experimentation'.

Example of the subset of qualitative criteria for governance in complexity principle - Experimentation.

Experimentation as a transversal principle - This phase looks for an inbuilt openness of the case study to embrace 'failures and opportunities to learn. Transformation governance is by its very nature flexible and innovative – therefore, the case study must have a dedicated process and resources to allow for and even facilitate this process.

Criteria 1.1 - Openness to experimentation & innovation - Explores the extent to which the case study (institution or governance process) allows, normalises, and learns from trial-and-error and innovation, including the acceptance of unplanned outcomes and potential failure.

Questions to look for:

- *Are 'failures', unintended consequences, lessons learned explicitly documented and shared*
- *Was there evidence for or a 'defined process' by which the stakeholders had the capacity to be creative and innovative?*

Potential Indicators/Sources: Project documents, internal reports, staff surveys, meeting minutes or specific reference or evidence of learning and embracing things that are unexpected. Experts can also look for an explicit document that is used to record the outcomes that may include such trials and/or failures. It could also be useful to look at the participation/co- creative processes that underpin some case studies, and these can serve as clear test beds for innovation and sharing lessons learned.

Keywords: 'failures', 'unexpected', 'lesson learned', 'recommendation' 'innovation', and 'creativity' can also be used to find this information.

Criteria 1.2 – Feedback & quality of learning - Explore whether the case study has dedicated feedback loops that can be used to facilitate iterative learning, not just isolated outcomes. Also, there is a need to check the clarity, credibility, and accountability of pathways through which participation influences outcomes, which is critical in governance of complexity.

Questions to look for:

- *Does the case study feature explicit and operational feedback loops that reinforce lessons learned from experimentation?*
- *How well (if at all) are those lessons learned integrated and considered going forward?*

Potential Indicators/Sources: Evaluation reports, policy revisions, learning repositories. The expert can also look for evidence of timely feedback loops throughout the case study's life span. Specific words such as 'feedback', 'iteration' can also help here. But the goal is to see if these aspects were indeed evident: the key is not just about recognising that things didn't go as planned but using that to inform outputs and developments going forward.

Criteria 1.3 – Institutional support & supporting capacities - Explore the extent to which the case study [re]allocates space, resources, leverages 'stranded assets thinking' and defines who is in charge for the case study in a specified timeframe. Do not look for future proofing here but instead focus on the project timeframe.

Question to look for:

- *Are there explicit resources formally allocated for experimentation in the case study?*
- *Has there been a clear reorganisation/reallocation of resources and supporting capacities to facilitate lessons learned?*
- *Has there been an assessment of 'stranded' or wasted assets?*

Potential Indicators/Sources: In this checklist we are looking to see if the case study has outlined resources allowing for experimentation, innovation, learning and applying lessons learned. Or alternatively there was evidence of the experts' reallocating resources to account for learning. Specific words that you can look for: budgets, organisational charts, strategy documents, reallocation, rethinking of resources, capacity building.

Criteria 1.4 - Shifting norms & reviewing capacities - Explore the evidence that the case study is attempting to change mindsets, norms, status quo and the political culture. It is also crucial to see if public administrators and other stakeholders possess the structures, skills, and mandates to design and sustain meaningful participation and embed what is being developed and experimented into current policy frameworks, practises or working culture.

Question to look for:

- *Are creativity and reflexive practices part of the culture within the study?*
- *Is there evidence of long-term societal behavioural change?*

- *Is there an attempt to change ingrained policy and/or practices?*

Indicators/Sources to look for: Media analysis, internal culture surveys, case studies. Also look for budgets, HR records, training logs, institutional guidelines, and legal frameworks.

The six principles, and their underlying subset of criteria, formed the basis for the evaluation of the case studies.

In selecting the six case studies, an initial pool of 22 potentially relevant case studies were identified for consideration in the report. These 22 case studies were then subjected to a shortlisting process to arrive at the final six case studies. The shortlisting process was structured as follows. First, case studies were identified through pre-existing internal databases and ongoing professional contacts with experts and policymakers working on issues related to compounding and cascading risks. This approach was intended to ensure that, for each selected case, the research team had an existing point of contact with relevant expertise, thereby increasing the likelihood of securing an interview and validating the final fiche within the project timeframe. Second, the case studies were preliminarily screened against the 'governance in complexity' criteria to identify those that aligned most strongly with the analytical framework and offered the clearest evidence of how these criteria could be operationalised in practice. Third, the cases were further shortlisted on the basis of the availability of relevant supporting material, including policy documents, news articles, blog posts, research articles, and reports, that could inform the analysis. Finally, the shortlist was refined to ensure adequate coverage of the four systems defined within the project.

To create the case study fiches, researchers conducted a desktop search of preexisting material on the case studies. This included, but was not limited to, policy documents, news articles, blog posts, research articles and reports (all of which have been included in the case study fiches as references). Using these sources as a base, the researchers created a preliminary draft of a case study fiche using a predesigned template. Developing the draft case study fiches facilitated the identification of knowledge gaps or sections of drafted fiches that lacked clarity. The knowledge gaps or unclear sections informed the development tailored questions that formed the interview guide for semi-structured interviews for each of the case studies.

Knowledge gaps and unclear information for each of the case studies was addressed through 60-minute semi structured interviews with an expert who had either worked on, or was intimately familiar with, the case study itself. During the interviews, the experts were asked the predefined tailored questions, and the responses were directly integrated into the case study fiche contents. The final case study fiches were validated by the same interviewed expert before publication.

It is important to acknowledge several limitations associated with both the case studies and the methodology. First, a substantial share of the case study material is based on secondary data collected through desk research. While the researchers sought to address this limitation by relying on credible sources and incorporating a validation step with case study experts, this remains an important caveat. Second, because each case study fiche was informed by a single expert interview, there is a potential for bias in the interview material. The following section examines the case studies in greater detail.

5.2 Overview of the six case studies and their relation to the environmental risk drivers

While the six case studies and their main characteristics are briefly outlined in this section, the full case study fiches are provided in **ANNEX 5**, and the cases are summarised in Table 3. It is important to note that these case studies should be understood as illustrative rather than representative. They are intended to demonstrate a range of transformative resilience approaches (see EEA, 2024b, Transformational Resilience Pathway 3) that align with the principles of governance in complexity, rather than to present ideal or model approaches.

As noted in Section 5.1, governance in complexity should be understood as a flexible perspective or 'frame of mind', rather than as a fixed toolkit to be applied rigidly. Accordingly, the selected case studies reflect diversity across systems, scales, countries, governance approaches, and levels of maturity. The six cases presented below are therefore not intended to be exhaustive, but rather to illustrate different governance in complexity principles, governance archetypes, and their connections to the systems and pathways assessed in the preceding chapters.

Table 3: Overview of the six case studies shortlisted and the rationale for their selection.

No.	Case Study Name and Detail	Rationale for Selection	Specific Risk Addressed
1	The Rotterdam Resilience Strategy, Rotterdam, Netherlands	This case study addresses a range of compounding environmental drivers, including sea-level rise, heatwaves, and drought, alongside important non-climatic drivers such as socioeconomic inequality. It examines the Rotterdam Resilience Strategy as an example of transformative urban resilience, with a particular focus on how the strategy seeks to strengthen institutional resilience.	The city of Rotterdam is facing a myriad of compounding risks, including rising sea level, heat waves, droughts, and socioeconomic inequality.
2	Doughnut Economics in Grenoble, France	This case study addresses key systemic environmental risks that threaten long-term urban resilience and the well-being of local populations. It examines the implementation of an innovative Doughnut Economics model, understood as a governance framework for sustainable development that aligns with Pathway 3 on transformative resilience. The model encourages an economic approach that balances social foundations, including health, equity, and well-being, with ecological ceilings and planetary boundaries.	The city of Grenoble's implementation of Doughnut Economics is designed to address key systemic environmental risks such as water stress and extreme weather events that threaten long-term urban resilience and local population well-being.

3	Energy clusters in Poland	This case study demonstrates an emerging shift in socio-technical systems, including community-owned microgrids, and new governance arrangements that support a more resilient and decentralised energy transition, particularly in contexts where institutional support has been more challenging.	The formation of the Polish energy communities serves as a multifaceted response to a contemporary "polycrisis" characterised by overlapping climate, economic, and geopolitical threats.
4	Room for River 2.0, Rijkswaterstaat, Netherlands	This case study provides a well-documented historical example of a large-scale strategy designed to enhance resilience through nature-based solutions. It demonstrates a long-term approach to investing in the sustainability and resilience of river systems, so that these vital waterways can continue to support both ecological functions and economic activity in the context of climate change.	The Room for River programme responds to flood risks due to high water levels in rivers – related to more frequent and heavier rainfall because of climate change
5	Environmental, social and economic regeneration of the Steppe Highlands in southeastern Spain (AlvelAl).	The AlVelAl case study illustrates a local example of transformation in response to systemic risks linked to environmental degradation, biodiversity loss, and climate change. At its core, it offers a valuable example of experimentation, combining collaboration, training, innovation, and financial	The Steppe Highlands region is affected by systemic risks linked to soil degradation, drought, loss of ecosystem services, heat stress, and

		support to advance regenerative agriculture and territorial restoration.	extreme weather events.
6	Ireland's Action Plan on Competitiveness and Productivity	This case study focuses on Ireland's Action Plan on Competitiveness and Productivity, a national policy instrument intended to strengthen economic resilience in a rapidly changing and uncertain global environment. Developed in response to geopolitical uncertainty, rising protectionism, and growing trade fragmentation, the plan does not address systemic environmental risk drivers directly. Nevertheless, it was included because it aligns closely with the report's broader narrative of resilience in economic and financial systems as a key enabling condition for competitiveness.	The action plan supports resilience within the current growth-oriented economic model at times of greater uncertainty. Not solely a response to environmental drivers but focuses on the security of the economic system with implications across other social and environmental drivers.

Case Study 1: The Rotterdam Resilience Strategy, Rotterdam, Netherlands

Recognised as one of Europe's most innovative cities, Rotterdam provides a compelling model of how transformative governance can address complex risks to navigate the polycrisis. The city of Rotterdam exemplifies transformative urban resilience, aligning with Pathway 3 'Transformative Resilience' (EEA, 2024b) through its Resilience Rotterdam Strategy (Rotterdam Municipality, 2022). The city of Rotterdam is facing a myriad of compounding risks, including rising sea level, heat waves, droughts, and socioeconomic inequality. The Rotterdam case aligns with the system of resilient ecosystems, nature protection, climate resilience, and restoration as sea-level rise from environmental risks are a central part of the city's resilience strategy. However, its resilience strategy goes beyond environmental risks and drivers. It adopts a systems approach to institutional resilience that connects environmental, social, and economic dimensions through the ethos of bolstering generic resilience to crises rather than specific resilience to one crisis.

Since 2016, the city has focused on strengthening institutional resilience to cross-sectoral crises, defining resilience across four characteristics: resistibility, recoverability, learning ability, and adaptability.

Central to the city's approach is institutionalised experimentation, where pilot projects, cross-sector coordination, and structured learning create a self-reinforcing ecosystem that strengthens adaptive capacity. By way of example, is the Resilient BoTu pilot, launched in 2019, which aims to support the neighbouring districts of Bospolder and Tussendijken in becoming Rotterdam's first "resilient district". The project combines transformative infrastructure investments with social programmes addressing debt, access to education, employment opportunities, and housing quality.

Complementing this, Rotterdam operationalises system thinking, making cascading risks and interdependencies visible and enabling integrated, anticipatory action. For example, resilience is structured across distinct but interconnected lenses: Climate, Ecological, Energy, Social, Economic, and Digital, with each addressing urgency, guiding policy documents, objectives, current conditions, and strategic choices. By scaling lessons city-wide and aligning local experimentation with multi-level governance, the strategy fosters long-term transformative capacity.

Participation is another core pillar, combining bottom-up engagement with top-down governance to ensure interventions are socially embedded, context-sensitive, and innovative. This is visible throughout the Rotterdam resilience strategy in which local citizens or 'Rotterdammers' are actively encouraged to participate through practical tools such as the digital platform 'My Rotterdam', which allows continuous sharing of ideas, feedback, and concerns directly with municipal authorities Furthermore, it is also important to highlight the development of a self-reinforcing "Resilient Rotterdam Ecosystem", in which knowledge development, policymaking, innovation, pilot projects, knowledge exchange, and city branding mutually reinforce one another, generating further learning and innovation. This process has contributed to the establishment of a strong and recognisable "resilient" identity among city stakeholders.

Similarly, a precautionary approach integrates structural, relational, and behavioural interventions to prepare for both known and unknown risks, embedding lessons from pilot projects through the "Resilience by Design" framework. This philosophy reflects a deep appreciation for uncertainty and the systemic nature of risk. The strategy embeds this understanding within its systems change approach, which distinguishes three levels of intervention: structural, relational, and transformative.

Finally, Rotterdam's strategy also emphasises anticipation and care: forward-looking interventions address seven crisis areas with adaptive, context-specific measures, while community-centred governance empowers residents and aligns actions with local priorities. Together, these principles enable the city to enhance its adaptive capacity, promote social legitimacy, and achieve actionable, sustainable resilience outcomes across multiple sectors. This is evident throughout the case study but is also captured in the consideration of the 'Rotterdammers' themselves: rather than imposing resilience from the top down, the approach seeks to understand and build on the capacity of communities. Initiatives such as Happy Streets address local needs while fostering well-being, social cohesion, and a sense of belonging.

Case Study 2: Doughnut Economics in Grenoble

The second case study examines the city of Grenoble, France, and its application of Doughnut Economics. Doughnut Economics is a governance framework for sustainable development that aligns with Pathway 3 transformative resilience because it is attempting to define a safe and just space by balancing social foundations (such as health, equity, and well-being) with ecological ceilings/planetary boundaries that must not be exceeded.

Grenoble adopted this framework in 2022 as the foundation of its Grenoble 2040 strategy, embedding the approach across municipal strategies, project assessment tools, and internal organisational practices. By integrating environmental risks alongside broader social and economic goals, the city uses the framework to identify trade-offs, reveal policy blind spots, and guide long-term transformation within planetary boundaries. In practice, applying the principles of Doughnut Economics across all aspects of city management has required the city to move away from conventional approaches, such as prioritising growth in gross domestic product, and to explore new governance, planning, and decision-making methods. Central to Grenoble's approach is experimentation, implemented through cross-departmental collaboration, evidence-based decision tools, and organisational practices aligned with planetary limits. By way of example, Grenoble was among the first European cities to develop a "Doughnut diagnosis" tool, which assesses the city's performance in relation to planetary boundaries. The implementation of the doughnut diagnosis was itself experimental and therefore after December 2022, when the initial diagnosis was completed, a second version was published in 2025 with updated indicators and more recent data.

This experimental governance structure embeds sustainability principles into project selection, municipal operations, and public awareness, fostering systemic and forward-looking resilience. Complementing this, the city applies systems thinking, assessing cross-sector interactions, neighbourhood inequalities, and global impacts while linking local actions with EU policy frameworks, data-driven tools, and international networks. One example of the commitment to system thinking is a "portrait" of Grenoble's 16 neighbourhoods, to reveal social and environmental inequalities, focusing on exposure (to extreme weather, pollutants, urban heat islands), accumulation (of social, economic, and environmental problems), and access (to aid, facilities, and amenities).

Participation also plays a critical role in Grenoble's governance model. The city integrates citizen engagement and co-creation into the Doughnut Economics framework through participatory workshops, budgeting initiatives, and transparent reporting processes. For example, Grenoble organised various workshops inviting citizens to reflect on what transition means and dedicate events such as the 2023, "Cities in Transition Biennial" around the theme *Révolutionnons demain* [Let's revolutionise tomorrow]. These mechanisms strengthen inclusivity, legitimacy, and collaborative decision-making while ensuring that sustainability transitions reflect local priorities.

Grenoble further reinforces resilience through precaution and anticipation, adopting adaptive governance strategies that integrate environmental, social, and economic risk management. Through foresight analysis, interdisciplinary knowledge, and cross-system planning, the city enhances its capacity to respond to both known and emerging challenges. By way of example, Grenoble's territorial resilience strategy explicitly categorises a wide range of environmental, social, and economic risks. It recognises uncertainties linked to climate change, such as heatwaves, flooding, and resource stress, as well as social vulnerabilities and economic transitions, integrating these considerations into long-term planning and policy priorities.

Finally, the case study incorporates a principle of care, embedding ethical and relational governance principles into decision-making processes. By systematically assessing trade-offs and visualising potential blind spots, Grenoble ensures that sustainability and resilience outcomes remain coordinated, equitable, and transparent across municipal systems.

Case Study 3: Energy Communities / Energy Clusters in Poland

Poland is undergoing an emerging shift in socio-technical systems, such as community-owned microgrids, to support a more resilient and decentralised energy transition. This shift responds to the systemic vulnerabilities exposed by overlapping climate, economic, and geopolitical crises. Energy communities in Poland are frameworks allowing citizens, municipalities, and businesses to collectively produce, manage, and consume energy, primarily from renewable sources. These initiatives aim to decentralise the power sector, shifting the paradigm from large-scale, state-owned monopolies to local democratic systems that prioritise social and environmental benefits over profit. Polish energy communities operate within three primary governance frameworks, each promoting different levels of decentralisation. These are Energy Clusters, Energy Cooperatives and Citizen Energy Communities.

Energy clusters, introduced in 2016, are cooperative agreements rather than formal legal entities. They operate within a limited geographical area (up to five municipalities or one county) and must include an entity linked to local government, such as a municipality or municipal company. Their main role is to coordinate regional energy generation, balancing, and demand management.

Energy cooperatives are formal legal entities based on democratic governance, following the principle of "one member, one vote." They are restricted to rural or urban–rural areas and focus on producing energy primarily for the members' own consumption. This model is well established, with over 630 cooperatives registered in Poland as of February 2026.

Citizen energy communities, introduced through the 2023 amendment to the Energy Law, have a broader scope of activities and can be established by individuals, local governments, or companies. They aim to deliver environmental, economic, and social benefits while supporting sustainable development and local energy self-sufficiency. However, unlike cooperatives, they lack dedicated financial incentives or support schemes, which has limited their uptake, with only a few registered communities as of early 2026

Together, these different governance approaches represent a gradual transition away from a highly centralised, monopoly-based energy sector towards more decentralised, socially oriented, and locally embedded energy systems. Energy communities in Poland also illustrate the role of experimentation in developing new forms of participatory energy governance. Through local initiatives and pilot projects, these communities demonstrate how decentralised energy systems can strengthen local autonomy, social cohesion, and renewable energy adoption. However, the effective scaling of these initiatives requires stronger policy support, clearer long-term strategies, and targeted capacity-building measures.

The development of these initiatives increasingly reflects systems thinking, recognising the interdependencies between energy, society, and the environment. Emerging projects incorporate broader sustainability objectives such as circular economy practices, climate resilience, air quality improvements, ecological restoration, and energy security. These initiatives are often supported through cross-sector collaboration between municipalities, universities, businesses, and local communities.

Participation is formally embedded in the governance structure of citizen energy communities, which are designed to operate through democratic and inclusive decision-making processes. Participatory workshops and capacity-building initiatives demonstrate the potential for co-design and social learning. By way of example, in Krakow, participatory workshops, commissioned by the city and led by an association CoopTechHub, were conducted, involving residents, scientists, and businesses to co-create specific models for "collective prosumers". However, in practice, participation is often constrained by technical, legal, financial, and organisational barriers, as well as lingering distrust in collective ownership and administrative complexity.

From a resilience perspective, these initiatives also reflect principles of precaution and anticipation. Decentralised energy communities can reduce vulnerability to grid failures, market volatility, and geopolitical disruptions while enhancing local energy security. National policy frameworks are increasingly recognising this role. The draft Polish National Energy and Climate Plan (NECP) identifies energy communities as a key element of the national energy transition, outlining supportive administrative and financial measures and proposing an indicative target of approximately 1,000 communities by 2030.

Finally, the development of energy communities reflects a principle of care, as these initiatives are typically structured as non-profit, democratically governed organisations designed to generate environmental, economic, and social benefits. By promoting local renewable energy production, reinvesting surpluses in community initiatives, and addressing issues such as energy poverty and local economic development, these communities aim to strengthen both social equity and energy sovereignty.

Case Study 4: Room for River 2.0, Rijkswaterstaat

The Room for River programme responds to flood risks due to high water levels in rivers – related to more frequent and heavier rainfall caused by climate change, or changes upstream that lead to higher discharges in the Netherlands. As a result, it aligns with the system of Resilient ecosystems, nature protection, climate resilience and restoration. The *Room for the River 2.0* programme is an extension of the original *Room for the River* strategy in the Netherlands, updated to reflect a changing risk context and broader long-term challenges. By investing in a sustainable, resilient future for its rivers, it aims to ensure that these vital waterways continue to serve both the environment and the economy, even in the face of a changing climate.

The Room for the River programme in the Netherlands represents a transformative shift in flood risk management from traditional infrastructure-based solutions toward an integrated, nature-based approach. Implemented between 2006 and 2015, with an extension until 2022, the programme funded 30 flood safety projects along the Dutch river system with a total budget of €2.3 billion. The initiative emerged after near-catastrophic flooding events in 1993 and 1995, when rising water levels in the Rhine and Meuse rivers forced the evacuation of around 250,000 residents and nearly one million livestock. Recognising the limits of conventional flood defences such as dikes and barriers, the programme adopted a new strategy of giving rivers more space through river widening and landscape redesign. In addition to improving flood safety, the programme introduced the enhancement of spatial quality as a second core objective, integrating environmental, social, and economic considerations into flood management. A follow-up initiative, Room for the River 2.0, is now being developed, demonstrating how long-term adaptive strategies can evolve in response to future uncertainties and emerging polycrisis dynamics.

Central to the programme's success was an emphasis on experimentation and adaptive governance. The initiative operationalised a learning-by-doing approach in which 39 projects were implemented, evaluated, and refined through continuous feedback and stakeholder engagement. By combining nature-based solutions with collaborative governance structures, the programme not only reduced flood risks but also informed broader adaptive delta management policies in the Netherlands. An example of one of these projects includes the design for lowering groynes along the Waal River, which was adjusted to improve outcomes (Zevenbergen et al., 2015) in the second iteration of the strategy.

The programme also applied strong systems thinking, integrating flood safety with wider socio-economic, ecological, and spatial objectives. Multi-level governance and participatory planning allowed for coordination across national, regional, and local scales, enabling context-specific solutions that strengthened both resilience and landscape quality.

Participation played a key role in shaping the programme's implementation. Through workshops, consultations, and decision-support tools, stakeholders—including residents, farmers, and local authorities—were involved in co-designing interventions. This participatory approach helped build trust, improve legitimacy, and ensure that solutions reflected local needs and knowledge. In fact, The Room for the River is considered the first programme in the Netherlands to adopt a multi-level governance approach in which national government agencies (notably Rijkswaterstaat, the executive agency of the Dutch Ministry of Infrastructure and Water Management), regional authorities (provinces and regional water authorities), and local governments (municipalities) actively collaborated to reduce flood risk while enhancing spatial quality. The explicit inclusion of spatial quality as a programme objective stimulated the integration of flood protection measures with local and regional investment agendas

Principles of precaution and anticipation were embedded in the programme through forward-looking climate adaptation strategies. Risk assessments, independent evaluations, and expert reviews ensured that decisions were robust under future climate scenarios. The emerging Room for the River 2.0 initiative further strengthens this anticipatory approach through long-term scenario planning, modelling, and reflexive governance aimed at guiding flood management decisions over the coming century. For example, an assessment was conducted to determine how much additional space would be required for rivers to safely carry 18,000 m^3/s of water in the future, compared to the 16,000 m^3/s capacity for which the original programme measures were designed, and what the associated costs would be. The 16,000 m^3/s target was based on extreme flood estimates at the time and corresponded to a very rare high-water event with an estimated 1-in-1,250-year probability, which was the flood protection standard then in place. However, projections indicate that climate change could increase peak river discharge to around 18,000 m^3/s by the end of the century, mainly due to more intense rainfall and reduced snow storage in the Rhine basin

Finally, the programme incorporated a principle of care by addressing societal and economic concerns alongside environmental goals. Participatory processes, compensation mechanisms for affected landowners, and comprehensive impact assessments helped balance flood safety with agricultural interests, spatial quality, and economic considerations. In doing so, the programme delivered outcomes that were not only technically effective but also socially legitimate and environmentally responsible.

Case Study 5: Environmental, Social and Economic Regeneration of the Steppe Highlands in Southeastern Spain (AlVelAl).

AlVelAl is an association established in 2015 to promote environmental, social, and economic regeneration in the Steppe Highlands of southeastern Spain. The AlVelAl case study aligns with several of the identified systemic risks from the research, particularly those related to environmental degradation, biodiversity loss, and climate change. The Steppe Highlands region is especially affected by systemic risks linked to soil degradation, drought, loss of ecosystem services, heat stress, and extreme weather events. Further compounding these challenges are a range of social and economic drivers, including depopulation and intensive agricultural practices.

The region faces challenges including desertification, biodiversity loss, depopulation, and reliance on extensive agriculture and livestock farming. AlVelAl applies the 4 Returns Framework—return of inspiration, social return, natural return, and financial return—to foster a regenerative landscape, supporting the development of a sustainable and local food system through regional farming and shorter supply chains.

Central to AlVelAl's approach is experimentation, using collaboration, training, innovation, and financial support to advance regenerative agriculture and territorial restoration. For example, a central element of their vision is a transition to regenerative agriculture, designed to improve soil health, biodiversity, water retention, and carbon sequestration. This is achieved by helping farmers access finance for implementing practices within the regenerative protocol and providing access to research and innovation projects, which typically cover the costs of practice implementation. Through engagement in projects such as Farms4Climate, Pasture+, and GOV4ALL, AlVelAl enables land managers to learn from experimentation and share experiences with other stakeholders.

The association integrates systems thinking, linking local initiatives with regional and international networks, promoting cross-disciplinary collaboration, and enhancing ecological, social, and economic resilience across the territory. For example, the association supports farmers in commercialising products and developing regenerative enterprises, which brings together over twenty producers of certified, high-quality almonds using organic regenerative agriculture.

Participation is embedded through co-created visions, inclusive engagement, and multi-level partnerships, ensuring local stakeholders have ownership and accountability in transformation efforts. A core element here is the 4 Returns Framework under which AlVelAl serves as a mechanism to bring together local farmers, conservationists, government actors, and entrepreneurs to create a shared vision for the territory. A key objective is to mobilise the local community and foster engaged citizens who contribute to revitalising the region.

Precaution is applied via adaptive learning, preventive measures, and transparent governance, reinforcing legitimacy while ensuring practices are context-sensitive and effective. AlVelAl also emphasises anticipation, developing a long-term, co-created vision for regenerative land management and socio-economic development, with adaptive management and continuous stakeholder feedback. Finally, the principle of care is central, supporting ethical governance, social inclusion, capacity-building for farmers, and responsive action that strengthens trust, legitimacy, and the overall resilience of the territory.

Case Study 6: Ireland's Action Plan on Competitiveness and Productivity.

Ireland's Action Plan on Competitiveness and Productivity is a national policy instrument designed to strengthen economic resilience in a rapidly changing and uncertain global environment. Developed in response to geopolitical uncertainty, rising protectionism, and trade fragmentation, the plan outlines 85 concrete actions, including 26 priority measures, across six key areas: productivity, international engagement, SMEs, competition, infrastructure, and sustainability. The strategy aims to make the Irish economy more shock-resistant, focusing on "controlling the controllable" and enabling timely, adaptive responses to emerging challenges.

The plan incorporates experimentation through systematic improvements in productivity, infrastructure, skills, and regulatory efficiency, while embedding learning and accountability into governance. Systems thinking is applied by linking innovation, SMEs, and sustainability to competitiveness and risk mitigation, with cross-level governance and multi-actor coordination ensuring inclusive and adaptable growth aligned with both national and European priorities. The plan also addresses institutional and systemic reforms needed to support productivity and competitiveness. Under the theme "Regulating for Growth and Controlling Costs," the Government is modernising aspects of the Irish judicial system to align with international standards. Recommendations from the 'Review of the Administration of Civil Justice Report' are being implemented, including simplifying procedural rules, accelerating case timelines, reducing litigation costs, and enhancing digitalisation.

Participation was central to the plan's development, with structured engagement across government, business, and civil society, and continuous feedback loops reinforcing legitimacy and adaptive implementation. Precaution is embedded through proactive risk management, preventive governance, and alignment of economic, environmental, and social objectives. Similarly, anticipation is integrated via strategic foresight, scenario analysis, and adaptive governance to ensure that long-term investments and policies remain coherent and resilient. Finally, the plan reflects care by incorporating bottom-up Regional Enterprise Plans, tailoring initiatives to local strengths and needs, and promoting equitable growth, innovation, and employment across Ireland's regions.

5.3 An Integrated Overview of the Case Studies

Experimentation

Success across all the case studies depends on piloting, testing, and adapting the interventions based on feedback from the stakeholders and pilot projects. The case studies demonstrated that developing an evidence base and proving that the transformation governance approach did indeed work in practice was crucial to build momentum and trust. Second, there was a clear emphasis on working across departments, agencies, and stakeholder groups that is essential for effective implementation. In fact, some cases, such as Rotterdam and Grenoble, have special cross sector departments or individuals to facilitate this process. Finally, it was essential to ensure alignment between the organisational culture and practices underpinning the experimentation, and the existing governance arrangements and practices of the local communities and organisations involved. This was crucial for securing uptake and fostering ownership of the initiatives, thereby helping to embed systemic principles into day-to-day operations and support lasting change.

System thinking

Systems thinking emerged as a fundamental feature across all the case studies, serving as a critical tool for integrating policies or pilots and enhancing the transformational resilience of communities, cities, and regions. While each case study applied systems thinking differently, common patterns and insights can be observed. For example, the Rotterdam Resilience Strategy takes a broad, institutional approach. Its primary aim is to strengthen the city's institutional resilience, under which various types of resilience such as, climate, social, ecological, infrastructural are coordinated. This thematic umbrella allows Rotterdam to address multiple interdependencies simultaneously, providing a structured framework for adaptive and multilevel governance. In contrast, the Grenoble case study illustrates a more targeted application of systems thinking. Here, the focus is on economic resilience within the context of planetary boundaries. By using a specific entry point, Grenoble aligns interventions with broader sustainability limits while still acknowledging cross-sectoral and systemic linkages.

Together, these cases demonstrate that systems thinking is not a one-size-fits-all approach. Effective application depends on aligning systemic analysis with the priorities and context of the place. Broad thematic frameworks can foster coordination across multiple dimensions, while focused entry points can guide targeted, actionable interventions. Across all examples, the recognition of interdependencies, cross-scale linkages, and adaptive governance emerges as a key lesson for driving resilient and transformative change. In some cases, dedicated experts or 'departments' operate across these sectors. However, this opens a critical discussion around capacities and expertise of these individuals (see discussion).

Participation

Stakeholder engagement was a key aspect of the transformational resilience case studies Especially participation which involved clearly defined inclusive, participatory processes. By way of example, some case studies involved the creation of engagement platforms between like-minded stakeholders, which helped to establish a collective or collaborative ecosystem. This is especially evident in the Rotterdam case study, where a "Resilient Ecosystem" developed as a spin-off from the resilience strategy. This was possible because the idea of a "Resilient Rotterdam" became a positive and widely recognised brand. The concept of resilience was one that citizens and stakeholders could support and take pride in. In turn, this strengthened motivation and encouraged investment from citizens, organisations, and communities in resilience-related pilots and projects.

Furthermore, the importance of participation was evident in both the Energy communities in Poland and the environmental, social and economic regeneration of the Steppe Highlands in southeastern Spain. In both case studies, local stakeholder groups at the community level pool resources to develop decentralised community-led entities. The difference was in the level of institutional support. Legal, institutional, and financial frameworks. Bottom-up initiatives require supportive policies and resources to scale successfully in the long term. Finally, the case studies also underscored the importance, as reflected in the experimentation principle, of aligning new approaches with existing organisational structures and embedding them in practice.

Precaution

Across the case studies, the principle of precaution is reflected in the recognition of uncertainty in the fact that the type, magnitude and severity of environmental risk drivers may evolve over time. Precaution requires explicit recognition of uncertainty and systemic risk within governance frameworks.

Taking this into account, the case studies show that precaution is most effectively operationalised when both environmental and economic risks are explicitly acknowledged and addressed through proactive (rather than reactive) policy design. For example, within the Irish Action Plan, precaution is demonstrated through the identification of structural vulnerabilities within the national economy. This includes exposure to global trade disruptions and the uncertainties associated with climate change and the energy transition. The strategy highlights the importance of anticipating these risks and responding through preventive governance measures such as strengthening regulatory frameworks, diversifying foreign direct investment sources, and expanding international market engagement.

Alternatively, the Room for the River programme in the Netherlands illustrates how precaution can be embedded in infrastructure and environmental planning. Rather than relying solely on historical flood risk estimates, the programme incorporated updated climate projections that suggested higher future river discharges. Such precautionary approaches demonstrate that proactive and forward-looking policy design such as diversifying economic systems or designing infrastructure for more extreme future scenarios can reduce long-term vulnerabilities. Planning scenarios were revised to ensure the river system could accommodate greater water volumes in the long term. Preventive measures such as expanding floodplains and creating additional retention areas demonstrate how precaution can translate into spatial interventions that increase flexibility and adaptive capacity. The Room for River programme also highlights the value of independent expert evaluation and oversight in strengthening accountability and ensuring robust decision-making under conditions of uncertainty.

Anticipation

Across the case studies, anticipation is understood as the ability of stakeholders to proactively identify potential risks and manage uncertainty. A clear theme emerges while accounting for uncertainty often addressed through precaution is essential, it remains inherently difficult to anticipate events that are completely unknown or unprecedented.

To strengthen anticipation, the case studies highlight the importance of data-driven decision-making. Continuous monitoring, evaluation, and knowledge management allow stakeholders to prioritise actions effectively and adapt as new information becomes available. By way of example, Rotterdam institutionalises learning through pilot projects such as Resilient BoTu, where lessons are scaled and integrated into the broader "Resilience by Design" framework. Similarly, Grenoble revises its knowledge base through iterative tools like the Doughnut diagnosis, updating indicators and data between its 2022 and 2025 versions. In the Room for the River programme, projects are continuously evaluated and refined, such as adjustments to groyne designs, while long-term modelling informs the evolution toward Room for the River 2.0.

Anticipation is also supported by fostering inherent resilience within systems and communities. By embedding resilience into local practices, capacities, and knowledge, stakeholders create the flexibility needed to respond effectively to unexpected challenges. Ultimately, these approaches show that anticipation is not just about predicting the future; it is about preparing systems, organisations, and communities to respond flexibly and adaptively, ensuring they are better equipped to navigate uncertainty when it arises.

Care

Across the case studies care was integrated through recognition of the needs and wants of the local communities. This was achieved through comprehensive and dedicated participation processes in which the local community members were encouraged to share experiences, insights and knowledge freely. In some cases, continuous platforms for engagement (such as online messaging services) were established. These mechanism for continuous engagement were essential to building momentum and trust between different scales of governance and stakeholders within those scales. These engagement mechanisms enable locally tailored approaches, which are essential for effective resilience. They go beyond simple participation by actively incorporating feedback to refine solutions, so they are better grounded in local contexts and realities. Examples include the Rotterdam case study, which used digital interaction platforms, and Polish energy communities, where democratically governed legal entities were established. Finally, with the in AlVelA Spanish case study in person gatherings such as the 4 Returns Framework serves as a mechanism to bring together local farmers, conservationists, government actors, and entrepreneurs to create a shared vision for the territory.

Furthermore, across all the case studies, local actions were tailored to broader strategic objectives through a bottom-up approach. The bottom-up approaches were central to the philosophy that is embodied by the governance in complexity principles. Governance in complexity must be understood as a flexible perspective or 'frame of mind 'rather than a fixed toolkit that must be rigidly applied. By taking the time to engage with and understand the needs and goals of the stakeholders on the ground, policy makers can co-design plans, polices, projects and approaches that reflect real-world conditions. These approaches can enhance local ownership and generate more context sensitive outcomes. These approaches are exemplary of the principle of 'care' as they help to bridge the gap between local insights and needs and higher-level policy ambitions. In doing so, they enhance resilience by ensuring that goals are both strategically aligned and socially grounded.

6. DISCUSSION

The following section aims to distil cross-cutting lessons, interpret their relevance for EU priorities, and were possible identify implications for policy and governance. The discussion is structured around the EU priorities of Competitiveness, Security, Preparedness and Resilience.

6.1 Competitiveness & Security

Competitiveness in the EU is increasingly framed not only in terms of productivity, innovation and growth, but also in terms of decarbonisation, reduced strategic dependencies and the capacity of core systems to remain functional under pressure. This is reflected in the Competitiveness Compass, which builds on the Draghi report and links Europe's future competitiveness to innovation, decarbonisation and greater strategic autonomy. The Clean Industrial Deal reinforces this direction by explicitly presenting decarbonisation as a driver of industrial renewal and competitiveness, while the Savings and Investments Union seek to improve the mobilisation of capital in support of the EU's competitiveness, security and green transition objectives.

Read in this context, the findings of this report suggest that environmental risk is not external to the competitiveness agenda; rather, it increasingly shapes the material conditions on which competitiveness depends. This is particularly evident in Narrative 1, which highlights the interconnections between the Energy Transition and Industrial Transformation System and the Resilient and Competitive Economic and Financial System. As the report shows, climate hazards can cascade across energy, water, land and ecosystems, directly disrupting the energy transition, degrading ecosystems, intensifying unsustainable land-use pressures and increasing economic costs. These interconnections are reinforced by the risk fiches, particularly Risk fiche 2, *Risk to economy and financial systems from loss of ecosystem services*, and Risk fiche 11, *Risk to energy transitions and industrial transformation from heat stress, water stress and drought*. Together, these findings suggest that maintaining energy and financial competitiveness cannot rely solely on technical or sector-specific adaptation responses. Instead, adaptation approaches need to account for the way in which risks can compound and cascade across systems, pointing towards integrated water-energy planning, investment in resilient and anticipatory infrastructure, and efficiency measures that reduce systemic vulnerabilities while supporting sustainable growth and industrial transition.

This systems perspective is highly relevant to current EU energy policy. The Renewable Energy Directive (RED III) provides the legal framework for scaling up renewable energy and supports the EU's 2030 renewable target of at least 42.5%, with the aspiration to reach 45%. The wider EU climate and industrial policy framework, including the EU ETS and the Clean Industrial Deal, is intended to support decarbonisation, industrial transformation and lower dependence on imported fossil fuels. Workshop participants also identified greater decentralisation as an important trend, with fossil fuels increasingly displaced by electrification and renewable energy technologies.

However, this transition should not be interpreted too simplistically. Narrative 2 demonstrates that renewable energy technologies continue to depend on ecosystem services and wider resource conditions; for example, water stress can directly affect the availability of water for cooling, while extreme weather and flooding can disrupt infrastructure and magnify wider system vulnerabilities. This is reinforced by Risk fiche 5, *Risk to energy transitions and industrial transformation from extreme weather events including flooding*, which underlines the systemic nature of these risks and the deep interdependence of modern energy infrastructure with other sectors. Thus, a more decentralised energy system does not automatically imply a more resilient or competitive one.

This tension came through clearly in the workshops. As one participant put it, the EU's transition is "like changing horses' mid-stream". This captures the scale of the challenge involved in moving away from fossil fuels while simultaneously trying to maintain affordability, reliability and competitiveness. A more decentralised and renewable-based energy system may ultimately strengthen resilience and strategic autonomy, but in the short to medium term it may also introduce new uncertainties, transition risks and governance challenges. The Polish Energy Communities case study illustrates the potential of decentralised, community-owned renewable energy structures to bolster local economies and support shorter, more secure energy supply chains, while also showing that such approaches depend on supportive governance arrangements and face constraints linked to uneven local capacity, digitalisation and funding.

A related issue is food security, which emerged in the report not as a single-sector outcome, but as the cumulative result of interacting pressures across soils, water, biodiversity and agricultural production systems. Narrative 4 makes this point explicitly; in addition, food security is directly referenced in 10 of the 20 risk fiches and indirectly linked to many more. Within the workshops, experts also highlighted a rise in adaptation thinking and the gradual entry of preparedness concerns into municipal agendas, which in turn has encouraged interest in more local and regional food systems as a way of strengthening resilience and security. In competitiveness terms, this matters because local and regional farming systems with shorter supply chains may reduce some external dependencies, even if they cannot eliminate them entirely.

This aspect of food security can be grounded most clearly in the EU's Common Agricultural Policy (CAP) and the Vision for Agriculture and Food, which followed the Strategic Dialogue on the Future of EU Agriculture. The CAP remains the EU's core framework for supporting farm income, food security, environmental protection and rural viability, while the Vision explicitly links the future of farming and food to competitiveness, attractiveness, long-term growth, innovation and food security. Read alongside the findings of this report, these policy developments suggest that food-system competitiveness cannot be reduced to output or cost alone. It also depends on the long-term viability of farming systems under climate pressure, rising production costs, water stress, ecological degradation and supply-chain disruption. In this sense, competitiveness in the food system increasingly depends on adaptive capacity, strategic autonomy and the ability to support context-specific transitions rather than one-size-fits-all solutions.

The value of the AlVelAl case study lies in demonstrating how governance-in-complexity principles can support context-specific responses to interacting risks. The case brings together environmental degradation, biodiversity loss, soil degradation, drought, loss of ecosystem services, heat stress and extreme weather, alongside social and economic pressures such as depopulation and intensive agricultural practices. Its relevance to competitiveness and security lies in showing that more localised and resilient farming systems depend not only on technical measures, but also on trust, local ownership and governance arrangements capable of aligning higher-level objectives with the realities faced by communities on the ground.

Taken together, these findings suggest that EU competitiveness and security should be understood not only in terms of industrial productivity or cost reduction, but also in terms of the capacity of interconnected systems to remain functional under interacting environmental and geopolitical pressures. This report therefore surfaces an important systemic dimension to the EU competitiveness agenda: it suggests that decarbonisation, strategic autonomy and long-term competitiveness will increasingly depend on whether environmental interdependencies are governed more coherently across energy, finance, ecosystems and food systems. **The main governance priority is therefore to address environmental dependencies more explicitly within industrial, energy and food-system policies to reduce structural vulnerabilities over time.**

6.2 Resilience

The EU Adaptation Strategy (2021) aims to strengthen the EU's resilience through smarter, faster, and more systemic adaptation. It focuses on reducing climate risks, protecting critical resources such as water, and integrating climate resilience across sectors by supporting local action and nature-based solutions. Building on this, the integrated framework for European Climate Resilience and Risk Management is being developed to translate these principles into concrete actions. The framework aims to strengthen resilience while supporting Europe's security, competitiveness, and prosperity, with stakeholders highlighting the need for harmonised climate risk assessments, nature-based solutions, and stable long-term adaptation funding.

The concept of resilience has become a central concern in the EU policy agenda. However, in practice, resilience is no longer only about helping individual sectors cope better with shocks. It increasingly depends on whether policy can recognise how risks move across systems and how vulnerabilities in one area can weaken others, making them difficult to address through siloed responses alone. Read in this context, the findings of this report support a more systems-based understanding of resilience, in which energy, finance, ecosystems and food systems need to be considered together rather than in isolation. This reflects the systems thinking principle within the EEA's governance in complexity framework, which emphasises the need to understand sustainability challenges in terms of interconnections, feedback and cross-system effects (EEA, 2024c). This in turn implies that resilience policy must be designed to strengthen coordination and adaptive capacity across systems, not simply within them.

Across the four systems, risks do not remain neatly contained within administrative or sectoral boundaries. Instead, they interact through shared drivers, amplifiers and dependencies, producing compounding and cascading effects. Water is a particularly clear example. It appears throughout the report not only as a resource under pressure, but also as a transmission pathway through which impacts spread across energy generation, food production, ecosystems and wider socio-economic systems. This is reflected most clearly in Narrative 3 – Water resilience as key enabler for economic and financial systems, which presents water as a cross-cutting connector through which multiple environmental pressures interact and propagate, and in Narrative 5 – Pollution as a systemic and cascading risk driver for nature protection and restoration, which shows how pollution can degrade ecosystems while also amplifying wider cross-system vulnerability. The same is true of ecosystem services, which are often treated as environmental outcomes but, in reality, function as enabling conditions for resilience in the other systems. This suggests that resilience is not simply a matter of adding more resilience measures within each sector; it also requires a better understanding of how systems are connected, where vulnerabilities accumulate, and how interventions in one area may create co-benefits or trade-offs elsewhere. Thus, the implication is that institutions need stronger mechanisms for cross-system coordination and shared problem-solving where risks cut across established mandates.

This perspective is increasingly relevant to current EU policy developments. The Nature Restoration Regulation is particularly important here, as it sets binding targets to restore degraded ecosystems, especially those with the greatest potential to capture and store carbon and to prevent or reduce the impacts of natural disasters. The Water Resilience Strategy points in a similar direction, treating water not only as an environmental concern but as a foundation for economic stability, climate adaptation and societal wellbeing. Read alongside the findings of this report, both instruments reinforce the need to see restoration, water retention and ecosystem condition as central components of resilience, rather than as secondary environmental objectives. This applies to the Carbon Removal and Carbon Farming Certification Framework (CRCF), which points to a related governance challenge: how to ensure that incentives for land-based climate action are designed in ways that also support biodiversity, ecosystem services and wider resilience, rather than creating new trade-offs.

This challenge is also visible in the energy system. The wider EU transition framework emphasises renewables, electrification and reduced dependence on imported fossil fuels. However, this report demonstrates that resilience in the energy system cannot be understood only in terms of supply diversification, infrastructure build-out or technological flexibility. Energy systems remain dependent on land, water and ecosystem conditions, and they are increasingly exposed to heat stress, drought, flooding and wider environmental degradation. This means that strengthening resilience in the energy transition requires more than scaling up infrastructure; it also requires planning for resource constraints, ecosystem dependencies and cross-system disruption.

Food systems fit this logic as well, but here the policy emphasis should be slightly different from the competitiveness discussion. From a resilience perspective, the question is not primarily whether the CAP supports productivity or strategic autonomy, but whether governance arrangements support the adaptive capacity of farming systems under stress. The report points to a set of pressures that make this especially important: climate-related yield variability, water scarcity, ecological degradation, rising costs and structural dependencies in supply chains. This is consistent with Narrative 4 – Compounding risks for food security: droughts, biodiversity loss and environmental degradation, which shows that food security is best understood as a downstream resilience outcome shaped by interacting pressures across soils, water, biodiversity and agricultural production systems.

In this context, the relevance of agricultural policy lies in whether it helps farming systems cope with repeated shocks, adapt over time and avoid becoming more vulnerable in the long run. This makes resilience in food systems less a question of short-term support alone and more one of long-term system reconfiguration. However, such reconfiguration is inherently challenging when the EU's main policy instrument for the food system (the CAP) operates through seven-year funding cycles, which can make it challenging to adjust iteratively to emerging risks and changing conditions. A key governance challenge, therefore, is how to invest in long-term system reconfiguration within policy structures that may not always be designed for iterative adaptation.

This report links this systems perspective to governance capacity. Applying these kinds of approaches alongside climate risk assessments could help move policy discussions from lists of priority risk drivers towards a better understanding of cascading and compounding effects. But this also requires institutional conditions that are often missing: stable long-term funding, professional capacity, and governance structures that allow experts to work across departmental boundaries. Thus, resilience is not only about the design of individual measures, but also about whether institutions have the support, space and skillset needed to engage meaningfully with systemic risk. The Room for the River case study demonstrates how long-term flood management can shift from reactive protection towards more integrated spatial and ecological approaches. The Rotterdam case study similarly demonstrates the value of institutionalised systems thinking, practical learning, and capacity-building within governance structures. The Grenoble case is also useful here, particularly in showing how local government can use a cross-sector framework to reveal trade-offs, identify blind spots and connect environmental risks with wider social and economic priorities. Together, these cases suggest that resilience is built across systems when governance is able to work across sectors, engage with uncertainty and support context-specific responses over time.

Taken together, the findings of the report suggest that resilience in the EU context should be understood less as the capacity of individual sectors to "bounce back" and more as the ability of interconnected systems to remain functional, adapt and reorganise under pressure. Future EU resilience efforts should be assessed not only by the number of resilience measures adopted, but also to the extent that they reduce structural vulnerability, improve coordination across systems and strengthen the institutional capacity to deal with complexity before risks become more difficult to manage. Thus, **a governance priority is therefore to strengthen cross-system institutional adaptive capacity and coordination, while also investing in the longer-term reconfiguration of systems that are currently locked into structural vulnerability.**

6.3 Preparedness

Preparedness is becoming a more explicit objective in EU policymaking. The Preparedness Union Strategy frames this around an integrated all-hazards approach, stronger anticipation, and a "preparedness by design" culture, supported by whole-of-government and whole-of-society approaches. The strategy sets out 30 key actions for 2025–2027 and is intended to strengthen the EU's civilian and military readiness for future crises. Read in this context, the findings of this report suggest that preparedness for systemic environmental risk cannot be understood only as emergency response or contingency planning aftershocks occur. Rather, it depends on whether institutions are able to anticipate how risks interact across systems, identify vulnerabilities before they become entrenched, and act early enough to reduce the likelihood of cascading disruption.

This is where the report's methodological contribution is most relevant. The use of risk constellations and system network diagrams helps shift the discussion from isolated priority risks towards the connections between them. Environmental risks rarely materialise in isolation. They interact through shared drivers, amplifiers and dependencies, producing knock-on effects across energy, food, ecosystems, finance and wider society. In this sense, preparedness depends not only on identifying high-priority risks, but also on understanding how they may combine, propagate and reinforce one another across systems. The narratives from this report support this directly: across several pathways, risks originating in energy, water, pollution or ecosystem degradation do not remain within one system, but cascade into broader economic pressures and food-security outcomes. The value of these tools lies precisely in making complex interdependencies more visible and therefore more actionable for preparedness policy.

The report also points to an important capacity challenge. Applying these kinds of approaches alongside national climate risk assessments could help move policy discussions beyond lists of individual hazards towards a better understanding of compounding and cascading risk. However, this requires more than new analytical tools. It also requires professional capacity, institutional support, and the time and space for experts to work across departmental boundaries. Preparedness for systemic risk depends on whether officials and practitioners have the skills, experience and support needed to engage with complex interdependencies and communicate them meaningfully across sectors. Stable long-term funding, training, simulation exercises and dedicated cross-sector structures are therefore not peripheral issues; they are part of the institutional foundations of preparedness. Anticipatory governance therefore depends not only on foresight, but on the professional and organisational capacities needed to use it in practice.

A further issue raised by the report is that of risk ownership. Preparedness becomes much more challenging when responsibility for monitoring, managing and mitigating systemic risks is diffuse or unclear. This is especially true where risks cross sectoral mandates, governance levels or traditional policy boundaries. Clarifying risk ownership therefore does not mean assigning a single owner to each risk, but rather ensuring that responsibilities for monitoring key variables, coordinating action, and responding to emerging signals are sufficiently clear. In the context of systemic environmental risk, this may require more explicit arrangements for shared ownership, joint monitoring and cross-sector coordination, particularly where one system's risks are transmitted through another. This is particularly relevant in light of Narrative 3, which shows that water functions not only as a resource under pressure, but also as a cross-cutting connector through which multiple environmental pressures interact and propagate, making it difficult for preparedness planning to remain sector-specific. This is a practical governance issue, not only a conceptual one, and it highlights the need for clearer operational arrangements for anticipatory action.

Preparedness policy is particularly challenging where risks are nonlinear, highly interconnected and subject to deep uncertainty. Once risks become systemic and embedded across sectors, the scope for effective intervention narrows. This makes anticipatory governance especially important. It also reinforces the need to track key risk variables, update assumptions and remain open to the possibility that conditions underpinning current systems may no longer hold under growing environmental stress.

This is closely related to the issue of tipping points. Tipping points create a distinctive preparedness challenge because they are not simply larger versions of familiar risks. They involve thresholds beyond which change may become abrupt, self-reinforcing and difficult to reverse. The *Global Tipping Points Report* (2025) argues that climate tipping points are interconnected and that destabilisation in one system can increase the likelihood of destabilisation in others. The narratives in this report illustrate why this matters for preparedness: environmental pressures can propagate through shared resources and dependencies. Narrative 4 demonstrates that food insecurity is often produced not by one shock alone, but by the interaction of chronic environmental degradation with acute climate pressures such as drought. This compounding dynamic that becomes more challenging to manage where thresholds are approached or crossed.

For preparedness, the implication is clear: policy cannot rely only on historical baselines or gradualist assumptions. It also needs to grapple with the possibility of discontinuity, irreversibility and escalating cascade effects across ecological and social systems. That is precisely where early warning, precaution and stronger anticipatory governance become most important.

A further challenge, which the report captures, is what might be called a complexity ceiling. As systems become more interconnected, it becomes harder for institutions and experts to stabilise them under stress, and more difficult to maintain a clear overview of how risks interact. This does not mean that complexity cannot be governed, but it does mean that preparedness tools need to be usable in practice. The value of the constellation approach used in this report is that it helps break complexity into manageable configurations without losing sight of the wider system. For preparedness policymaking, institutions need approaches that are sophisticated enough to capture interdependence, but practical enough to support action before crises escalate. This reinforces the need to invest in methods and tools that make complexity manageable for decision-makers, rather than simply documenting it.

The case studies also help to illustrate what preparedness looks like in practice, without being treated as models to be replicated. *Room for the River* is particularly relevant here, as it reflects a precautionary approach to flood risk that moves beyond reactive protection and instead plans for future climatic conditions through anticipatory spatial and water management. The Rotterdam case similarly highlights the role of institutional preparedness, showing how resilience-oriented governance can help embed longer-term risk awareness into strategic planning and urban decision-making. At a different scale, the AlVelAl case demonstrates that preparedness also depends on local capacity, trust and the ability of communities to respond early to interacting environmental pressures before they intensify.

The findings of the report suggest that preparedness for systemic environmental risk should be understood as a governance capacity built on anticipation, coordination, institutional support and the ability to develop context-specific actions under conditions of uncertainty. While resilience is about whether systems can continue to function and adapt under pressure; preparedness is about whether governance arrangements, capacities and responsibilities are in place before disruption escalates. Preparedness in the face of systemic environmental risk depends not only on better risk information, but also on clearer ownership, stronger professional capacity, more practical ways of navigating complexity, and a greater willingness to act before risks become harder to manage. **The main governance priority is therefore to strengthen anticipatory governance capacities and to develop practical methods and tools that help institutions understand, coordinate and respond to systemic and complex risks before they escalate.**

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8. ANNEX

8.1 Annex 1 – Risk Fiches

Risk ID: Risk_01

Risk to ecosystems, and human systems including food and energy security, health, and economic stability from the Atlantic meridional overturning circulation (AMOC) collapse

Systems affected: MULTI; ECON; FOOD; ECOSYS; ENER

The collapse of the Atlantic Meridional Overturning Circulation (AMOC) is increasingly recognised as a major security threat and a security blindspot to Europe (JRC, 2025b). Current modelling work indicates that a substantial weakening, or, in the worst case, an abrupt shutdown, would produce pronounced cooling across large parts of Europe. It would substantially alter atmospheric circulation patterns, leading to major shifts in precipitation. While regional outcomes remain uncertain, simulations suggest much drier conditions in parts of Europe relative to previous projections. A rapid AMOC decline would also raise regional sea levels along the Atlantic coast of Europe due the dynamic ocean-circulation effects. Northern Europe, which is currently planning for continued warming and increased precipitation, would instead need to adapt to sharp cooling and altered hydrological patters, with potential reversal of long-established climate trends. An AMOC collapse would likely generate long-term cascading and compound multi-hazard impacts acroos coupled human-natural systems. These include profound stresses on food security with risk of a global catastrophic food failure. Widespread cooling would increase energy demand for heating while changes in precipitation patterns could impair energy generation. Such changes would heighten pressure on on communities through impacts on food, water availabiliy, infrastructre and economic stability (University of Exter, 2023; Westcombe et al., 2025).

There is high uncertainty regarding the precise timing, likelihood, and full consequences of a potential AMOC collapse. However, scientific assessments consistenly show that if such a tipping event were to occur the resulting impacts would propagate through highly interconnected global systems. These cross-sectoral and transboundary effects could trigger subsequent failures and reinforce negative feedbacks across multiple connected natural and human systems.

Drivers:

Primary environmental driver: climate change	**Primary environmental driver (subcategory):** tipping points (AMOC collapse)	**Other environmental drivers:**
Non-environmental drivers (STE(E)PV): (T) Path dependence / lock-in hinder decarbonisation efforts; (P) Lack of appropriate governance framewors / preparedness for tipping points scenarios (JRC 2025)		

Pathways:

Direct pathways:	**Indirect pathways:**
• Reduced northward heat transport --> Rapid cooling over the Northern Hemisphere --> Disruption of agriculture and energy systems; • Changes in ocean circulation --> Dynamic sea level rise --> Impacts on coastal infrastructure and communities.	• Large-scale climatic shifts--> Global reductions in food production --> Heightened risk of a global food security crisis • Coastal inundation --> Damage to critical infrastructure --> Cascading economic losses • Reduced water availablity --> Intensifed water scarcity --> Potential for conflict and health emergencies • Reversal of regional climate trends --> Breakdown of existing adaptation strategies --> financial destabilisation (University of Exeter, 2023)

Unequal exposure and impacts (risk inequalities):

• Western and Northern Europe are projected to experience the strongest cooling by changing weather patterns; while North Atlantic coastlines faced pronounced dynamic sea-level rise (University of Exeter, 2023);

• AMOC collapse is simulated to change patterns of precipitation and water availability worldwide, with reduced annual mean precipitation in Europe, northern South America, central Africa and southern Asia, and increased annual mean precipitation in southern North America, north-eastern South America, southern Africa and western Australia (University of Exeter, 2023)

• These changes would drive major disruptions in precipitation patterns and significantly affect vegetation and crop productivity worldwide, with some regions seeing sharp declines and others experiencing increases.

• Sectoral exposure: agriculture/food production predicted to be hit in a catastrophic way with Europe predicted to be particularly impacted (Wescombe et. al., 2025);

• Energy sector in Northern hemisphere economies would face increased heating demand, with studies suggesting increases in heating energy consumption of 10–20 per cent in the UK and Europe (University of Exeter, 2023);

Magnitude, likelihood and uncertainty:

Magnitude of impact (category): Catastrophic	**Magnitude basis:** University of Exeter

	(2023) [Global Tipping Points Report]
Likelihood: The AMOC is very likely to weaken over the 21st century for all considered scenarios (high confidence), however an abrupt collapse is not expected before 2100 (medium confidence).	**Likelihood basis:** (IPCC, 2023)

Uncertainty: The AMOC is very likely to weaken over the 21st century for all considered scenarios (high confidence), however an abrupt collapse before 2100 is not expected (medium confidence) (IPCC, 2023)

• Deep uncertainty: neither the probability of an event nor its impacts (i.e., harm) can be adequately expressed in terms of economic costs or other quantitative measures (University of Exeter, 2023)

• Knowledge gaps incl. lack of data (AMOC monitoring only since 2004) (University of Exeter, 2023)

• Driver complexity; model uncertainty; scenario uncertainty

Timing:

Onset: sudden

Time horizon: uncertain

Duration: chronic

Trend: increasing

Geography:

Geographic scale: global

Geographic contexts: all: coastal; urban/peri-urban; mountain; river basin; islands; arid/semi-arid; Arctic; alpine; forest; agricultural

Interlinkages:

Interlinkages to other systemic risks (shared risk pathways):
Risk_02: Risk to economy and financial systems from loss of ecosystem services; Risk_05: Risk to energy transitions and industrial transformation from extreme weather events including flooding ; Risk_10: Risk to human health from climate change ; Risk_15: Risk to wellbeing, health and mental health from biodiversity loss / loss of nature; Risk_18: Risk to economy and financial systems from changing weather patterns, water stress and drought ; Risk_19: Risk to economy

from extreme weather events incl. flooding ; Risk_20: Risk to energy transitions and industrial transformation from soil degradation and loss of ecosystem services

Cascading & compounding mechanism(s):
The collapse of the AMOC, a major climate tipping element, would severely disrupt global atmospheric and ocaanic circulation, driving abrupt changes in temperature and precipitation patters. These shift would result in direct and cascading impacts on food systems including dramatic reduction in crop productivity and widespread ecosystem disruption, with modelling studies indicating a potetial global catastrophic food failure (Wescombe et. al., 2025). The resulting resource scarcity and environmental destabilisation would cascade into societal and economic systems, increasing the likelihood of negative social tipping points (University of Exeter, 2023). An AMOC collapse would also interact with other Earth system tipping points, amplifying risks through creating tipping cascades (University of Exeter, 2023)

Examples / case studies:

References:
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Risk ID: Risk_02

Risk to economy and financial systems from loss of ecosystem services

Systems affected: ECON

The loss of ecosystem services is widely recognised as one of the most severe long-term threats to human well-being. Consequently, it also poses a significant systemic risk to the European economy and to the financial stability of countries, institutions, and businesses. The European Central Bank estimated in 2023 that 75% corporate loans in the EURO area have a strong dependency on at least one ecosystem service (ECB, 2023). Ecosystem services underpin production and consumption processes across virtually all sectors, yet their continued provision is increasingly jeopardised by environmental degradation and biodiversity loss. Because ecosystem services are diverse, interconnected, and often invisible within traditional economic metrics, the dependencies of societies and markets on them are frequently underestimated. The Integrated Natural Capital Accounting (INCA) project, accounting ecosystem services in the EU, estimated that in 2019, 10 ecosystem services in the EU28 generated a total annual flow of benefits worth €234 billion. Many global supply chains, business models, and financial assets ultimately rely on ecological functions that are difficult to trace or quantify. Moreover, ecological systems are non-linear and dynamic: the loss of a single service can trigger feedback loops that degrade other services, producing far-reaching and sometimes unpredictable disruptions.

As a result, the global degradation of ecosystem services can produce cascading effects throughout the European economy and financial system, including production shocks, asset devaluation, stranded natural-capital-dependent assets, and increased volatility in markets. This systemic nature of ecological risk means that the erosion of ecosystem services can propagate across regions and sectors, ultimately threatening macroeconomic stability.

Drivers:

Primary environmental driver: biodiversity loss	**Primary environmental driver (subcategory):** loss of ecosystem services	**Other environmental drivers:** environmental degradation
Non-environmental drivers (STE(E)PV): (S) low awareness on society's dependence on ecosystem services; (T) technological lock-ins of nature intensive production systems; (Econ) Undervaluation of ecosystem services, short term profit orientation; global supply chain dependence on ecosystem services; (P) weak environmental laws enforcement and governance, lack of integration of nature related risk in finance; political instability or corruption; harmful subsidies; short term political cycles; (V) preference for economic growth		

Pathways:

Direct pathways:	**Indirect pathways:**
• River flooding (loss of flood protection services) --> inundation of settlements, deterioration of assets, --> negative impacts	• Loss of water provision --> curtailments in electricity generation --> reductions in power availability (Mediterranean Region and

on financial performance of firms, risk premium charged on interest rates on loans to SMEs exposed to high flood risk • Loss of soil retention --> reduction of essential soil nutrients in top soil --> reduced crop yields or areas becoming unsuitable for agriculture, higher fertiliser costs --> loss of productivity for agricultural firms, higher production costs • Loss of pollination services --> decreased crop yields --> higher production costs --> increased consumer prices • Loss of access to nature --> mental health issues --> rising burden on mental healthcare system --> economic impacts	Western Europe) --> impact on SMEs (higher financial fragility than bigger businesses), businesses • Loss of soil retention --> impact on supply chain linkages --> direct impacts on EU area economy (loans) (ECB, 2024) • Loss of ecosystem services (eg. flood protection) --> increased infrastucture damage and repair costs --> lack of cash or easily-convertible-to-cash assets across businesses or financial institutions, lack of liquidity --> growing insurance costs and increasing number of uninsurable assets - unstability of economic system (Sanchez Garcia et al, 2025)

Unequal exposure and impacts (risk inequalities):

• By sector in the EU : agriculture, forestry and fishing most affected, Manufacturing, Wholesale and retail trade too (higest materiality dependency scores) (ECB, 2023) • By country: biggest economic losses in Germany because manufacturing sector is dependent on biodversity (ECB, 2024) • Banks with lower capital most exposed to biodiversity risks (ECB, 2024)

Magnitude, likelihood and uncertainty:

Magnitude (limited; critical/substantial; catastrophic): critical/substantial to catastrophic.	**Magnitude basis:** literature
Likelihood (unlikely; about as likely as not (33-66%); likely): likely.	**Likelihood basis:** peer-reviewed literature, grey literature
Confidence levels (high / medium / low) and sources of uncertainty: High confidence • 'An increasing number of studies highlight the growing consensus among central banks and supervisors that nature-related risks could have significant macroeconomic implications and, if ignored, could lead to financial stability implications (ECB, 2023). • However, the literature also points out the lack of studies on the dependency of financial systems and businesses on Ecosystem services, underlining a research blindspot.	

• High confidence that the impacts of ecosystem services will be high on the economy, but the quantification of this impact is difficult to predict (interrelated and dynamic systems). The quantification of ES loss may be outside of business' capacities to monitor. The ES they benefit from may not be under their direct control (La Notte et al, 2025). In addition, the loss of ecosystem services is categorised as 'difficult to foresee', in the sense that it is difficult to assess the probability that a certain consequence will occur at a specific time / place / condition (JRC, 2025).

Timing:

Onset: gradual

Time horizon: already occuring

Duration: chronic

Trend: increasing

Geography:

Geographic scale: global

Geographic contexts: all: coastal; urban/peri-urban; mountain; river basin; islands; arid/semi-arid; Arctic; alpine; forest; agricultural

Interlinkages:

Interlinkages to other systemic risks (shared risk pathways):
Risk_01: Risk to ecosystems, and human systems including food and energy security, health, and economic stability from the Atlantic meridional overturning circulation (AMOC) collapse; Risk_04: Risk to ecosystems from intensive agriculture and soil degradation ; Risk_05: Risk to energy transitions and industrial transformation from extreme weather events including flooding ; Risk_06: Risk to resilient ecosystems, nature protection, climate resilience and restoration from hot and dry weather (heat stress, drought, wildfire); Risk_07: Risk to food systems from extreme weather events (incl. drought, water stress and heat stress); Risk_08: Risk to food systems from pollinator loss; Risk_10: Risk to human health from climate change ; Risk_14: Risk to health, economy, wellbeing from chemical pollution; Risk_15: Risk to wellbeing, health and mental health from biodiversity loss / loss of nature; Risk_16: Risk to marine food systems from overfishing and invasive alien species; Risk_17: Risk to resilient ecosystems, nature protection, climate resilience and restoration from biodiversity loss; Risk_18: Risk to economy and financial systems from changing weather patterns, water stress and drought ; Risk_19: Risk to economy from extreme weather events incl. flooding ; Risk_20: Risk to energy transitions and industrial transformation from soil degradation and loss of ecosystem services

Cascading & compounding mechanism(s):

- Cascading hazards: biodiversity loss triggering multiple secondary hazards (eg : mangrove erosion triggering loss of coastal protection, triggering collapse of nearshore habitats…

- Concurrent hazards : biodiversity loss coinciding with other hazards : loss of multiple ecosystem services at once.

Examples / case studies:

75% of all corporate loan exposures in the euro area have a strong dependency on at least one ecosystem service (ECB, 2023)

References:

JRC (2024a). European SMEs' exposure to ecosystems and natural hazards: A first exploration. JRC Publications Repository. https://publications.jrc.ec.europa.eu/repository/handle/JRC136901; JRC (2025a). The EU economy's dependency on nature. JRC Publications Repository. https://publications.jrc.ec.europa.eu/repository/handle/JRC140003; Network for Greening the Financial System. (2024). Nature-related Financial Risks: A Conceptual Framework to Guide Action by Central Banks and Supervisors [Technical document]. https://www.ngfs.net/en/publications-reports/nature-related-financial-risks-conceptual-framework;European Central Bank. (2023). Living in a World of Disappearing Nature: Physical Risk and the Implications for Financial Stability. SSRN Electronic Journal. https://doi.org/10.2139/ssrn.4630721;European Central Bank (2024). Economic and financial impacts of nature degradation and biodiversity loss. https://www.ecb.europa.eu/press/economic-bulletin/articles/2024/html/ecb.ebart202406_02~ae87ac450e.en.html; Sánchez-García, P. A., Galaz, V., Rocha, J. C., & Barbour, F. (2025). Climate change, nature degradation, and financial stability: A review of domino-effects between finance, climate, and the biosphere. Ecology and Society, 30(2). https://doi.org/10.5751/ES-16130-300236; La Notte, A., Marques, A., Petracco, M., Paracchini, M. L., Zurbaran-Nucci, M., Grammatikopoulou, I., & Tamborra, M. (2025). The assessment of nature-related risks: From ecosystem services vulnerability to economic exposure and financial disclosures. Ecological Economics, 235, 108636. https://doi.org/10.1016/j.ecolecon.2025.108636; JRC (2025). Analysis of Risks Europe is Facing: An Analysis of Current and Emerging Risks (No. EUR 40352). European Commission, Joint Research Centre. https://doi.org/10.2760/0176850

Risk ID: Risk_03

Risk to food systems from soil degradation

Systems affected: FOOD

Soil degradation reduces the capacity of land to sustain crop production and undermines the resilience of food systems. It includes nutrient imbalances, acidification, loss of soil organic carbon, erosion, compaction, salinisation, declines in soil biodiversity, and soil sealing: processes that increasingly interact and reinforce each other. These dynamics make soil degradation a highly complex risk driver: deterioration in one property (e.g. organic carbon loss) can accelerate others (e.g. erosion or nutrient loss), creating cascading impacts on crop yields, input needs, and long-term land productivity. Soil degradation affects European food systems both directly and indirectly: within the EU it diminishes agricultural productivity, while worldwide land degradation disrupts global food supply chains, which in turn negatively impacts the EU. The dependence of the EU on agri-food imports is clear: in 2023, the EU27 imported €158.6 billion's worth of agri-food goods from all corners of the globe, which represent just under 10% of total EU food consumption expenditure (DG AGRI, 2024).

Degraded soils are more vulnerable to climate change and climate extremes, heightening the effects of existing threats. The impacts are already substantial: more than 60% of soils in the EU are degraded (EEA & JRC, 2024). In the EU, data show that 89% of the agricultural area in Europe is likely to have its soil degraded by processes such as soil erosion and loss of soil organic carbon (EEA, 2025- state of environment). Unsustainable soil erosion rates affect 25% of EU's agricultural soils, with 7% of agricultural soils suffering from extreme erosion (Panagos et al, 2020).The associated cost of productivity loss in the EU is estimated at EUR 1.2 billion per year (Panagos et al., 2018).

Drivers:

<table>
<tr><td>Primary environmental driver:
environmental degradation</td><td>Primary environmental driver (subcategory):
soil degradation</td><td>Other environmental drivers:
Climate change and extreme weather events</td></tr>
<tr><td colspan="3">Non-environmental drivers (STE(E)PV): (S) population pressure on land can lead to overuse of soil; limited training on soil health and sustainable practices can lead to soil degradation; (T) dependency on intensive agriculture may mask soil degradation until it becomes severe, increasing systemic risk; (Econ) market volatility and global competition increase pressure towards use of intensive agriculture; (P) poor enforcement of land use regulation can lead to over exploitation, same for weak and misaligned agricultural policies; (V) consumer values favouring unsustainable diets and inability to change</td></tr>
</table>

Pathways:

Direct pathways:	**Indirect pathways:**
• heavy machinery, intensive tillage --> break down of soil aggregates, reduced soil porosity --> compaction --> reduced water availability,	• Agriculture intensification, pollution --> loss of soil biodiversity, loss of ecosystem services (carbon sequestration, water filtration, pest

reduction of crop growth (root gowth hampered), reduced productivity (by 10-15%), reduced fertility • Heavy Phosphorus input --> cadmium pollution --> contamination of food products • Fungicide treatments --> high copper concentrations (pollution) • Intense tillage, overgrazing, monoculture, improper irrigation practices --> displacement of soil, weakened soil structure --> soil erosion, including removal of topsoil, rich in organic matter --> loss of soil fertility, loss of nutrients (including P) --> lower yields , soils may become uncultivatable, soil inundation • Agriculture-induced sallinisation (Med region) (poorly managed irrigation) --> Reduced yields • Acidification --> reduced nutrient availability (especially calcium, phosphore, Mg, K) --> reduction of primary productivity	regulation) --> reduced agricultural productivity • Agricultural intensification (intensive use of chemical pesticides, simplification of agricultural landscapes) --> loss of pollinators --> decreased agricultural yields (70% of major food crops are dependent on animal pollination)

Unequal exposure and impacts (risk inequalities):

• Sallinisation of soil is acute in the Mediterranean Region. • The Mediterranean Region is particularly affected, compared to the rest of the EU, because of combined high pressure from other drivers (rapid land use change, socio economic activities, climate change) (Ferreira et al, 2022) • About 8.2% of Europeans experience food insecurity, with disadvantaged groups and populations in Eastern Europe most affected. These groups are also the most vulnerable to any further soil degradation (European Parliament, 2025).

Magnitude, likelihood and uncertainty:

Magnitude (limited; critical/substantial; catastrophic): Critical soil erosion is unlikely to remain stable, projected increase of 13-22.5% by 2050. Soil erosion responsible for reduction in global agri-food production of 33.7 M tons annually. In the EU, soil erosion rates	**Magnitude basis:** peer-reviewed literature

of 24% per year exceed the rate of soil renewal through weathering and pedogenesis (Panagos et al, 2015)	
Likelihood (unlikely; about as likely as not (33-66%); likely): likely	**Likelihood basis:** peer-reviewed literature
Confidence levels (high / medium / low) and sources of uncertainty: High confidence (EEA & JRC, 2024). Comprehensive, large scale assessments of soil pollution are scarce.	

Timing:

Onset: gradual **Time horizon:** already occuring **Duration:** chronic **Trend:** increasing

Geography:

Geographic scale: global **Geographic contexts:** agricultural

Interlinkages:

Interlinkages to other systemic risks (shared risk pathways): Risk_04: Risk to ecosystems from intensive agriculture and soil degradation ; Risk_09: Risk to ecosystems from pollution and eutrophication ; Risk_13: Risk to food systems from pollution (general, antibiotics, soil, water, chemicals); Risk_14: Risk to health, economy, wellbeing from chemical pollution **Cascading & compounding mechanism(s):** Intricate connections between soil degradation processes in Europe: chemical pollution exacerbates existing threats (soil erosion, etc); loss of soil carbon contributes to loss of soil biodiversity, which further degrades soil health; soil erosion creates nutrient loss which requires the need for more chemical inputs , which leads to further soil degradation, etc.

Examples / case studies:

References:

Panagos et al, (2020) A Soil Erosion Indicator for Supporting Agricultural, Environmental and Climate Policies in the European Union; Panagos et al, 2018; DG AGRI (2024) EU agri-food trade achieved a record surplus in 2023;

IPBES (2025). Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. IPBES secretariat, Bonn, Germany. 1144 pages. ISBN: 978-3-947851-20-1 ; EEA & JRC (2024). The state of soils in Europe. JRC Publications Repository. https://doi.org/10.2760/7007291; EEA (2022). Rethinking agriculture. https://www.EEAeuropa.eu; European Parliament. (2025). Climate change impacts on food security in the European Union. Members' Research Service.

Risk ID: Risk_04

Risk to ecosystems from intensive agriculture and soil degradation

Systems affected: ECOSYS

Soil degradation covers a wide range of issues including nutrient imbalances, acidification, loss of organic carbon, erosion, compaction, salinisation, declining soil biodiversity, and soil sealing, many of which increasingly interact and reinforce one another. Intensive agriculture in the EU one is of the main drivers of soil degradation and subsequent loss of below- and above-ground biodiversity, representing 21% of all reported pressures for habitats and species (EEA, 2025d). In addition, almost 50% of all pressures related to pollution can be attributed to air, water and soil pollution caused by agriculture. Two-thirds of the EU's semi-natural habitats dependent on agricultural management are classified as in 'bad' conservation status by the EEA (EEA, 2025d). Indeed, farmlands are the most extensive habitat for biodiversity in Europe, harbouring, for example more than one half (250 species) of European bird species, of which 50% are either threatened or have suffered steep population declines (42% decline between 1990 and 2023) (EEA, 2025d).

The degradation of soil biodiversity impairs ecosystem processes, such as decomposition, pollination, and pest regulation, creating cascading effects across landscapes. Collectively, these dynamics lead to habitat fragmentation, declining species richness, and altered ecosystem functioning, ultimately reducing the stability and adaptability of natural systems.

Drivers:

Primary environmental driver: environmental degradation	**Primary environmental driver (subcategory):** soil degradation	**Other environmental drivers:** climate change, land use and land cover change,
Non-environmental drivers (STE(E)PV): (S) population pressure drives demand for land and overexploitation; (T) dependence of global agricultural systems on high technology equipment (chemical inputs, heavy machinery, monoculture), driving intensification; (Econ) global market demand for feed crops (soy, palm, oil, corn...) leading to intensive agriculture; externalised degradation costs not borne by producers and consumers; low economic valution of ecosystem services; (P) Environmental regulations not enforced, inadequate or misaligned governance, EU Policies driving agricultural intensification; (V) strong dependence on conventional farming practices		

Pathways:

Direct pathways:	**Indirect pathways:**
• Excessive N in soils - soil acidification - alteration of the composition of plant communities (acid sensitive ones) - reduction of biodiversity	• Excessive use of P fertilisers, fungicides --> heavy metals and other soils pollutants --> water pollution --> impact on biodiversity • soil erosion --> loss of nutrients --> decreases soil ability to store carbon, nutrients,

• Excessive use of P fertilisers, fungicides --> heavy metals and other soils pollutants --> biodiversity impacts (microbial communities in soils) • Excessive use of chemical pesticides --> negative impact on pollinators --> loss of biodiversity • Drainage of organic soils due to agricultural activities --> degradation of peatlands --> disruption of ecosystems , and impacts on rare and specialised species --> shifts in vegetation composition, overall loss of biodiversity • Drainage of organic soils --> loss of water flow regulation --> reduction of water quality (nutrient run-off, contamination from agricultural chemicals...) --> impact on aquatic ecosystems • Poor land management practices (inappropriate tillage, monocultures, overgrazing) --> disturbance of soil structure --> soil erosion --> loss of nutrients and fertility --> loss of soil biodiversity and loss of terrestrial biodiversity • agriculture-induced Sallinisation, poor drainage --> desertification (Med region) • heavy machinery, intensive tillage --> break down of soil aggregates, reduced soil porosity --> compaction --> reduced water availability, reduced fertility and nutrient uptake by plants	water --> decreases soil ability to provide habitat for soil organisms, purify water --> loss of biodiversity • Spread of IAS via disturbed soils --> loss of biodiversity

Unequal exposure and impacts (risk inequalities):

Mediterranean ecosystems (and communities dependent on them) face disproportionate impacts (higher susceptibility to erosion, salinisation and organic carbon loss) (Ferreira et al, 2022).

Magnitude, likelihood and uncertainty:

Magnitude (limited; critical/substantial; catastrophic): crtitical (short/medium term) to catastrophic (long term) Expansion of global cropland by about 20% by 2050, taking into account combined effect of climate change (IPBES, 2019). BAU would result In further conversion of more than 50% of natural habitats to croplands. Fertiliser use is expected to increase by 58% by 2050. " A continued and focused reliance on land clearing, intensive use of agrochemicals and homogenization of crop diversity to maximize productivity will continue to degrade the underlying biodiversity and regulating services upon which agriculture depends, as well as failing to deliver nutritious food" IPBES, 2019	**Magnitude basis:** peer-reviewed literature
Likelihood (unlikely; about as likely as not (33-66%); likely): likely	**Likelihood basis:** peer-reviewed literature
Confidence levels (high / medium / low) and sources of uncertainty: High confidence	

Timing:

Onset: gradual **Time horizon:** already occuring **Duration:** chronic **Trend:** increasing

Geography:

Geographic scale: gradual **Geographic contexts:** all

Interlinkages:

Interlinkages to other systemic risks (shared risk pathways): Risk_02: Risk to economy and financial systems from loss of ecosystem services; Risk_03: Risk to food systems from soil degradation; Risk_06: Risk to resilient ecosystems, nature protection, climate resilience and restoration from hot and dry weather (heat stress, drought, wildfire); Risk_08: Risk to food systems from pollinator loss; Risk_09: Risk to ecosystems from pollution and eutrophication ; Risk_13: Risk to food systems from pollution (general, antibiotics, soil, water,

chemicals); Risk_14: Risk to health, economy, wellbeing from chemical pollution; Risk_15: Risk to wellbeing, health and mental health from biodiversity loss / loss of nature; Risk_16: Risk to marine food systems from overfishing and invasive alien species; Risk_17: Risk to resilient ecosystems, nature protection, climate resilience and restoration from biodiversity loss

Cascading & compounding mechanism(s):
Excessive use of pesticides creates loss of pollinators and farmland birds - a loss of pest control service creates need for more chemical inputs/fungicides, which exacerbates pressures on biodiversity.

Examples / case studies:

References:
Ferreira et. al. (2022) Soil degradation in the European Mediterranean region: Processes, status and consequences ; EEA & JRC (2024). The state of soils in Europe. JRC Publications Repository. https://doi.org/10.2760/7007291; EEA (2022). Rethinking agriculture. https://www.EEAeuropa.eu/en/analysis/publications/rethinking-agriculture;La Notte, A., Marques, A., Petracco, M., Paracchini, M. L., Zurbaran-Nucci, M., Grammatikopoulou, I., & Tamborra, M. (2025). The assessment of nature-related risks: From ecosystem services vulnerability to economic exposure and financial disclosures. Ecological Economics, 235, 108636. https://doi.org/10.1016/j.ecolecon.2025.108636; EEA (2023). The importance of restoring nature in Europe. https://www.EEAeuropa.eu/en/analysis/publications/the-importance-of-restoring-nature-in-europe; United Nations Office for Disaster Risk Reduction (UNDRR). (2024). Nature for Resilience: Policy Brief. UN Office for Disaster Risk Reduction. https://www.undrr.org, IPBES (2019). Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. IPBES secretariat, Bonn, Germany. 1144 pages. ISBN: 978-3-947851-20-1 ; Emmerson, Morales, Oñate, & Batáry. (2016). How Agricultural Intensification Affects Biodiversity and Ecosystem Services. In Advances in Ecological Research (Vol. 55, pp. 43–97). Academic Press. https://doi.org/10.1016/bs.aecr.2016.08

Risk ID: Risk_05

Risk to energy transitions and industrial transformation from extreme weather events including flooding

Systems affected: ENER

The reliability and resilience of energy systems are increasingly threatened by the rising frequency and severity of climate events such as floods, storms, heatwaves, and droughts. These events can damage physical infrastructure, disrupt supply chains, and challenge overall system stability. The transition to a highly renewable, climate-dependent energy system introduces new risks due to increased system complexity. Climate-related hazards are expected to increase the challenges of this transition. There is a concern that the climate risk profile for future renewable energy systems might exceed that of fossil-based systems unless robust risk-reducing strategies are implemented (Aall et al., 2025).

The risk to energy transitions from extreme weather, including flooding, is fundamentally systemic due to the inherent complexity and interdependence of modern energy infrastructure and its deep connections to other sectors (Seshadri et al., 2025). The energy system is becoming highly interconnected, consisting of numerous new and untested technological combinations (Seshadri et al., 2025). The problem is compounded by the fact that much of Europe's critical infrastructure base is ageing and suffering from existing failures, representing an "adaptation deficit" even before considering future climate change impacts (EEA, 2024). Energy system failures cascade to nearly all aspects of society (EEA, 2024).

Drivers:

Primary environmental driver: climate change	**Primary environmental driver (subcategory):** extreme weather events, flooding	**Other environmental drivers:** environmental degrdation - loss of ecosystem services affects the severity of flooding impacts
Non-environmental drivers (STE(E)PV): (S) Urbanisation and settlement patterns (JRC, 2025) (S/P) levels of public awareness and preparedness; (T/P) Lack of appropriate integration of hydrological forecasting and monitoring systems in planning for energy infrastructure; (T/Econ) inflexible demand/consumption patterns can increase vulnerability. (S) poverty and socio-economic vulnerability drive unequal impacts - vulnerable groups more affected by outages or rising costs during extreme events. (EEA, 2025a)		

Pathways:

Direct pathways:	**Indirect pathways:**
• River flooding --> Inundation of assets located in flood plains --> damage to energy transportation/storage infrastructure	• Flooding causes physical damage to power infrastructure --> Power outages quickly spread across interconnected networks,

• coastal flooding (sea level rise/storm surges) --> inundation and erosion of facilities located in low-elevation coastal areas --> Physical damage to coastal energy facilities and disruption of cooling water flows at coastal power plants • extreme rainfall --> overburdening and failure of urban drainage --> surface runoff --> damage to urban drainage infrastructure, underground infrastructure, and electricity substations • flood / storm events --> direct physical impact (e.g. water pressure, debris carried by the flood) --> damage to renewable energy sources, e.g. solar farm • windstorms / high wind speed --> Damage to energy distribution lines and transmission towers --> blackouts	affecting systems reliant on electricity --> disruption of essential services • Flooding causes major damage to critical infrastructure (energy, transport) --> Large, uninsured losses necessitate high government expenditure / reduced tax revenue --> financial instability and reduced adaptive capacity • Extreme weather events outside Europe --> disrupted global supply chains --> Shortages of critical raw materials or components needed for green technologies

Unequal exposure and impacts (risk inequalities):

• Income/socio-economic status: low-income households have reduced adaptive capacity and are more sensitive to possible energy price increases; risk of widening insurance protection gap (EEA, 2024) • Urban areas: flooding risks are worsened in cities by soil sealing from urban expansion and inadequate or outdated stormwater infrastructure (EEA, 2024) • Southern Europe is particularly susceptible to the impacts that extreme weather events pose to Europe's built environment and critical infrastructure (EEA, 2025a). • EU Outermost Regions are identified as hotspots due to their remote location, weaker infrastructure, and limited economic diversification. They are highly vulnerable to specific hazards like tropical cyclones and sea level rise (EEA, 2024)

Magnitude, likelihood and uncertainty:

Magnitude (limited; critical/substantial; catastrophic): Substantial (current/near-term) to critical (mid and long term) for risk of energy disruption due to damage to energy transportation or storage infrastructure following coastal or inland flooding	**Magnitude basis:** (EEA, 2024)

Likelihood (unlikely; about as likely as not (33-66%); likely): likely	**Likelihood basis:** (EEA, 2024)
Confidence levels (high / medium / low) and sources of uncertainty: Medium for risk of energy disruption due to damage to energy transportation or storage infrastructure following coastal or inland flooding (EEA, 2024) Evidence on climate impacts on Europe's energy system is strong, but uncertainty remains for regional drivers such as drought and wind, and is compounded by rapid energy system transformation. Impacts are expected to be most adverse in southern Europe, while northern and central regions may experience mixed effects (EEA, 2024).	

Timing:

Onset: sudden (for individual events) **Time horizon:** already occuring; increasing significantly by 2050 and further by 2100 (EEA, 2024 - EUCRA) **Duration:** acute **Trend:** increasing

Geography:

Geographic scale: Global + EU-wide; type of impacts vary across EU (e.g. more exposure to heat/drought impacts in Southern Europe - see Risk_Fiche_11; coastal areas and certain part of Europe more exposed to flooding (both coastal and inland with differing patterns) - c.f (EEA, 2024) **Geographic contexts:** coastal and urban and peri-urban areas particularly exposed (EEA, 2024)

Interlinkages:

Interlinkages to other systemic risks (shared risk pathways): Risk_01: Risk to ecosystems, and human systems including food and energy security, health, and economic stability from the Atlantic meridional overturning circulation (AMOC) collapse; Risk_02: Risk to economy and financial systems from loss of ecosystem services; Risk_10: Risk to human health from climate change ; Risk_11: Risk to energy transitions and industrial transformation from heat stress, water stress and drought; Risk_19: Risk to economy from extreme weather events incl. flooding ; Risk_20: Risk to energy transitions and industrial transformation from soil degradation and loss of ecosystem services **Cascading & compounding mechanism(s):** • Compounding mechanisms (for impact of flooding): landslides, heatwave and droughts; infrastructure failure (JRC (2025)

- The transition to a highly renewable, climate-dependent system inherently increases its exposure to weather events (sun, wind, precipitation) compared to fossil energy (Aall et. al. 2025)
- Amplifying risks within the energy sector (e.g., damage from flooding or drought) can erode financial stability, hindering the net-zero transition (Seshadri et. ael., 2025).
- Dunkelflauten (Dark Doldrums): This is a concrete example of a compound weather event particularly relevant to renewable energy systems. These conditions, often associated with a stationary high-pressure system lead to negative anomalies in wind speed (e.g., over the North Sea) and negative anomalies in solar radiation (e.g., over the Iberian Peninsula) at the same time. This concurrence happens during cold conditions when energy demand is high, causing high energy shortfalls due to little available wind and solar power supply. European countries are exposed to more than two winter energy compound events per year (Aall et. al. 2025)

Multi-driver compounding: risks are compounded when extreme weather events, such as flooding, interact with the long-term alteration of renewable resource patterns (e.g., reduced streamflow for hydropower) (Aall et. al. 2025)

Examples / case studies:
The 2021 Texas winter blackout illustrates how cascading failures across a tightly coupled, weather-exposed energy system can lead to widespread and prolonged outages, underscoring the need to integrate both climate hazard and system vulnerability into p

References:
EEA (2025a). Renewables, electrification and flexibility—For a competitive EU energy system transformation by 2030 (No. EEA report 16/2024). https://www.EEAeuropa.eu/en/analysis/publications/renewables-electrification-and-flexibility-for-a-competitive-eu-energy-system;

JRC (2025). Analysis of Risks Europe is Facing: An Analysis of Current and Emerging Risks (No. EUR 40352). European Commission, Joint Research Centre. https://doi.org/10.2760/0176850

EEA (2024). European climate risk assessment. Publications Office. https://data.europa.eu/doi/10.2800/8671471

Seshadri, A. K., Gambhir, A., & Debnath, R. (2025). Navigating systemic risks in low-carbon energy transitions in an era of global polycrisis. Global Sustainability, 8, e6. https://doi.org/10.1017/sus.2025.7

Aall, C., Chang, M., Elliot, T., Holm, T. B., Løkke, S., Mati, A., Mayer, S., & Skov, I. R. (2025). Overlooked climate risks in the ongoing renewable energy transitions. Energy, 335, 137986. https://doi.org/10.1016/j.energy.2025.137986

Risk ID: Risk_06

Risk to resilient ecosystems, nature protection, climate resilience and restoration from hot and dry weather (heat stress, drought, wildfire)

Systems affected: ECOSYS

The impacts of hot and dry weather hazards on ecosystems have a significant risk multiplier effect: ecosystems provide essential services such as water purification, flood mitigation, and carbon storage; when they fail, crises cascade across food and water security, health, infrastructure, and the economy. European Climate Risk Assessment (EUCRA) identifies ecosystems as the policy area with the most risks requiring urgent or additional action. Although EU awareness is high and many policies exist, major gaps remain. These stem from ecosystems' multiple, sometimes competing roles, and sectoral management approaches that create incoherence, reduce effectiveness, and can worsen biodiversity loss or miss co-benefits (EEA, 2024)

Hot and dry weather typically involves multiple hazards occurring simultaneously or consecutively, leading to combined impacts greater than the sum of their individual effects. Events like the 2022 compound drought and heatwaves caused about EUR 40 billion in losses (EEA, 2024). Pollution, poor water management, land-use pressures, and inequalities further increase ecosystem vulnerability, making them prone to systemic failure under heat or drought. Resulting impacts form complex cascading chains, including positive climate feedbacks from lost carbon sinks, disruptions to critical infrastructure and energy, and significant health risks.

Drivers:

Primary environmental driver: climate change	**Primary environmental driver (subcategory):** heat stress, drought, wildfire	**Other environmental drivers:** environmental degradation
Non-environmental drivers (STE(E)PV): (S) Human action/ignition for wildfires (JRC, 2024); Urbanisation (JRC, 2025); (Econ) unsustainable resource extraction / harvesting (EEA, 2024); Agriculture - unsustainable irrigation practices (EEA, 2024); (P) Unsustainable land use and management (EEA, 2024)		

Pathways:

Direct pathways:	**Indirect pathways:**
• Warming --> shifts the timing of species' life-history events (phenology), alters species and community dynamics, and changes ecological processes and ecosystem functioning (EEA, 2024) • Increases in temperature --> opportunities for colonisation by invasive non-native species (EEA 2024b)	• Longer dry periods --> lower river flows, reduced groundwater recharge and aquifer depletion --> reduced water quality, increasing risk of eutrophication and harmful algal blooms --> impact on aquatic and terrestrial ecosystems --> impact on food systems(e.g. contaminated fish / seafood) (EEA, 2024b)

• Extreme heat in combination with prolonged drought --> direct impacts on ecosystems (EEA, 2024) • Water stress --> reduced size of wetlands --> direct decrease in habitat provision and ecosystem services (EEA 2024b) • Wildfire --> biomass carbon loss, tree mortality (EEA, 2024)	• Drought/wildfire --> tree mortality/biomass and soil carbon loss from fires, pests, and heat stress --> Forests switch from being a carbon sink to a net source of Greenhouse Gas (GHG) emissions --> acceleration of climate change (EEA, 2024; JRC, 2025) • Wildfires --> loss of vegetation cover --> increased soil erosion and landslides --> damage to downstream infrastructure

Unequal exposure and impacts (risk inequalities):

• Southern Europe is especially exposed to risks from heat and prolonged drought (EEA, 2024) • "In rural areas, individuals and communities who are more reliant on ecosystem services are more affected by climate-induced disruptions of these services. In urban areas, vulnerable groups usually benefit from services provided by urban green spaces, but the neighbourhoods with less and lower quality green spaces are typically found in communities of lower socio-economic status, overlapping with and exacerbating pre-existing vulnerabilities. Traditional lifestyles closely dependent on ecosystems are also at risk. With a clear hot spot in northern regions, Europe's indigenous Sámi people are witnessing threats to cultural and traditional livelihood practices, such as fishing and reindeer-herding activities" (EEA, 2024);

Magnitude, likelihood and uncertainty:

Magnitude (limited; critical/substantial; catastrophic): • Substantial (current/near term) to catastrophic (long term) for risk to biodiversity and carbon sinks from increased frequency and intensity of wildfires. • Substantial to critical for risk to aquatic and wetland ecosystems and their services due to reduction of low flow in rivers	**Magnitude basis:** (EEA, 2024)
Likelihood (unlikely; about as likely as not (33-66%); likely): likely	**Likelihood basis:** (EEA, 2024)
Confidence levels (high / medium / low) and sources of uncertainty: High (in the current/near term) to medium in the mid and long term (EEA, 2024). Overall confidence is high that climate change is a direct and significant driver of biodiversity loss in Europe’s terrestrial and freshwater ecosystems, although impacts are highly context-specific across regions and taxa. Strong evidence shows that climate change alters species phenology, distributions, interactions, and ecosystem functioning, while important knowledge gaps remain on physiological responses and adaptive capacity, even as projections indicate increasingly negative impacts across European ecosystems (EEA, 2024).	

Timing:

Onset: gradual

Time horizon: already occuring

Duration: chronic

Trend: increasing

Geography:

Geographic scale: EU-wide but Southern Europe particularly afftected by heat and prolonged drought (EEA, 2024); EU Outermost Regions (OMRs) are designated as hotspots for multiple climate risks. Wildfires are a threat, and ecosystems face critical risks from ocean warming and marine heatwaves (EEA, 2024).

Geographic contexts: all

Interlinkages:

Interlinkages to other systemic risks (shared risk pathways):
Risk_02: Risk to economy and financial systems from loss of ecosystem services; Risk_04: Risk to ecosystems from intensive agriculture and soil degradation ; Risk_07: Risk to food systems from extreme weather events (incl. drought, water stress and heat stress); Risk_08: Risk to food systems from pollinator loss; Risk_11: Risk to energy transitions and industrial transformation from heat stress, water stress and drought; Risk_14: Risk to health, economy, wellbeing from chemical pollution; Risk_15: Risk to wellbeing, health and mental health from biodiversity loss / loss of nature; Risk_16: Risk to marine food systems from overfishing and invasive alien species; Risk_17: Risk to resilient ecosystems, nature protection, climate resilience and restoration from biodiversity loss; Risk_18: Risk to economy and financial systems from changing weather patterns, water stress and drought

Cascading & compounding mechanism(s):

- Compound relationships exist between heatwaves, drought, wildfires and storms, floods and landslides (JRC, 2025)

- Pollution, eutrophication and habitat fragmentation severely increase the vulnerability of ecosystems, water quality, and biodiversity to climate hazards like drought and warming. Land degradation, soil compaction, and artificial impermeable surfaces can exacerbate drought conditions (EEA, 2024)

- The functioning of marine ecosystems is threatened by the combined effects of climate-related drivers (e.g. marine heatwaves, acidification and oxygen depletion) and other anthropogenic drivers (e.g. pollution and eutrophication, fishing and the adverse impacts of maritime activities). This can result in substantial biodiversity loss, including mass mortality events, and declines in ecosystem services. (EEA, 2024)

Examples / case studies:

References:

EEA (2024). European climate risk assessment. Publications Office. https://data.europa.eu/doi/10.2800/8671471; JRC (2024). Cross-border and emerging risks in Europe: Overview of state of science, knowledge and capacity. Publications Office. https://doi.org/10.2760/184302; JJRC (2025). Analysis of Risks Europe is Facing: An Analysis of Current and Emerging Risks (No. EUR 40352). European Commission, Joint Research Centre. https://doi.org/10.2760/0176850;EEA (2024b). Europe's state of water 2024: The need for improved water resilience. https://www.EEAeuropa.eu/en/analysis/publications/europes-state-of-water-2024

Risk ID: Risk_07

Risk to food systems from extreme weather events (incl. drought, water stress and heat stress)

Systems affected: FOOD, ECON

Extreme weather events are increasingly threatening Europe's food systems. Climate change has already contributed to rising food insecurity for around 12 million Europeans, and recent years show a clear acceleration of climate-related impacts. The severity of extreme heat and drought events has tripled over the past 50 years in Europe, resulting in economic losses in crops, including staples like wheat, and livestock production (Brás et al, 2021). In 2024, Europe recorded the second-highest number of heat-stress days and tropical nights, alongside the most widespread flooding since 2013 (European Parliament, 2025). These events are reducing agricultural productivity: crop losses over the past decade were up to 30% higher than expected, with droughts accounting for 54% of EU agricultural losses (JRC, 2020). Long-term trends are also concerning: for example, wheat yields in Germany declined by around 30% between 1961 and 2014 (JRC, 2020). These shocks directly affect European farmers, markets, and consumers through lower yields, higher production costs, increased price volatility, and, in some cases, reduced food availability.

The EU's vulnerability is further compounded by its dependence on global supply-chains. Many key commodities - maize, wheat, cocoa, coffee, soy, and rice - are partially imported from countries with low adaptive capacity and climate resilience, making them highly exposed to climate extremes outside of Europe. For instance, in 2023, 55% of EU rice imports originated from countries with low-to-medium resilience, with around 35% sources from countries classified as having low climate readiness. Climate-related disruptions in these regions can propagate quickly, amplifying domestic shortages and price volatility (Foresight Transition, 2025).

Extreme events increasingly affect multiple crops, regions, and interconnected systems simultaneously. Direct impacts within the EU (reduced yields, damaged infrastructure, higher prices) combine with indirect impacts through global markets (supply disruptions, price spikes), creating cascading effects across the food system.

Drivers:

Primary environmental driver: climate change	**Primary environmental driver (subcategory):** extreme weather events	**Other environmental drivers:** biodiversity loss, environmental degradation (soil and land)
Non-environmental drivers (STE(E)PV): (S) low income households experience disproportionate impacts on food access and affordability ; training gaps for farmers to transition away from conventional high input monoculture systems (Econ) Persistently low profit margins and limited access to finance in agriculture constain investment in adaptation measures; reinforces the continued cultivation of water intensive or heat sensitive crops in the Mediterranean regions; (P) inadequate governance for climate adaptation (including drought and flood management plans); lack of cross-border coordination to manage supply during extreme weather disruptions; (T) lack of irrigation technologies and water efficiency systems; lack		

of adoption of heat tolerant varieties; mechanisation designed for uniform cropping systems, irrigation technologies optimised for high water demand crops (irrigation dependent systems)

Pathways:

Direct pathways:	**Indirect pathways:**
• heatwave --> crop heat stress and accelerated evapotranspiration --> reduced crop yields , heat stress in livestock and increased spoilage during transport/storage --> lower production/increased food prices • prolonged drought --> lower river flows, reduced groundwater recharge --> reduced water for irrigation and poorer water quality --> reduced yields, crop failure and livestock water stress • intense rainfall --> waterlogged soils and inundation of fields/infrastructure --> reduction in haverstable area, potential disrupted logistics --> loss of production/ yields • storms -->physical damage to crops, orchards -->reduced production • heatwave + dry vegetation --> wildfire ignition and spread --> destruction of crops , loss of productive land -> loss of production	• drought impacts on imported commodities in climate vulnerable countries --> global supply chain impacts --> shortages of supply in the EU (cocoa, coffee, maize, soy) • warm/humid period after storms --> increased pathogen and vector activity --> higher disease in herds and crop depletion • heatwave + prolonged drought --> extreme irrigation demand, low river flow --> reduced hydropower, restrictions on cooling water use in nuclear plants --> higher electricity prices --> increased food processing costs, spoilage, reduced supply --> higher consumer prices • drought --> weakened, water stressed crops --> multiple pest breeding cycles --> reduced yields

Unequal exposure and impacts (risk inequalities):

• 8.2 % of the European population faces moderate-to-severe food insecurity, which notably affects disadvantaged groups and eastern European countries. These populations are more at risk in case of extreme weather events (European Parliament, 2025)

• With drier conditions in Southern Europe and more heavy rainfall events in northern and central Europe regional differences will widen over time, and so will production gaps between Southern and Northern Europe (North is less vulnerable with more opportunities) (European Parliament, 2025, Naumann et al, 2021).

• Maize and wheat will be most affected in Southern Europe (JRC, 2020). In its 2024 European Climate Risk Assessment (EUCRA), the EEA rated the level of risk to crop production from climate

hazards as substantial for Europe and critical for southern Europe in the medium term (2041-2060). (EEA, 2024).

Magnitude, likelihood and uncertainty:

Magnitude (limited; critical/substantial; catastrophic): limited currently to critical by mid century (intensity and frequency of droughts)	**Magnitude basis:** JRC (2020), Naumann et al, (2021); European Parliament (2025) JRC (2023)
Likelihood (unlikely; about as likely as not (33-66%); likely): very likely	**Likelihood basis:** WEF (2025), Naumann et al, (2021); JRC (2023)
Confidence levels (high / medium / low) and sources of uncertainty: The impact on food security will depend on emissions scenarios: under a high emissions scenario, wheat yields in Southern Europe could drop by 49% by 2050 but incrase by 5-16% in Northern Europe. Effects of extreme weather events are likely to be underestimated, due to missing processes, like description of heat stress impact on crop development (JRC, 2020). In a 2-degree temperature rise scenario, it is predicted that declines in maize yields could be higher than 20% in all EU countries, and up to 80% for some southern European countries (IPCC 2022). The impact on EU food security will depend on the ability of agricultural management to adapt (e.g. introducing new varieties and relocating crops, changes in rotation patterns and diversification strategies). Little information is available on the economic cost of drought impacts, due to their delayed and diffuse nature (Naumann et al., 2021).	

Timing:

Onset: By 2100, heatwave days could increase fivefold in cooler regions and up to thirtyfold in warmer ones, while drought severity in southern Europe may triple (European Parliament, 2025) **Time horizon:** already occuring, risks to food security increasing by the end of the decade. In the EU, grain maize will be the most affected crop by climate change, being most severe in Southern Europe. For wheat, all models but one project yield reductions for Southern Europe around 2050 reaching up to -49% (JRC, 2020) **Duration:** chronic **Trend:** increasing

Geography:

Geographic scale: global

Geographic contexts: agricultural

Interlinkages:

Interlinkages to other systemic risks (shared risk pathways):
Risk_02: Risk to economy and financial systems from loss of ecosystem services; Risk_06: Risk to resilient ecosystems, nature protection, climate resilience and restoration from hot and dry weather (heat stress, drought, wildfire); Risk_08: Risk to food systems from pollinator loss; Risk_11: Risk to energy transitions and industrial transformation from heat stress, water stress and drought; Risk_18: Risk to economy and financial systems from changing weather patterns, water stress and drought

Cascading & compounding mechanism(s):

• heavy rainfall after drought --> rapid runoff + severe soil erosion --> loss of topsoil, nutrient depletion --> reduced yield

• soil degradation --> reduced ability to retain water during droughts and increases erosion during storms --> more damage to crops

• Heat and dryness --> increased pest and disease pressure --> reduced yields

• high crop-dependence on irrigation --> makes production really vulnerable in case of droughts and potential lack of water for irrigation --> loss of production

• limited financial protection or insurance for farmers limit ability to recover quickly

• inadequate land use planning, lack of water governance, lack of early warning systems

Examples / case studies:

References:

EEA (2024). European climate risk assessment. Publications Office. https://data.europa.eu/doi/10.2800/8671471;World Economic Forum. (2025). The Global Risks Report 2025. https://www.weforum.org/publications/global-risks-report-2025/]; Green Finance Institute. (2023). Greening Finance for Nature: Unlocking the Potential of Green Finance for Nature-Positive Outcomes. Green Finance Institute. https://www.greenfinanceinstitute.co.uk/greening-finance-for-nature/; JRC (2023). Risks and vulnerabilities in the EU food supply chain. https://doi.org/10.2760/171825; EEA (2022). Rethinking agriculture. https://www.EEAeuropa.eu/en/analysis/publications/rethinking-agriculture; European Parliament. (2025). Climate change impacts on food security in the European Union. Members' Research Service.; IPCC (2022) Climate Change 2022: Impacts, Adaptation, and Vulnerability; Naumann, G., Cammalleri, C., Mentaschi, L., & Feyen, L. (2021). Increased economic drought impacts in Europe with anthropogenic warming. Nature Climate Change, 11(6), 485–491. https://doi.org/10.1038/s41558-021-01044-3; JRC. (2020). Analysis of climate change impacts on EU agriculture by 2050, EUR 30078 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-76-10617-3, doi:10.2760/121115, JRC119632; Brás et al (2021). Severity of drought and heatwave crop losses tripled over the last five decades in Europe. Environmental Research letters. Vol 16; Foresight Transitions (2025) Climate and biodiversity risks to EU food imports, https://static1.squarespace.com/static/652f320921259e4fce918746/t/682e4f28e630b37d69062e2f/1747865481531/Climate_and_Biodiversity_Risks_to_EU_Food_Imports.pdf

Risk ID: Risk_08

Risk to food systems from pollinator loss

Systems affected: FOOD, ECON, ECOSYS

Pollinators are facing substantial declines, primarily driven by land-use change, intensive agricultural practices, and climate change (Feuerbacher et al., 2025). In the EU, 84% of crops species at least partially depend on pollination by insects, and restoring pollinator habitats helps improve future food security (EEA, 2023).Estimates suggest that at least EUR 5-15 billion of the EU's annual agricultural output is directly attributed to insect pollinators (EEA, 2023). In Europe, the contribution of bees to crop pollination has been estimated at €3 billion a year (JRC, 2018).

Direct impacts of pollinator decline in Europe include reduced crop yields, lower quality fruits, vegetables, nuts, and oilseeds, and decreased availability of micronutrient-rich foods such as apples, tomatoes, almonds, and hazelnuts (JRC, 2018; EEA, 2023). Beyond production losses, declining pollination services weaken ecological resilience, by reducing the functional biodiversity in agricultural landscapes to buffer climate shocks, pests, and diseases, thereby amplifying systemic risks to food security both within Europe and globally (EEA, 2023; Foresight Transitions, 2025).

Indirectly, pollinator decline affects the global food supply chain by increasing dependency on imports for pollinator-dependent crops, heightened exposure to international price volatility and trade disruptions. The EU still relies on agri-food imports to meet its food consumption and production needs. For example, imports of cocoa are at risk because they come from countries where biodiversity levels are far below the estimated safe biodiversity vulnerability score threshold (Foresight Insight, 2025).

Drivers:

Primary environmental driver: biodiversity loss	**Primary environmental driver (subcategory):** pollinator loss	**Other environmental drivers:**
Non-environmental drivers (STE(E)PV): (S) lack of uptake of pollinator friendly farming; (T) mechanisation of agriculture including monocultures or habitat removal, pesticide dependency; (Econ) limited financial resilience of farmers (fewer resources to invest in habitat restoration), trade dependency on pollinator-dependent food products (cocoa, coffee)…(P) weak pesticide regulation; insufficient incentives for pollinator friendly practices; subsidies for agricultural intensification/lack of integration of biodiversity in farming policies; (V) low societal valuation/awareness of pollination services		

Pathways:

Direct pathways:	**Indirect pathways:**
• loss of pollinating insects --> reduced productivity of pollinator-dependent	• global pollinator decline --> reductions in crop production --> disruption to key commoditiy supply chains--> rising and more

horticulture --> lower production volume, reduced farm incomes • loss of pollinators --> loss of micronutrient density when poorly pollinated --> nutritional decline and lower quality of products	volatile global commodity prices --> inflation on food products in the EU (GFI, 2023) • loss of wild pollinators --> increased reliance on managed pollinators --> increased costs of food products

Unequal exposure and impacts (risk inequalities):

• Italy and Poland are the countries that have the highest share of crops with a high dependency on pollinators (including apples, pears, peaches) (JRC, 2018) • Consumers would pay the burden of price increases for pollinator-dependent crops, due to inelastic nature of agricultural supply and demand (Feuerbacher et al, 2025)

Magnitude, likelihood and uncertainty:

Magnitude (limited; critical/substantial; catastrophic): substantial: in a hypothetical collapse scenario in Europe in 2030, overal yields in Europe would decline by 8% (Feuerbacher et al, 2025)	**Magnitude basis:** (JRC, 2023)
Likelihood (unlikely; about as likely as not (33-66%); likely): Likely	**Likelihood basis:** JRC (2023): lowest exposure values within the Biophysical and Environmental risk type, varying between 39 and 42%
Confidence levels (high / medium / low) and sources of uncertainty: The global agri-food system's vulnerability to pollinator loss remains poorly understood (Feuerbacher et al, 2025).	

Timing:

Onset: gradual **Time horizon:** already occuring **Duration:** chronic **Trend:** increasing

Geography:

Geographic scale: global

Geographic contexts: agricultural

Interlinkages:

Interlinkages to other systemic risks (shared risk pathways):
Risk_02: Risk to economy and financial systems from loss of ecosystem services; Risk_04: Risk to ecosystems from intensive agriculture and soil degradation ; Risk_06: Risk to resilient ecosystems, nature protection, climate resilience and restoration from hot and dry weather (heat stress, drought, wildfire); Risk_07: Risk to food systems from extreme weather events (incl. drought, water stress and heat stress); Risk_14: Risk to health, economy, wellbeing from chemical pollution; Risk_15: Risk to wellbeing, health and mental health from biodiversity loss / loss of nature; Risk_16: Risk to marine food systems from overfishing and invasive alien species; Risk_17: Risk to resilient ecosystems, nature protection, climate resilience and restoration from biodiversity loss; Risk_18: Risk to economy and financial systems from changing weather patterns, water stress and drought

Cascading & compounding mechanism(s):

- unsustainable agricultural practices + landscape simplification: soil degradation (in particular soil erosion) and lack of habitat for wild pollinators create higher vulnerability to food insecurity (like South of Spain, border between Romania and Bulgaria) (La Notte et al, 2025)
- climate change: flowering periods shift faster than pollinator life cycles, reducing pollination window for crops; increasing temperatures can shift the timing of plant flowering, disrupting plant pollinator networks
- heat stress and droughts: lower nectar/pollen productivity weakens pollinators
- agricultural intensification: leasd to landscape simplification and loss of semi natural habitats, which negatively affect pollinators
- invasive alien species

Examples / case studies:

References:

JRC (2018) Ecosystem services accounting: Part I - Outdoor recreation and crop pollination EEA (2025) [Protecting and restoring Europe's wild pollinators and their habitats]; GFI (2023) Assessing the Materiality of Nature-Related Financial Risks for the UK; JRC (2023) Risks and vulnerabilities in the EU food supply chain; La Notte et. al. (2025) [The assessment of nature-related risks: From ecosystem services vulnerability to economic exposure and financial disclosures]; EEA (2023) The importance of restoring nature in Europe; Foresight Transitions (2025) Climate and biodiversity risks to EU food imports; IEEP (2022) [Nature Restoration as a driver for Resilient Food Systems]; Feuerbacher et al, (2025) [The economic, agricultural, and food security repercussions of a wild pollinator collapse in Europe] ; Kleijn et al, (2015) [Delivery of crop pollination services is an insufficient argument for wild pollinator conservation]

Risk ID: Risk_09

Risk to ecosystems from pollution and eutrophication

Systems affected: ECOSYS, Human health

Risk ID: Risk_01

Pollution continues to pose a significant threat to ecosystems across Europe, contributing to the broader "triple planetary crisis" of climate change, pollution, and biodiversity loss. Multiple pollution pathways - including airborne deposition, contaminated runoff, soil contamination, plastic waste, and the release of persistent and hazardous chemicals - are undermining biodiversity, ecosystem functioning, and overall environmental health. Pollutants originate from agriculture, industry, domestic activities, and transport, creating a combination of direct and diffuse pressures across terrestrial and aquatic environments (EEA & JRC, 2025).

Across Europe, the impacts of pollution are increasingly evident. Only 29% of Europe's surface waters achieved good chemical status between 2016 and 2021, reflecting ongoing challenges posed by hazardous substances. Soil quality is also compromised, with pesticide residues detected in 75% of EU agricultural soils surveyed in 2018 (EEA & JRC, 2025). Chemical pollutants of high concern continue to accumulate in the environment: the environmental quality standard (EQS) for PFOS was exceeded in 51% to 60% of river sites and in 47% to 100% of transitional and coastal waters between 2018 and 2022 (ibid). Contaminants accumulate and circulate through food webs, degrade habitats, disrupt ecosystem functions, and interact with other stressors such as climate change or invasive alien species. Pollution is also transboundary by nature, as air and waterborne contaminants move across regions and national borders, making local mitigation insufficient without coordinated European and global action. Plastics and chemical pollutants can travel long distances and accumulate in remote ecosystems.

Emerging pollutants, such as microplastics, PFAS, pharmaceutical residues, and complex chemical mixtures, pose risks that are not yet fully understood. Interactions among pollutants and other environmental pressures can amplify impacts in unpredictable ways, making ecological responses difficult to anticipate.

Drivers:

Primary environmental driver: chemical pollution; air pollution; water pollution; plastic pollution; land pollution; soil pollution	**Primary environmental driver (subcategory):** chemical accident; marine chemical pollution; air pollution; chemicals in environment;household and industrial activities; environmental accidents, such as oil spills; and radioactive contamination; water pollution; soil pollution; land pollution, plasti	**Other environmental drivers:** environmental degradation (soil)
Non-environmental drivers (STE(E)PV): (Econ) pressure for economic growth prioritises industrial/agricultural expansion over environmental safeguards; externalisation of environmental costs; (T) emergence of new and persistent chemical pollutants sources; (P) policy incentives for agricultural/industrial intensification; lack of regulatory enforcement and frameworks to regulate pollution; lobbying and vested interests		

Pathways:

Direct pathways:	**Indirect pathways:**
• Nitrogen deposition --> causes eutrophication when it surpasses critical thresholds --> nutrient imbalance, high rate of primary productivity -->changes in species composition, increased risk of algal bloom (oxygen depletion) --> decline of biodiversity in freshwater, and marine ecosystems, • Excessive concentrations of ground-level ozone --> Ozone enters plant leaves and reduces photosynthesis, which slows a plant's growth and increases its vulnerability to pests and disease --> damage plants, reduce growth rates • Atmospheric deposition of heavy metals (such as arsenic, cadmium, lead, and mercury) poses risks due to exposure and bioaccumulation in the food chain, contamination of soils (cadmium, copper, zinc)	•Altered food-web dynamics --> Pollutants reduce populations of sensitive species (e.g., phytoplankton, zooplankton, insects), disrupting predator–prey relationships --> trophic cascades, imbalanced species interactions, and reduced ecosystem stability •chemical residues, heavy metals, and persistent pollutants impair soil microbial communities and soil fauna --> slowing down of decomposition, reduction of nutrient cycling, and alteratio of soil structure --> indirect decrease of plant productivity and the health of dependent herbivore and predator communities.

•Deposition of sulphur dioxide, nitrogen oxides, and ammonia changes the chemical composition of soils, lakes, rivers, and marine waters, leading to acidification •Sewage sludge --> introduces heavy metals, organic pollutants, pathogens, and microplastics into soils → affects soil microbial communities, reducing soil fertility→ ultimate degradation of soil quality and ecosystem services. •pesticides residues in agricultural soils --> risk to non-target soil organisms •ubiquitous, persistent, bioaccumulative, and toxic substances (uPBTs), particularly mercury and brominated flame retardants --> persist in the environment, bioaccumulate in organisms, and travel long distances --> contribution to chemical status failure in freshwater ecosystems, reproductive toxicity in fish and birds, and long-term ecosystem degradation. •groundwater pollution (nitrates and pesticides, mainly from agriculture) -->(freshwater ecosystems) •emerging contaminants (PFAS) --> harmful effects on freshwater and terrestrial organisms even at low concentrations, including reproductive, hormonal, and immune disruption --> long-lasting ecosystem consequences. •micro and macro plastics --> accumulate in soils, rivers, and oceans → physical obstruction, ingestion, and toxicity in terrestrial and aquatic organisms. Plastics alter soil structure and nutrient cycling and serve as vectors for pathogens and chemicals. •marine macrolitter and microlitter: Both macro-litter (larger than 2.5 cm) and micro-litter (particles below 5 mm) cause loss of biodiversity and ecosystem integrity--> Physical debris harms marine life through	

entanglement, damages habitats, and can potentially disrupt marine food webs.	

Unequal exposure and impacts (risk inequalities):

• Air pollution: pronounced hotspots in north-western and central Europe, illustrating clear spatial inequality in ecosystem risk from air pollution (EEA, 2024c); • Eutrophication hotspots: highest exceedances of nitrogen critical loads were specifically identified in environmental hotspots such as the Po Valley in Italy, the border areas between the Netherlands and Germany, the border between Denmark and Germany, and north-eastern Spain (in 2022) (EEA, 2024c) • Marine eutrophication: Baltic sea most impacted, Mediterranean sea mixed (EEA &JRC, 2025) • Acidification hotspots (in 2020) in the Netherlands and its borders, Germany and Belgium, small parts of southern Germany and Czechia (EEA, 2022) • Ozone damage to vegetation: particularly problematic in Central, Southern and Eastern Europe (EEA, 2024c) • Nitrates and fertilizers: overuse of mineral fertilizer and organic amendments leads to eutrophication and acidification in 65–75% of European agricultural areas (Ferreira et al, 2022) • Heavy metals are among the most frequent contaminants in European Mediterranean countries, accounting for around 60% of soil contamination (Ferrreira et al, 2022). High concentrations of copper are reported, often driven by the extensive use of copper-based fungicides, particularly in olive and wine-producing regions (e.g., Greece and Portugal). Cadmium also accumulates in agricultural soils in the region, linked primarily to mineral phosphorus fertilizers (ibid)

Magnitude, likelihood and uncertainty:

Magnitude (limited; critical/substantial; catastrophic): substantial	**Magnitude basis:** (EEA & JRC, 2025)
Likelihood (unlikely; about as likely as not (33-66%); likely): likely, although not all sources of pollution have the same likelihood. Eg Marine chemical pollution: High impact, low probability.	**Likelihood basis:** (EEA & JRC, 2025)
Confidence levels (high / medium / low) and sources of uncertainty: Emerging pollutants, such as microplastics, PFAS, pharmaceutical residues, and complex chemical mixtures pose risks that are not yet fully understood, complicating assessment, regulation, and long-term planning. Interactions among pollutants and other environmental	

pressures can amplify impacts in unpredictable ways, making ecological responses difficult to anticipate (EEA & JRC, 2025).

Timing:

Onset: gradual

Time horizon: already occuring

Duration: chronic

Trend: increasing -- Not all sources of pollution are evolving in the same way. Projections indicate that nearly 70% of ecosystems are expected to remain affected by eutrophication in 2030. For heavy metals, the trend is currently decreasing: between 2005 and 20

Geography:

Geographic scale: global

Geographic contexts: all ecosystems

Interlinkages:

Interlinkages to other systemic risks (shared risk pathways):
Risk_03: Risk to food systems from soil degradation; Risk_04: Risk to ecosystems from intensive agriculture and soil degradation ; Risk_13: Risk to food systems from pollution (general, antibiotics, soil, water, chemicals); Risk_14: Risk to health, economy, wellbeing from chemical pollution; Risk_16: Risk to marine food systems from overfishing and invasive alien species

Cascading & compounding mechanism(s):
• Climate change: for marine ecosystems: rising sea temperature combines with eutrophication leads to increased risk for ecosystems

• Pollution-induced stress weakens plant immune responses and reduces natural pest control species, enabling pest outbreaks, increased disease prevalence, and invasive species establishment leading to ecosystem degradation.

• Land-use change and habitat fragmentation reduces ecosystem buffer capacity, increases runoff of nutrients and chemicals, and isolates species making populations more vulnerable to pollution pressures.

• Agricultural intensification: greater fertiliser, pesticide, and manure use results in higher emissions, runoff, and soil residues leading to biodiversity loss

• Cascading effects: trophic cascades (emphasised by bioaccumulation); loss of ecosystem services

Examples / case studies:

References:

Ferreira, C. S. S., Seifollahi-Aghmiuni, S., Destouni, G., Ghajarnia, N., & Kalantari, Z. (2022). Soil degradation in the European Mediterranean region: Processes, status and consequences. Science of The Total Environment, 805, 150106. https://doi.org/10.1016/j.scitotenv.2021.150106;

JRC (2025). Analysis of Risks Europe is Facing: An Analysis of Current and Emerging Risks (No. EUR 40352). European Commission, Joint Research Centre. https://doi.org/10.2760/0176850; EEA & JRC (2025). Zero pollution monitoring and outlook 2025 (No. 13/2024). https://data.europa.eu/doi/10.2800/6470682; EEA (2024a). Plastics. https://www.EEAeuropa.eu/en/topics/in-depth/plastics; EEA (2024b). Europe's state of water 2024: The need for improved water resilience. https://www.EEAeuropa.eu/en/analysis/publications/europes-state-of-water-2024; EEA (2022a). Air quality in Europe 2022 (No. 05/2022). European Environment Agency. https://doi.org/10.2800/488115; EEA (2025b). Waste and recycling. https://www.EEAeuropa.eu/en/topics/in-depth/waste-and-recycling; EEA (2024c). Impacts of air pollution on ecosystems in Europe. European Environment Agency. https://www.eea.europa.eu/en/analysis/publications/impacts-of-air-pollution-on-ecosystems-in-europe

Risk ID: Risk_10

Risk to human health from climate change

Systems affected: ECON / OTHER (Human health)

Key climate-related risks to human health include (1) increased mortality and morbidity associated with heat stress, often compounded by air pollution; (2) heightened occupational health risks for outdoor workers due to rising temperatures and heat strain; (3) geographic expansion and altered transmission dynamics of climate-sensitive infectious diseases; (4) health risks linked to increased occurrence of harmful algal blooms and waterborne pathogens (EEA, 2024). Health and human life are also impacted by extreme weather events - through direct impacts but also spread of water and foodborne diseases (EEA, 2024; WEF, 2025). Indirect and cascading health risks include furthermore risk to food and nutrition security from increasing food prices due to climate impacts on food production in Europe and health risks driven by increased water stress (EEA, 2024; UNEP, 2021). A combination of increased demand (e.g., from heat stress-related illnesses and infectious disease outbreaks) and climate-related damage to health infrastructure (e.g., flooding or high temperatures affecting facilities) can considerably strain health systems already under pressure (EEA, 2024). Floods, storms, wildfires, and long-term changes (like drought or permanent environmental alteration) can lead to substantial psychological impacts, including stress, anxiety, and trauma-related disorders (University of Exeter, 2023).

Drivers:

Primary environmental driver: climate change	**Primary environmental driver (subcategory):** heat stress, water stress, flooding, extreme weather events	**Other environmental drivers:** environmental degradation, biodiversity loss
Non-environmental drivers (STE(E)PV): (S) Pre-existing inequalities; poverty; ageing population; social isolation; urbanisation (exposure to heat stress); (T) Vulnerability of key infrastructure like water treatment plants and sewage systems (especially small/local ones) to extreme events, particularly flooding; non-adapted buildings; poor insulation; lack of air conditioning in health and social care facilities; (Econ) Lower-income households have less capacity to adapt; occupational exposure; (P) Institutional barriers complicate the widespread implementation of health policy measures; Underinvestment in national health systems risks pushing them beyond their capacity when faced with growing climate risks; The lack of consistent reporting of heat-related mortality makes precise estimates and effective policy difficult		

Pathways:

Direct pathways:	**Indirect pathways:**
• Increasing frequency and intensity of heatwaves --> Direct loss of life, causing premature deaths (e.g. an estimated 60,000–	• Extreme weather events --> disruption or failure of critical infrastructure --> strain on

70,000 in the 2022 European summer heatwave) • Gradual warming / heatwaves --> Worsening of chronic conditions such as cardiovascular, respiratory, and cerebrovascular diseases • Increasing temperature, humidity and rainfall variability --> enhanced availability of breeding sites and improved vector survival and development, combined with faster pathogen replication within vectors --> shorter time to infectiousness, higher biting frequency and expanded vector distribution --> increased transmission and emergence of vector-borne diseases • Warming and changing rainfall patterns --> more favourable conditions for the emergence and transmission of climate-sensitive infectious diseases • Interaction of air pollution and extreme heat --> Linked to higher mortality rates, mainly driven by cardiovascular and respiratory disease, particularly harmful to those with pre-existing conditions • Extreme precipation and flooding --> Direct causes of physical injuries and deaths • Extreme precipitation and flooding --> sewage overflow --> potential waterborne disease outbreak • Wildfires --> burns and injuries • Wildfires --> hazardous air quality --> worsened respiratory conditions (EEA, 2024)	health systems, inability to provide care, higher mortaility • Extreme weather events outside Europe --> interruption of pharamceutical supply chains --> Risk of a public health crisis due to shortages of essential medicines • Climate change / habitat loss / land use change --> Alters species localization and interactions --> Increased risk of zoonotic spillover • Droughts / heatwaves --> compromised food production --> food insecurity, undernutrition

Unequal exposure and impacts (risk inequalities):

• Climate-senstivie health risks disproportionately impact elderly and children, individuals with pre-existing medical conditions, lower-income households and socially isolated individuals (EEA, 2024)

• Some climate-sensitive health risks are gender-sensitive. In the general population, women are more affected by heatwaves than men due to biological, demographic and socio-economic factors. At the same time, men are disproportionally exposed to climate-related hazards at work because more men than women work in construction and agriculture, or as firefighters. (EEA, 2024) • Climate change poses health risks to outdoor workers due to increased heat stress. This heat strain leads to increased discomfort, decreased cognitive functioning, more workplace accidents (EEA, 2024) • Risks related to heat are already at critical levels in Southern Europe (EEA, 2024)

Magnitude, likelihood and uncertainty:

Magnitude (limited; critical/substantial; catastrophic): • Critical (current/near term) to catastrophic (mid/long-term) for risk to human health from heat stress increased by climate change • Limited (current/near term) to substantial/critical (mid/long-term) for risk from geographic expansion and increased transmission of infectious diseases • Limited (current/near term) to substantial/critical (mid/long-term) forstress to health systems, including health infrastructure, from climate change	**Magnitude basis:** (EEA, 2024)
Likelihood (unlikely; about as likely as not (33-66%); likely): very high likelihood for heat-related impacts, and likely but more context-dependent risks for infectious, water/foodborne, and wildfire-related health outcomes	**Likelihood basis:** (EEA, 2024)
Confidence levels (high / medium / low) and sources of uncertainty: Confidence in health risks from climate change varies across impact pathways and is shaped by uncertainties in climate, socio-economic and demographic trajectories, as well as adaptive capacity and public health responses. While confidence is high for some observed impacts (e.g. heat stress and occupational health), evidence remains limited or low for others, including wildfire smoke, drought-related diseases and foodborne risks, leading to overall uneven and impact (EEA, 2024).	

Timing:

Onset: gradual **Time horizon:** already occuring **Duration:** chronic

Trend: increasing

Geography:

Geographic scale: global; EU-wide; localised hotspots (e.g. Southern Europe)

Geographic contexts: urban/peri-urban areas particularly affected

Interlinkages:

Interlinkages to other systemic risks (shared risk pathways):
Risk_01: Risk to ecosystems, and human systems including food and energy security, health, and economic stability from the Atlantic meridional overturning circulation (AMOC) collapse; Risk_02: Risk to economy and financial systems from loss of ecosystem services; Risk_05: Risk to energy transitions and industrial transformation from extreme weather events including flooding ; Risk_12: Risk to health from air pollution; Risk_13: Risk to food systems from pollution (general, antibiotics, soil, water, chemicals); Risk_14: Risk to health, economy, wellbeing from chemical pollution; Risk_15: Risk to wellbeing, health and mental health from biodiversity loss / loss of nature; Risk_19: Risk to economy from extreme weather events incl. flooding ; Risk_20: Risk to energy transitions and industrial transformation from soil degradation and loss of ecosystem services.

Cascading & compounding mechanism(s):

- The combination of extreme heat and air pollution (such as ozone or particulate matter) is particularly harmful to human health, linked to higher mortality rates driven by cardiovascular and respiratory disease (EEA, 2024)

- The synergy between heatwaves and prolonged droughts increases the risk of wildfires, which then compound health impacts by worsening air quality (smoke and particulate matter) (JRC, 2024)

- The convergence of infectious disease outbreaks and a surge in heat stress-related illnesses could place considerable strain on health systems already struggling with existing pressures (EEA, 2024)

- Climate change-induced health impacts can be aggravated by the transmission and spread of Antimicrobial Resistance (AMR), a significant cross-border threat, as rising temperatures influence resistant pathogens (JRC, 2024)

- Contamination has negative effects on soil organic matter (SOM) and aggregate stability (Soil contamination lowers the activity of soil biota, affecting community structure and reducing biodiversity)--> erosion risks--> spreads pollutants (Ferreira et al, 2022)

Examples / case studies:

Between June and August 2022, most of Europe experienced at least 10 days of strong heat stress. Much of the southern and western Europe had at least five days of very strong heat stress and parts of the southwest had close to 50 days. Across Europe, that

References:

EEA (2024). European climate risk assessment. Publications Office. https://data.europa.eu/doi/10.2800/8671471; JRC (2024). Cross-border and emerging risks in Europe: Overview of state of science, knowledge and capacity. Publications Office. https://doi.or; World Economic Forum. (2025). The Global Risks Report 2025. https://www.weforum.org/publications/global-risks-report-2025/; United Nations Environment Programme. (2021). Making Peace with Nature: A Scientific Blueprint to Tackle the Climate, Biodiversity and Pollution Emergencies. United Nations Environment Programme. https://www.unep.org/resources/making-peace-nature

Risk ID: Risk_11

Risk to energy transitions and industrial transformation from heat stress, water stress and drought

Systems affected: ENER

The transition to a highly electrified energy system, largely run on renewable energy technologies, entails exposure to climate risks because many renewable sources are directly or indirectly dependent on weather patterns and hydrological conditions(Aall et.al., 2025). Drought events and reduced river flows significantly threaten hydropower generation. Loss of snow and glacial retreat in regions like the Alps will further limit hydropower generation, particularly in the spring (EEA, 2024). Water shortages affect not only renewable energy generation: currently, approximately 60% of the EU's electricity production depends on water availability for cooling, primarily in nuclear and fossil fuel power plants. (EEA, 2024b). It is projected that climate change could reduce usable cooling water capacity at power plants by over 15% by mid-century (EEA, 2024). The combination of heat and prolonged droughts affecting electricity supply simultaneously with heatwaves driving peak electricity demand can lead to power cuts, especially in Southern Europe - the risk of electricity disruption due to heat and drought is already substantial across Europe and reaches critical levels in Southern Europe (EEA, 2024). Rising temperatures and increasing frequency and intensity of heatwaves significantly increase energy demand for cooling, increasing overall energy demand (EEA, 2025a). Higher temperatures and heatwaves reduce the transmission capacity of electricity infrastructure (EEA, 2024).

Drivers:

Primary environmental driver: climate change	**Primary environmental driver (subcategory):** water stress, heat stress, drought	**Other environmental drivers:**
Non-environmental drivers (STE(E)PV): (S) Europe's ageing population increases overall vulnerability to heat stress; rapid urbanisation can overwhelm existing infrastructure and services ; (T) some new energy technologies are water sensitive (e.g. large scale hydrogen production), increasing pressure on already scarce water resources (EEA, 2024b); vulnerable agining infrastructure (EEA, 2024); (P) trendency to overlook transition-related risks in the shift to renewables by focusing on current systems rather than anticipating changes in vulnerability (Aall et. al., 2025).		

Pathways:

Direct pathways:	**Indirect pathways:**
• Warming/heatwaves --> increased demand for energy for cooling --> Increased peak alectricty demand, heightened strain on the energy grid	• Drought / heatwaves (global) --> Disruption of international supply chains for raw materials and manufacturing components --> Shortages of critical raw materials required for renewable technologies --> Increased capital costs and

• Higher temperatures --> reduction in the transmission capacity of power lines and transformers --> risk of energy disruption and power outages • Droughts/water scarcity --> reduced river flow --> decreased hydropower production potential • Droughts/water scarcity --> reduced availability of cooling water necessary for thermal power plants --> reduced production capacity, risk of plant shutdowns (EEA, 2024)	production delays for low-carbon energy infrastructure

Unequal exposure and impacts (risk inequalities):

• the risks of electricity disruption due to the combined impacts of heat and drought are already substantial and are expected to reach critical levels in Southern Europe (EEA, 2024) • Low-income households are more sensitivie to price volatilities; may also lack the financial means to invest in necessary adaptations like energy-efficient upgrades or cooling system replacements; policies relying on private incentives, such as those for clean heating retrofits often exclude tenants

Magnitude, likelihood and uncertainty:

Magnitude (limited; critical/substantial; catastrophic): Limited (current/near term) to substantial/critical (long term) for risk of energy disruption due to the impacts of heat and drought on energy production and peak demand: all Europe Substantial (current/near term) to critical (long term) for risk of energy disruption due to the impacts of heat and drought on energy production and peak demand: Southern Europe	**Magnitude basis:** EEA, 2024
Likelihood (unlikely; about as likely as not (33-66%); likely): likely	**Likelihood basis:** EEA, 2024
Confidence levels (high / medium / low) and sources of uncertainty: Medium to low confidence (EEA, 2024) There is strong evidence on observed and projected climate change impacts on Europe's energy system, though uncertainty remains for some regional climate drivers and is compounded by rapid system changes linked to decarbonisation, technology, and geopolitics. Impacts are	

expected to be most adverse in southern Europe, while northern and central regions may experience a mix of negative effects and some limited benefits (EEA, 2024).

Timing:

Onset: gradual

Time horizon: already occuring

Duration: chronic

Trend: increasing

Geography:

Geographic scale: global and EU-wide with Southern Europe particularly affected.

Geographic contexts: arid/semi-arid; river basins; urban/peri-urban; mountain/alpine regions particularly affected

Interlinkages:

Interlinkages to other systemic risks (shared risk pathways):
Risk_05: Risk to energy transitions and industrial transformation from extreme weather events including flooding ; Risk_06: Risk to resilient ecosystems, nature protection, climate resilience and restoration from hot and dry weather (heat stress, drought, wildfire); Risk_07: Risk to food systems from extreme weather events (incl. drought, water stress and heat stress); Risk_18: Risk to economy and financial systems from changing weather patterns, water stress and drought

Cascading & compounding mechanism(s):
• Energy is the backbone of modern society: disruptions in electricity supply cascade far beyond the power sector, affecting virtually all critical systems and services, from industry and food supply chains to housing, transport, healthcare, and digital infrastructure: thereby amplifying societal and economic risks during heat and drought events.

• Reduced thermal and hydropower output due to heat and water stress leads to compromise in power supply. This loss of reliable supply, coupled with surging demand for cooling in heatwaves, places extreme strain on the electricity grid, increasing the risk of cascading failures, power outages, and blackout (EEA, 2024; Aall et.al., 2025).

• Drought-driven low river flows concentrate pollutants, while higher temperatures promote toxic biological activity. This compounding of water stress, heat and pollution results in worsened water quality and limits the remaining water usable by industry and power plants for cooling. The resulting pollution can even lead to ecological disasters, as seen in the Oder River incident in 2022, which was triggered by low flow, high temperature, and salt pollution (EEA, 2024).

• Periods of hydrological drought (reducing hydropower) occuring simultaneously with low wind speeds and/or low solar radiation (due to clouds or shading) could result in high energy shortfall ("dark doldrums" scenario) (Aall et. al., 2025).

Examples / case studies:

References:

Aall, C., Chang, M., Elliot, T., Holm, T. B., Løkke, S., Mati, A., Mayer, S., & Skov, I. R. (2025). Overlooked climate risks in the ongoing renewable energy transitions. Energy, 335, 137986. https://doi.org/10.1016/j.energy.2025.137986; EEA (2024). European climate risk assessment. Publications Office. https://data.europa.eu/doi/10.2800/8671471; EEA (2025a). Renewables, electrification and flexibility—For a competitive EU energy system transformation by 2030 (No. EEA report 16/2024). https://www.EEAeuropa.eu/en/analysis/publications/renewables-electrification-and-flexibility-for-a-competitive-eu-energy-system; EEA (2024b). Europe’s state of water 2024: The need for improved water resilience. https://www.EEAeuropa.eu/en/analysis/publications/europes-state-of-water-2024

Risk ID: Risk_12

Risk to health from air pollution

Systems affected: ECON / OTHER (Human health)

Air pollution remains the largest environmental health risk in Europe. Long-term exposure to fine particulate matter and high nitrogen dioxide levels is estimated to cause more than 250,000 premature deaths annually across Europe (EEA & JRC, 2025). Beyond mortality, air pollution causes substantial morbidity, where people live with chronic diseases, resulting in significant personal suffering and high healthcare and societal costs (EEA, 2022a). Air pollution contributes to the development and aggravation of respiratory and cardiovascular diseases, is a recognised cause of cancer and impacts mental and congnitive health (EEA, 2022a; EEA & JRC, 2025). Despite emissions having fallen significantly over the past two decades, air quality remains poor in many parts of Europe. In 2020 in the European Union, an estimated 96% of the urban population was exposed to levels of fine particulate matter above the health-based guideline level set by the WHO (EEA & JRC, 2025; EEA, 2022a). The health risk primarily stems from exposure to fine particulate matter (PM2.5), nitrogen dioxide (NO2), and ozone (O3) (EEA, 2022a). Wildfires are an increasingly significant source of air pollution in Europe, particularly in Southern Europe, where climate change is driving more intense fires and longer fire seasons. This trend triggers cascading impacts on human health, often compounding with other environmental stressors like heatwaves. The risk from air pollution is considered systemic as it involves complex interactions of diverse anthropohgenic sources compunded by environmental factors (e.g. rising temperatures) (EEA, 2022a; EEA & JRC, 2025). Moreover it leads to cascading and compounding effects throughout the economy and society (JRC, 2025).

Drivers:

Primary environmental driver: pollution	**Primary environmental driver (subcategory):** air pollution	**Other environmental drivers:** climate change (risk amplifier)
Non-environmental drivers (STE(E)PV): (S) Urbanisation and population density (EEA, 2022a; EEA & JRC, 2025); Consumption patterns driving pollution (e.g. mobility, energy consumption in residential sector) (EEA, 2022a; EEA & JRC, 2025); (T) Road transport dependence (EEA, 2022a); emissions from industrial production (EEA & JRC, 2025); (Econ/P/T) continued fossil fuel reliance in energy sector (EEA, 2022a);		

Pathways:

Direct pathways:	**Indirect pathways:**
• Exposure to high PM 2.5, NO2, O3 concentrations--> premature deaths, primarily due to heart disease and stroke, followed by lung diseases and lung cancer (EEA, 2022a).	• Morbidity --> significant health care costs / burden on healthcare systems (EEA, 2022a) • Premature death and chronic ilnness -> reduced workforce productivity --> economic downturns, business disruptions, and increased

• Exposure to high PM 2.5, NO2, O3 concentrations --> morbidity: chronic obstructive pulmonary disease, lower respiratory infections, lung cancer, heart disease, diabetes mellitus, stroke, asthma (EEA, 2022a). • Wildfires --> emission of high concentrations of smoke and pollutants (e.g. PM 2.5, PM10) --> human inhalation and physical exposure --> first-order health impacts: premature mortality and acute morbidity (e.g., respiratory issues, asthma, COPD, and cardiovascular diseases (EEA & JRC, 2025; EEA, 2025d)	healthcare cost --> negative impact to economic stability and growth. (JRC, 2025)

Unequal exposure and impacts (risk inequalities):

• Older people (aged 65 and above) and children are the demographic groups most negatively affected by air pollution (EEA & JRC, 2025). • Air pollution significantly increases the risk of mortality in people with pre-existing health conditions (EEA & JRC, 2025). • Urban populations particularly exposed: 96% of the urban population in the EU was exposed to concentrations of PM 2.5 above the health-based guideline set by the WHO (EEA, 2022a) • The highest concentrations of particulate matter (PM 2.5 and PM 10) were concentrated in northern Italy and some eastern European countries (EEA, 2022a). • the highest concentrations of carcinogenic pollutants like benzoapyrene (BaP) were found in eastern Europe where the use of coal and other solid fuels for residential heating is widespread (EEA, 2022a) • Levels of PM 2.5 concentrations are consistently higher in the poorest regions of the EU, sometimes by about one third, compared to the richest regions (EEA & JRC, 2025). • The highest absolute numbers of premature deaths attributable to PM 2.5 exposure were seen in Italy, Poland, Germany, Romania, and Spain (EEA, 2022a) • The highest absolute number of premature deaths attributable to NO2 exposure occurred in Türkiye, Italy, Germany, Spain, and France (EEA, 2022a) • In Southern Europe, wildfires often coincide with extreme heatwaves. The combined exposure to high temperatures and air pollution significantly increases the risk of mortality, especially for vulnerable groups with pre-existing conditions (EEA & JRC, 2025; JRC, 2025)

Magnitude, likelihood and uncertainty:

Magnitude (limited; critical/substantial; catastrophic): critical/substantial: ranked as highest environmental health risk in Europe	**Magnitude basis:** EEA, 2022a, EEA & JRC, 2025
Likelihood (unlikely; about as likely as not (33-66%); likely): likely	**Likelihood basis:** EEA, 2022a, EEA & JRC, 2025
Confidence levels (high / medium / low) and sources of uncertainty: High (EEA, 2025d) Estimates of the health impacts of air pollution are based on robust scientific evidence of causality and widely available data, particularly for mortality due to PM2.5, nitrogen dioxide (NO2), and ozone (O3) (EEA, 2022a).	

Timing:

Onset: gradual

Time horizon: already occuring

Duration: chronic

Trend: decreasing trend in emissions of key air pollutants and their concentrations in ambient air; decreasing trend in fatalities (EEA, 2022a)

Geography:

Geographic scale: global and EU-wide; Eastern Europe and Italy particularly affected

Geographic contexts: urban and peri-urban areas particularly affected

Interlinkages:

Interlinkages to other systemic risks (shared risk pathways):
Risk_10: Risk to human health from climate change ; Risk_13: Risk to food systems from pollution (general, antibiotics, soil, water, chemicals); Risk_14: Risk to health, economy, wellbeing from chemical pollution

Cascading & compounding mechanism(s):
• The risk to health from air pollution triggers various cascading and compounding mechanisms that spread impacts across health and economic systems (see indirect pathways)

• The increased frequency of heat waves in Europe, when coupled with exposure to air pollution, significantly increases the risk of mortality, especially in people with pre-existing health conditions (EEA & JRC, 2025)

Examples / case studies:

References:

EEA & JRC (2025). Zero pollution monitoring and outlook 2025 (No. 13/2024). https://data.europa.eu/doi/10.2800/6470682; EEA (2022a). Air quality in Europe 2022 (No. 05/2022). European Environment Agency. https://doi.org/10.2800/488115; JRC (2025). Analysis of Risks Europe is Facing: An Analysis of Current and Emerging Risks (No. EUR 40352). European Commission, Joint Research Centre. https://doi.org/10.2760/0176850; EEA. (2025d). Harm to human health from air pollution in Europe: Burden of disease status, 2025. https://www.eea.europa.eu/en/analysis/publications/harm-to-human-health-from-air-pollution-burden-of-disease-status-2025

Risk ID: Risk_13

Risk to food systems from pollution (general, antibiotics, soil, water, chemicals)

Systems affected: FOOD, ECOSYS

Pollution poses significant risks to food systems by contaminating essential resources, degrading production capacity, and threatening human health. Contaminated soils directly affect food safety and crop quality; for example, 21% of EU agricultural soils contain high cadmium levels, with copper and zinc often exceeding safe limits (EEA & JRC, 2024). Pollutants enter food systems through multiple pathways, including industrial accidents, contaminated recycling streams, and unreliable laboratory methods, leading to food-chain contamination. Heavy metals such as mercury and cadmium, along with persistent organic pollutants like PCBs, accumulate in soil, water, and living organisms, harming fish and aquaculture health and creating risks for human consumption (JRC, 2023). Water pollution—including pesticides, nutrient overload, PFAS, microplastics, antibiotics—further contributes to plant contamination, reduced crop growth, and the bioaccumulation of residues in fruits, vegetables, and animal feed, undermining both food production and safety (Ferreira et al., 2022; EEA, 2024b). In the EU, 10% of groundwater was contaminated with pesticides in 2021, illustrating the scale of risk to safe irrigation and drinking-water sources (EEA, 2024b). Pollution also includes antimicrobial resistance in the livestock sector from heavy antibiotic use, transmitted to humans via meat consumption and surface waters (JRC, 2023, EEA, 2025f).

Drivers:

<table>
<tr><td>Primary environmental driver:
pollution</td><td>Primary environmental driver (subcategory):
chemical pollution; water pollution; soil pollution</td><td>Other environmental drivers: environmental degradation (soil degradation); climate change (water scarcity)</td></tr>
<tr><td colspan="3">Non-environmental drivers (STE(E)PV): (S) lack of generational renewal in agriculture leads to lack of know how needed to change practices; lack of control and monitoring of contaminants that would allow for timely detection of contaminatin; lack of training and knowledge (Econ) lack of financial resources or limited economic marginsfor farmers to adapt to sustainability standards; market instability and unfair competition can discourage value chain actors from transitioning towards sustainable practices; cost minimisation in agri food production; weak market incentives for pollution control (P) Policy changes and new regulatory requirements to reduce pollution are perceived as risks by businesses, with potential disruptions and costs associated with compliance; lack of enforcement of regulatory frameworks targeting pollution (T) agriculture reliance on inputs (fertilisers, pesticides, veterinary drugs)</td></tr>
</table>

Pathways:

Direct pathways:	**Indirect pathways:**
• Food chain contamination: industrial accident, recycling related contamination, unreliable laboratory methods	• Soil pollution (cadmium, copper, zinc and pesticide residues, sewage sludge)-->soil not able to filter polluting substances-->

• Heavy metals (eg mercury, cadmium) and persistent organic pollutants (PCBs) --> accumulate in soil, water, living organisms, --> contamination , for fish and aquaculture: harms fish health and reproduction --> risks to human consumption (JRC, 2023) • Heavy antibiotic use in the meat sector --> development and spread of antimicrobial resistance (AMR) in livestock --> resistant bacteria transmitted to humans through food, environment, and direct contact --> reduced effectiveness of medical treatments, increased infection severity, higher healthcare costs, and elevated mortality risks (JRC, 2023) • Chemical contamination (incl. antibiotics) in meat/dairy production ---> expansion and worldwide spread of new antibiotic resistance genes --> emergence of human infectious diseases classified as zoonoses (JRC, 2023; EEA &JRC, 2025) • Water pollution (pesticide contamination, nutrient overload, emerging contaminants like PFAS and microplastics)--> absorption by crops and bioaccumulation in soils and feed --> reduced crop growth, residues in fruits, vegetables, livestock gets contaminated --> contamination of food supply chain, food production reduction (Ferreira et al, 2022; EEA, 2024b) • Water pollution (nutrients and pesticides) --> nutrient overload, pesticide contamination in freshwater and groundwater --> risk to food safety (10% of groundwater in the EU contaminated by pesticides in 2021) (EEA, 2024b) • Antimicrobial residues and genes --> contamination of aquatic systems through agriculture run-off and wastewater --> antimicrobial resistance transmission among microbial communities --> transmission to food supply chain	contamination of food products (JRC, 2023; EEA & JRC 2025) • Soil degradation from pollution --> loss of fertility, affects growth and health of plants; --> loss of agricultural productivity (EEA&JRC, 2025)

• Air pollution (ozone from industry and transport)--> excessive concentration of ground level ozone causes damage to plants --> reduces growth rates --> lower crop yields (EUR 2 billion in damage to food crops per year from ozone) (EEA&JRC, 2025) • Air pollution (ammonia from agriculture) --> acid deposition on soils and water bodies --> degradation of biodiversity and soil health --> lower food production (EEA&JRC, 2025)	

Unequal exposure and impacts (risk inequalities):

• Meat sector particularly exposed to chemical contamination, including antibiotics and hormones. • High copper concentrations are found in Mediterranean countries (esp. Greece and Portugal) drivent in part by extensive use of copper-based fungicides in olive and wine-producing regions, and the application of sewage sludge. (Ferreira et al, 2022; EEA & JRC, 2025) • Water pollution is more prevalent in parts of central and Western Europe, including Germany and the Netherlands . Groundwater from diffuse sources (particularly agriculture) is widespread in western and central Europe • Pesticide pressure is more acute in regions dominated by intensive arable and permanent crop farming, specifically naming countries like Belgium, Bulgaria, Cyprus, western and northern France, north-western parts of Germany, Italy, Malta, the Netherlands, Romania, and Spain (EEA, 2024b). • Eutrophication is mainly observed along the coasts of the North East Atlantic Ocean (high riverine nutrient inputs), from France to Denmark/Sweden. (EEA&JRC, 2025)

Magnitude, likelihood and uncertainty:

Magnitude (limited; critical/substantial; catastrophic): critical Pollution is widespread in Europe: pesticides residues in 75% of sites monitored by LUCAS in 2018 (EEA & JRC, 2025). Only 29% of European waters have good chemical status (most of this failure is due to toxic substances like mercury and brominated flame retardants). Ozone pollution concerns one third of Europe's agricultural land (EEA &JRC, 2025). 21% of EU agricultural soils have high cadmium levels (EEA&JRC, 2025)	**Magnitude basis:** EEA&JRC, 2025; JRC (2023); Ferreira et al, 2022

Likelihood (unlikely; about as likely as not (33-66%); likely): Likely. Nutrient losses: the EU is unlikely to meet 50% reduction in nutrient losses by 2030. The use and risk of chemical pesticides is likely to decrease (46% reduction betveen 2015-2017 and 2022). Soil degradation: unlikely to improve substantially over the next decades. PFAS and microplastics pollution are still causing a widespread public health crisis over the EU.	**Likelihood basis:** EEA&JRC, 2025; JRC (2023); Ferreira et al, 2022; (EEA, 2024b)
Confidence levels (high / medium / low) and sources of uncertainty: Medium • Antimicrobial resistance is still poorly monitored in the EU, especially in surface waters (EEA, 2025f) • The current harmonised risk indicators (HRIs) to track pesticide reduction have been criticised for their simplistic methodology. The actual volume of substances in the market is unclear (EEA & JRC, 2025) • Lack of a single, comprehensive indicator to assess progress in reducing nutrient losses. Data and indicators remain fragmented in the EU (EEA&JRC, 2025) • Soil contamination is still unadequately monitored, over 50% of potentially contaminated sites remain unregistered and have not been riks assessed (EEA&JRC, 2025) • Gaps in microplastic monitoring, standardised methodologies across different media are still being developed (EEA&JRC, 2025). • PFAS pollution has been poorly understood for a long time (only PFOS and PFOA were of primary concern for regulatory authorities). Lack of understanding about overall presence of PFAS in water at EU level (EEA, 2024b). There is no comparable EU-level quality standard for PFOS in groundwater (ibid)	

Timing:

Onset: gradual **Time horizon:** already occuring **Duration:** chronic **Trend:** increasing

Geography:

Geographic scale: global

Geographic contexts: agricultural

Interlinkages:

Interlinkages to other systemic risks (shared risk pathways):
Risk_03: Risk to food systems from soil degradation; Risk_04: Risk to ecosystems from intensive agriculture and soil degradation ; Risk_09: Risk to ecosystems from pollution and eutrophication ; Risk_10: Risk to human health from climate change ; Risk_12: Risk to health from air pollution; Risk_14: Risk to health, economy, wellbeing from chemical pollution; Risk_15: Risk to wellbeing, health and mental health from biodiversity loss / loss of nature

Cascading & compounding mechanism(s):
Pollution cascades from one environmental medium to others (soil, water, air): soil pollution creates water pollution through agricultural runoff, soil erosion (Ferreira et al, 2022)

Climate change: droughts and low river flow lead to increased pollutant concentrations in water bodies, worsening water quality (JRC, 2023)

More frequent rain events can increase run-off to rivers and lakes from agricultural areas and urban wastewater overflows. Flooding contaminates water supplies and soils. (EEA, 2024b).

Examples / case studies:

References:
JRC (2023). Risks and vulnerabilities in the EU food supply chain. https://doi.org/10.2760/171825; Ferreira, C. S. S., Seifollahi-Aghmiuni, S., Destouni, G., Ghajarnia, N., & Kalantari, Z. (2022). Soil degradation in the European Mediterranean region: Processes, status and consequences. Science of The Total Environment, 805, 150106. https://doi.org/10.1016/j.scitotenv.2021.150106; EEA (2024b). Europe’s state of water 2024: The need for improved water resilience. https://www.EEAeuropa.eu/en/analysis/publications/europes-state-of-water-2024; EEA & JRC (2025). Zero pollution monitoring and outlook 2025 (No. 13/2024). https://data.europa.eu/doi/10.2800/6470682; Antimicrobial Resistance in Surface Waters — Developing Environmental Monitoring for Better Risk Management. 18 Nov. 2025, https://www.eea.europa.eu/en/analysis/publications/antimicrobial-resistance-in-european-surface-waters-a-developing-area.

Risk ID: Risk_14

Risk to health, economy, wellbeing from chemical pollution

Systems affected: FOOD, ECON, ECOSYS, OTHER

Chemical pollution poses growing risks to human health, economy, and wellbeing due to widespread contamination of EU soils, water and air. For example, agricultural soils show high burdens of hazardous substances, with 21% containing elevated cadmium levels and pesticide residues detected in 75% of EU soils (EEA & JRC, 2024). Heavy metals (cadmium, lead, mercury, arsenic) accumulate in soils, water, and food chains, causing kidney, neurological, reproductive, and developmental harm. Microplastics and associated chemicals (BPA, phthalates, flame retardants) are ingested by humans and wildlife, disrupting ecosystems and entering food chains, while PFAS and other persistent organic pollutants persist in the environment, affecting immune and endocrine function. Agricultural chemicals, including pesticides and nitrogen compounds (NOx, ammonia), degrade soils, contaminate water, contribute to eutrophication, and damage crops, while industrial chemicals and consumer product pollutants add further exposure through inhalation and ingestion. Antimicrobial resistance from human and veterinary use, discharges from pharmaceutical industries, urban wastewater or agricultural manure put human health at risk, via transmission in the food chain and surface waters.

Direct exposure occurs through contact with contaminated consumer products, including plastics, textiles, electronics, as well as through inhalation and ingestion of polluted air and water.

Indirect pollution happens when industrial emissions, combustion processes, agriculture, and waste disposal release heavy metals into the atmosphere, which are deposited onto soils and water bodies where they bioaccumulate and biomagnify through food chains.

Beyond negative impacts on human health, chemical pollution creating direct and indirect costs on the economy. Direct costs include waste management and cleanup operations in response to oil spills or contaminated soils and water. Indirect economic impacts arise from disruption of ecosystem services. Contaminated soils, water and marine environments reduce the productivity of agriculture and fisheries. Lastly, accidents involving hazardous substances can create further negative impacts on the economy.

Drivers:

Primary environmental driver: pollution	**Primary environmental driver (subcategory):** chemical accident, marine chemical pollution, air pollution, chemicals in environment, household and industrial activities, plastic pollution, soil pollution, land pollution	**Other environmental drivers:** environmental degradation
Non-environmental drivers (STE(E)PV): (T and S) Inefficient recycling (eg batteries from electric vehicles); (P) weak governance and regulation (JRC, 2025); data and oversight gaps; transnational management challenges; (Econ) resource extraction and industrial pollution generating massive external costs; intensive agriculture with excessive chemical inputs (S) consumption patterns and lifestyle, social inequality (T) new chemical/ material development creating new sources of pollution ; (V) consumer preferences; disinformation campaigns about chemical risks from a product.		

Pathways:

Direct pathways:	**Indirect pathways:**
• Direct human contamination via consumer products and industry (chemicals incorporated into products) including plastics, textiles, electronics, food contact materials / direct inhalation of contaminated air/water--> contamination with PFAS and Brominated Flame retardants (BFRs), heavy metals, BPAs, inorganic arsenic (EEA, 2024b; EEA&JRC, 2024).Around 92% of the population of 11 EU countries have BPA concentration exceeding safe limits in urine (EEA & JRC, 2025); Contamination from the intake of microplastics (the estimated annual intake of microplastics by humans ranges from 70,000 to over 120,000 particles) (EEA, 2024a) • Plastic pollution -->direct impacts on marine life and indirect impacts via the food chain (in European seas; for instance, 93% of fulmar birds assessed in the North-East Atlantic Ocean had ingested some plastic) (EEA, 2024a)	•Atmospheric pollution generated by combustion processes, industrial activities, agricultural practices, waste disposal --> heavy metals released into the air and transported and deposited onto land and water bodies --> bioaccumulation and biomagnification in the food chain --> --> (mercury) negative impact on digestive, immune and nervous systems, kidneys and lungs; impacts development of fetuses and young children (lead) --> particularly concerning for neurodevelopment effecs in fetuses and children (cadmium)--> accumulates in the kidneys, potentially leading to renal failure , classified as a reproductive toxin and carcinogen (EEA& JRC, 2025) •Soil contamination with agricultural inputs-->pesticides and heavy metals in soils and

Risks to the economy: • Costs of waste management, costs of cleanup and containment operations (oil spills), costs of premature deaths (air pollution,) (JRC, 2025) • Ecosystem restoration costs • Technological risks from accidents involving hazardous substances : Natural Hazard Triggering Technological Disasters (Natech), Accidents related to the production and transport of hydrogen fuels and ammonia , the sourcing and processing of materials for renewable energy can involve environmental contamination from mining --> economic discruptions (JRC, 2025)	water (pollutants deposited on agricultural soils can migrate to aquatic ecosystems via surface runoff and groundwater transport --> •Contamination of plants and food products --> risks to human health •Atmospheric pollution generated by agricultural practices --> deposition of nitrogen oxides (NOx) and ammonia introduces excessive nitrogen into land and water bodies ---> eutrophication and acidification (EEA, 2022a) •Atmospheric pollution generated by agricultural practices --> formation of ground-level ozone --> taken up by plant leaves, damages agricultural crops and vegetation •Point source and wastewater (eg. urban wastewater treatment plants, urban discharges, landfills) --> pollution of soil and water by heavy metals, PFAS, micropollutants --> contamination via drinking water or bioaccumulation in the food chain (EEA, 2024b) •Discarded plastics --> leaching of toxic components --> contamination of soil and water --> risks to health (EEA, 2024a) Economic disruption: •Marine chemical pollution --> bans on aquaculture and shellfish harvesting to protect consumers --> business intrerruption for fisheries •Oil spills --> interruption of toursim activities, fisheries activity (JRC, 2025) •Discruption of ecosystem services due to environmental degradation from chemicals --> increased financial vulnerability •Chemical pollution --> pollution related health impacts --> increased healthcare costs (burden on the economy)

	• antibiotics pollution in the environment (human and veterinary use, discharges from pharmaceutical industries, urban wastewater and treated sewage sludge, and agricultural manures and waste)-->selection of antibiotic resistant gene --> transmission of antimicrobial resistance via food chain (including meat) and surface waters --> risk to human health (EEA, 2025f)

Unequal exposure and impacts (risk inequalities):

• Socioeconomic status linked to air pollution exposure : concentrations of fine particulate matter are consistently higher by around one third in the poorest regions of the EU, which often coincide with regions in the eastern part of Europe (EEA&JRC, 2025) Chemical pollution from agriculture: • Nitrogen (N) Surpluses are highest in areas with intensive livestock farming, including the Netherlands, Belgium, Germany, and Ireland (EEA & JRC, 2024) • Groundwater pollution failing good chemical status most often due to nitrates and pesticides is particularly widespread in western and central Europe (EEA, 2024b) Mercury soil pollution hotspots in Spain, Italy, Slovakia (EEA, 2024b) • Marine environment: The Baltic Sea remains largely unfavourable in terms of hazardous substances and eutrophication (EEA&JRC, 2025) • Children and the elderly are particularly vulnerable to air pollution, as well as lower-income individuals and communities (EEA&JRC, 2025) • Industrial workers involved in the handling and recycling of certain wastes, such as Waste Electrical and Electronic Equipment face risks due to exposure to chemicals (EEA&JRC, 2025)

Magnitude, likelihood and uncertainty:

Magnitude (limited; critical/substantial; catastrophic): Critical Mercury and brominated flame retardants individually cause chemical status failure in 49% of surface waters (EEA, 2024b) If ubiquitous, persistent, bioaccumulative, and toxic substances (uPBTs) were excluded from assessments, 80% of surface waters would achieve good chemical status (ibid)	**Magnitude basis:** EEA, 2024b; EEA, 2024a; EEA&JRC, 2025

Pesticides were detected above effect thresholds at between 10% and 25% of all surface water monitoring sites in Europe between 2013 and 2021 (EEA, 2024b) BPA exposure : up to 100% of people sampled in 11 EU countries were likely exposed above safe health thresholds, posing a potential risk to millions (EEA, 2024a) Microplastics : The annual intake of microplastic particles by humans is estimated to range between 70,000 and over 120,000 particles, acquired primarily through inhaled air, followed by food and drink (EEA, 2024a)	
Likelihood (unlikely; about as likely as not (33-66%); likely): likely - chemical pollution contributes to 10% of premature deaths in the EU (EEA&JRC, 2025). Widespread exposure to PFAS. BPA levels in urine exceed safety limits in 92% of the general population in 11 countries (EEA&JRC, 2025) 96% of urban population in the EU is exposed to PM2.5 levels exceeding strict WHO guidelines (EEA&JRC, 2025)	**Likelihood basis:** EEA, 2024b; EEA, 2024a; EEA&JRC, 2025
Confidence levels (high / medium / low) and sources of uncertainty: From low to high • microplastics : high uncertainty; cocktail effect of chemical mixtures (more research needed) • pollution driven non-communicable diseases : high uncertainty (complex interactions, unequal exposure…) (JRC, 2025) • antimicrobial resistance pollution in surface waters is still poorly monitored (EEA, 2025f) • uncertainty linked to cocktail effect of harmful substances in water (cumulative toxicity of chemical mixtures) (EEA, 2024b)	

Timing:

Onset: gradual **Time horizon:** already occuring **Duration:** chronic **Trend:** increasing

Geography:

Geographic scale: global

Geographic contexts: all

Interlinkages:

Interlinkages to other systemic risks (shared risk pathways):
Risk_02: Risk to economy and financial systems from loss of ecosystem services; Risk_03: Risk to food systems from soil degradation; Risk_04: Risk to ecosystems from intensive agriculture and soil degradation ; Risk_06: Risk to resilient ecosystems, nature protection, climate resilience and restoration from hot and dry weather (heat stress, drought, wildfire); Risk_08: Risk to food systems from pollinator loss; Risk_09: Risk to ecosystems from pollution and eutrophication ; Risk_10: Risk to human health from climate change ; Risk_12: Risk to health from air pollution; Risk_13: Risk to food systems from pollution (general, antibiotics, soil, water, chemicals); Risk_15: Risk to wellbeing, health and mental health from biodiversity loss / loss of nature; Risk_16: Risk to marine food systems from overfishing and invasive alien species; Risk_17: Risk to resilient ecosystems, nature protection, climate resilience and restoration from biodiversity loss

Cascading & compounding mechanism(s):
•Persistence of plastic pollution (plastic can last up to 500 years in some cases) (EEA, 2024a)

•Waste management impacts --> incinerating waste can contribute to air pollution

Examples / case studies:

References:
EEA (2024b), Europe’s state of water 2024: The need for improved water resilience. https://www.EEAeuropa.eu/en/analysis/publications/europes-state-of-water-2024; EEA & JRC (2025). Zero pollution monitoring and outlook 2025 (No. 13/2024). https://data.europa.eu/doi/10.2800/6470682; EEA (2022a). Air quality in Europe 2022 (No. 05/2022). European Environment Agency. https://doi.org/10.2800/488115; EEA & JRC (2024). The state of soils in Europe. JRC Publications Repository. https://doi.org/10.2760/7007291; EEA (2025b). Waste and recycling. https://www.EEAeuropa.eu/en/topics/in-depth/waste-and-recycling; EEA (2024a). Plastics. https://www.EEAeuropa.eu/en/topics/in-depth/plastics

Risk ID: Risk_15

Risk to wellbeing, health and mental health from biodiversity loss / loss of nature

Systems affected: OTHER, FOOD, ECON; ECOSYS

Biodiversity loss and ecosystem degradation undermine essential natural functions that protect human wellbeing, physical health, and mental health. When land use change destroys or fragments habitats, wildlife populations become stressed and more vulnerable to infection, increasing pathogen shedding and opportunities for spillover to humans. Degraded ecosystems also lose their "landscape immunity," reducing the natural ecological barriers that help prevent zoonotic transmission (Plowright et al., 2021; Breed et al., 2021).

The loss of regulating ecosystem services further exposes populations to environmental hazards. As freshwater ecosystems deteriorate, their ability to purify water declines, contributing to greater exposure to contaminated drinking and bathing water, an issue underscored by the fact that only 38% of European surface waters currently achieve good chemical status (EEA, 2020). These impacts are compounded by socio-economic factors, as economically precarious populations are more exposed (EEA, 2020).

Biodiversity loss also affects mental health and social wellbeing. The decline or absence of accessible, high-quality natural environments limits opportunities for recreation, relaxation, and social interaction, contributing to higher levels of psycho-physiological stress, mental fatigue, and chronic disease (EEA, 2020; Breed et al., 2021). However, establishing causal links and quantifying health risks stemming from the loss of these services remains challenging.

Drivers:

Primary environmental driver: environmental degradation; biodiversity loss	**Primary environmental driver (subcategory):** loss of pollinators, loss of ecosystem services,	**Other environmental drivers:** environmental degradation; habitat loss
Non-environmental drivers (STE(E)PV): (S) low socio-economic status; individual behaviour (diets, physical activity) (Econ) Unsustainable conusmption and production; unsustainable consumption and production (T) Dependency on vehicular transport leading to sedentary lifestyle (P) policies that fail to actively restore nature (Breed et al, 2021); considering hazards individually and not considering the environment media (V) lack of policies focusing on ecological health (Breed et al, 2021)		

Pathways:

Direct pathways:	**Indirect pathways:**
• Land use change inducing destruction and fragmentation of habitat -->increased vulnerability of animal host to infection -->infected host more likely to excrete	• Loss of air purification --> high pollution due to particulate matter, nitrogen oxide, ground-level ozone --> increased risk of cardiovascular, respiratory diseases, cancers,

pathogens into the environment (shedding), increased exposure of other individuals--> spillover of a pathogen to humans (Plowright et al, 2021; Breed et al, 2021) • Ecological degradation --> loss of landscape immunity --> weakened barrier against zoonotic spillovers (Plowright et al, 2021) • Ecological degradation in urban areas --> loss of temperature regulation effect ---> urban heat island effect --> increased exposure to high temperatures --> impacts on health (EEA, 2020) • lack of accessible , high quality natural environments --> loss of space for recreation, relaxation, social interaction --> decreased mental health (psycho-physiological stress and mental fatigue, chronic diseases) (EEA, 2020; Breed et al, 2021)	etc --> approximately 400,000 premature deaths annually in the EU (most from particulate matter) (EEA, 2020) • Loss of water purification capacity of ecosystems --> exposition to contaminated water through drinking and bathing (only 38% of surface waters achieve good chemical status) --> health impacts for human populations (EEA, 2020, Breed et al, 2021)

Unequal exposure and impacts (risk inequalities):

• Socially deprived populations are more affected by poor air quality, especially in urban areas (EEA, 2020). Children, pregnant women and elderly people are among the most sensitive to environmental stressors, in particular air pollution (EEA, 2020) • People relying on small water supplies and private wells face higher risks of water contamination compared to those served by large, regulated systemss (EEA, 2020) • Socially deprived populations tend to have reduced access to high-quality green spaces in urban areas (the richest 25% of the population in Greater Manchester had access to 2.7 times more green space than the most deprived 25%) (EEA, 2020; EEA, 2022b) • In the EU, the highest environmental contribution to mortality is seen in Romania (19 %) and the lowest in Sweden and Denmark (10 %)(EEA, 2020)

Magnitude, likelihood and uncertainty:

Magnitude (limited; critical/substantial; catastrophic): substantial air pollution : critical, largest environmental health risk zoonoses : substantial	**Magnitude basis:** EEA, 2020;

Likelihood (unlikely; about as likely as not (33-66%); likely): likely Ecosystem degradation is a recognised driver of the 13% of all deaths in the EU attributable to environmental stressors (EEA, 2020)	**Likelihood basis:** EEA, 2020, Breed et al, 2021
Confidence levels (high / medium / low) and sources of uncertainty: High • Dislocation in time and space : dirvers of degradation may be dislocated from the resulting health outcomes • Complexity of causality, with significant knowledge gaps. • Scarce data for indirect impacts: difficulty of attributing single events to broad environmental shifts and how they interact with social factors. • Difficulty to establish causal links , and quantify risks to health stemming from loss of ecosystem services (Breed et al, 2021) • Land use induced spill over : the causal associations between habitat change, physiological stress and pathogen shedding are rarely established. (Plowright et al, 2021) • The full potential of restoration is inadequately explored, quantification lacking regarding the health benefits of nature restoration (Breed et al, 2021) • Uncertainty regarding chemical and biological exposure and link to loss of ecosystem services.	

Timing:

Onset: gradual **Time horizon:** already occuring **Duration:** chronic **Trend:** increasing

Geography:

Geographic scale: global **Geographic contexts:** all ecosystems

Interlinkages:

Interlinkages to other systemic risks (shared risk pathways): Risk_01: Risk to ecosystems, and human systems including food and energy security, health, and economic stability from the Atlantic meridional overturning circulation (AMOC) collapse; Risk_02:

Risk to economy and financial systems from loss of ecosystem services; Risk_04: Risk to ecosystems from intensive agriculture and soil degradation ; Risk_06: Risk to resilient ecosystems, nature protection, climate resilience and restoration from hot and dry weather (heat stress, drought, wildfire); Risk_08: Risk to food systems from pollinator loss; Risk_10: Risk to human health from climate change ; Risk_13: Risk to food systems from pollution (general, antibiotics, soil, water, chemicals); Risk_14: Risk to health, economy, wellbeing from chemical pollution; Risk_16: Risk to marine food systems from overfishing and invasive alien species; Risk_17: Risk to resilient ecosystems, nature protection, climate resilience and restoration from biodiversity loss

Cascading & compounding mechanism(s):
• Low socio-economic status: The health and well-being of European citizens are fundamentally determined by economic circumstances and social dynamics. Wide disparities in socio-economic status lead to wide disparities in health outcomes. (EEA, 2020)

• Environmental synergies : stressors often combine (eg: air pollution + high temperature; living in urban environment concentrates stressors (air pollution + reduced access to nature) ; vulnerable populations suffering from increased exposure to environmental hazards.

Examples / case studies:
COVID-19

References:
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Risk ID: Risk_16

Risk to marine food systems from overfishing and invasive alien species

Systems affected: FOOD

Europe's seas are generally in poor condition due to increasing pressures, threatening the renewable living resources upon which fisheries rely (EEA, 2024e). The risk extends beyond commercial fish stocks : current trends indicate a likely decrease in the abundance of non-exploited animals (66.1% chance for pelagic and 69.1% for benthic species) (Bastardie & Brown, 2021). Invasive Alien Species (IAS) pose a major threat to local biodiversity and ecosystem functioning (Corrales et. al., 2018). Overfishing directly leads to reduced fish populations and, consequently, a likely decrease in fishing opportunities (53.8% probability under current trends), which subsequently drives a predicted decrease in profit (44.4%) (Bastardie & Brown, 2021). Excessive fishing also leads to economic losses, as more effort and cost are needed to catch reduced fish populations. Declining EU fisheries production, coupled with increasing pressures, means the EU is unable to meet consumer demand, relying heavily on imports (self-sufficiency is only 38%) (EEA, 2024d).

Overfishing affects the entire food web, not just target species, with the health and long-term resilience of marine ecosystems fundamentally at stake. The actual effect of fishing is hard to isolate because it constantly interacts with other pressures (e.g., climate variations, habitat degradation, and invasive species effects) (Bastardie & Brown, 2021).

Drivers:

Primary environmental driver: environmental degradation	**Primary environmental driver (subcategory):** overexploitation of resources, overfishing	**Other environmental drivers:** climate change
Non-environmental drivers (STE(E)PV): (S) Unsustainable consumption patterns; (P) Historically limited integration and coherence between fishery management and nature conservation policies; implementation and enforcement gaps of existing policies (Econ) profit maximisation/short-term focus, leading to overfishing; growing demand for seafood products; other elements of "blue economy" (e.g. offshore wind) put additional pressure on marine habitats; (T) fishing gear technology (e.g. bottom trawling, dredging) disrupts habitats; man-made interventions (e.g. Suez Canal enlargement) increase invasion rates for IAS		

Pathways:

Direct pathways:	**Indirect pathways:**
• excessive levels of fishing --> reproductive capacity of stocks affected • Direct exploitation of fish, shellfish, and other organisms --> Changes in fish communities and marine food webs	• Habitat degradation (e.g., from bottom trawling) --> reduced ecosystem resilience --> Limits the capacity of fish populations to adapt to concurrent environmental changes e.g. eutrphication, pollution, climate change -->

• Unintentional catch of juvenile and non-targeted species --> declines in populations of non-target species including Protected, Endangered, and/or Threatened species (PETs) (EEA, 2024d) • Use of certain fishing methods, such as bottom trawling and dredging --> disrupts seabed ecosystems, leading to the destruction of biogenic reefs and other vital habitats for marine life (EEA, 2024d) • Abandoned, lost, or otherwise disposed of fishing gear --> long-term threat to marine animals, causing death through entanglement or ingestion (EEA, 2024d) • Pollution from vessels and fishing activity --> marine pollution (EEA, 2024d) •IAS establish successful populations and compete with/prey upon native species --> Losses of local biodiversity, including endemic species, ecosystem functions, potential extinction of native species (EEA, 2025e, IPBES, 2019)	potential of stock depletion or fisheries collapse (EEA, 2024d) • Physical pollution (e.g. discraded gear) --> Microplastic entry into the food system (EEA, 2024d) • Cumulation of overfishing + climate change --> exacerbation of stocks decline and hbaitate degradation • Fishing vessel activity -> disruption of seafloor integrity --> release of carbon trapped in marine sediments (blue carbon stocks) into the water column, which contributes to ocean acidification and further exacerbates climate change and rising seawater temperatures --> fish distribution and other ecosystem dynamics (EEA, 2024d) • Declining fish populations --> Economic losses and increased effortneeded to find and catch reduced fish populations • Reduced EU fisheries production --> increased reliance on global supply chains

Unequal exposure and impacts (risk inequalities):

• The reliance of coastal communities/fishers on marine resources means they are exposed directly to the economic consequences of resource depletion; implementing necessary conservation measures, such as limiting fishing in MPAs, often entails short-term costs to these communities (EEA, 2024d) • Benthic habitats are generally more severely degraded than pelagic habitats. (Bastardie & Brown, 2021) • Mediterranean and Black Sea face a more critical situation regarding fisheries sustainability compared to the North-East Atlantic and Baltic Sea - in the Mediterranean and Black Sea only 9% of assessed stocks are sustainably fished and in good biological condition(EEA, 2024f) • In the Eastern Mediterranean (Israeli Mediterranean continental shelf, ICS), the ecosystem is exposed to extreme environmental conditions, high rates of climate change, intense fishing pressure, and is intensely invaded by Indo-Pacific species (Corrales et. al., 2018)

Magnitude, likelihood and uncertainty:

Magnitude (limited; critical/substantial; catastrophic): critical	**Magnitude basis:** (EEA, 2024f)
Likelihood (unlikely; about as likely as not (33-66%); likely): likely (for probability of biodiversity decline of target and non-target species and habitat degradation)	**Likelihood basis:** Bastardie & Brown, 2021
Confidence levels (high / medium / low) and sources of uncertainty: The general decline of marine ecosystems and the role of key drivers like overfishing and IAS are generally considered well established or established but incomplete: the overall global impact of human actions (including climate change, biological invasions, overexploitation, pollution, and habitat destruction) on marine ecosystems is recognized, but the cumulative effect of multiple stressors remains largely unknown (Corrales et. al., 2018).	

Timing:

Onset: gradual

Time horizon: already occuring

Duration: chronic

Trend: The overall trend for the health and resilience of marine ecosystems is deteriorating despite success in reducing overfishing for some stocks in certain EU waters (EEA, 2024d, EEA, 2024e);

Geography:

Geographic scale: global / EU-wide

Geographic contexts: marine

Interlinkages:

Interlinkages to other systemic risks (shared risk pathways):
Risk_02: Risk to economy and financial systems from loss of ecosystem services; Risk_04: Risk to ecosystems from intensive agriculture and soil degradation ; Risk_06: Risk to resilient ecosystems, nature protection, climate resilience and restoration from hot and dry weather (heat stress, drought, wildfire); Risk_08: Risk to food systems from pollinator loss; Risk_09: Risk to ecosystems from pollution and eutrophication ; Risk_14: Risk to health, economy, wellbeing from chemical pollution; Risk_15: Risk to wellbeing, health and mental health from biodiversity loss /

loss of nature; Risk_17: Risk to resilient ecosystems, nature protection, climate resilience and restoration from biodiversity loss

Cascading & compounding mechanism(s):
• Climate change (specifically rising sea surface temperature) acts as a powerful compounding driver, interacting with overfishing and IAS to increase negative impacts

• Compounding stress can push species beyond their capacity to cope, leading to abrupt outcomes. For example, in the Eastern Mediterranean, mullets and hake, already stressed by fishing and alien species, decreased notably once the boundary of thermal tolerance was crossed in cumulative impact scenarios (Corrales et. al., 2018)

• Fishing activities like mobile bottom contacting gear can also lead to the release of carbon trapped in marine sediments (blue carbon stocks), further contributing to climate change and ocean acidification (EEA, 2024d)

Examples / case studies:

References:
EEA. (2024d). Healthy seas, thriving fisheries: Transitioning to an environmentally sustainable sector. https://www.eea.europa.eu/en/analysis/publications/healthy-seas-thriving-fisheries; EEA. (2024e). Opportunities to secure healthy marine ecosystems and a sustainable future for European fisheries. https://www.eea.europa.eu/en/newsroom/news/opportunities-to-secure-marine-ecosystems; EEA. (2024f). Status of marine fish and shellfish stocks in European seas. https://www.eea.europa.eu/en/analysis/indicators/status-of-marine-fish-and; Bastardie, F., & Brown, E. J. (2021). Reverse the declining course: A risk assessment for marine and fisheries policy strategies in Europe from current knowledge synthesis. Marine Policy, 126, 104409. https://doi.org/10.1016/j.marpol.2021.104409; Corrales, X., Coll, M., Ofir, E., Heymans, J. J., Steenbeek, J., Goren, M., Edelist, D., & Gal, G. (2018). Future scenarios of marine resources and ecosystem conditions in the Eastern Mediterranean under the impacts of fishing, alien species and sea warming. Scientific Reports, 8(1), 14284. https://doi.org/10.1038/s41598-018-32666-x; EEA. (2025). Europe’s environment and climate: Knowledge for resilience, prosperity and sustainability. https://www.eea.europa.eu/en/europe-environment-2025/main-report

Risk ID: Risk_17

Risk to resilient ecosystems, nature protection, climate resilience and restoration from biodiversity loss

Systems affected: ECOSYS

Biodiversity is key to the functioning and resilience of ecosystems, providing the shelter and resources necessary for multiple species in a system of interactions and dependencies. Resilient ecosystems aid Europe in both adapting to intensifying crises (e.g. floods, droughts) and meet climate-neutrality objectives through carbon sequestration and storage (EEA, 2023). Current unsustainable use of natural resources is causing biodiversity to decline globally faster than at any time in human history (IPBES, 2019). Moreover, a complex dependency existis between climate and biodiversity: climate change is a driver of biodiversity loss; nature degradation is a driver of climate risk, and climate change mitigation and adaptation are a potential driver of nature risk (JRC, 2025). Currently, 81% of protected habitats and 63% of other protected species in the EU are in a poor or bad state (EEA, 2023). This loss destroys the complex web of life, potentially leading to the decline and extinction of other species, ultimately risking the collapse of entire ecosystems. Insect decline is a particularly alarming trend within this broader biodiversity crisis. Evidence from Europe shows severe reductions in insect abundance, including a reported 75% decline in total flying insect biomass in protected areas in Germany over 27 years, threatening key ecosystem functions such as pollination, pest control, decomposition, nutrient cycling, and food web stability (van der Sluijs, 2020).

The risk of biodiversity loss and ecosystem collapse is ranked highly among the most severe long-term risks globally, rated by experts as the second-most severe risk over a 10-year horizon in the Global Risks Perception Survey (WEF, 2025). The risk posed by biodiversity loss to resilient ecosystems, climate resilience, and restoration in Europe is considered an emerging risk with cross-border implications and is also classified as a High-Impact, Low-Probability (HILP) risk, primarily due to the uncertainty surrounding the timing, location, and specific triggers that could lead to catastrophic ecosystem collapse (JRC, 2025). Biodiversity loss and restoration warrant urgent policy and societal attention because reversing the negative trend is critical for the long-term viability of the planet and human prosperity (IPBES, 2019).

Drivers:

Primary environmental driver: Biodiversity loss	**Primary environmental driver (subcategory):**	**Other environmental drivers:** Climate change, environmental degradation, pollution
Non-environmental drivers (STE(E)PV): (Econ, S) Unsustainable consumption and production patterns; (T) Agricultural intensifcation, pesticide use; (Econ) Direct exploitation of natural resources (e.g. overfishing), unsustainable resources use; (S) Urbanisation; (P) Insufficient regulatory frameworks and legal protection for ecosystems; (P) Lack of policy coherence		

Pathways:

Direct pathways:	Indirect pathways:
• Unsustainable land/sea use change --> loss or degradation of natural habitats and decreased connectivity between natural areas --> impact on ecosystem structure and functioning (JRC, 2025) • Decline in key species (e.g. pollinators) --> destruction of the food web --> decline and extinction of other dependent species, potentially leading to the collapse of entire ecosystems (EEA, 2025)	• degradation of carbon sinks --> reduced carbon sequestration and storage --> accelerated climate change (EEA, 2023) • loss of natural habitats --> loss of natural buffering capacity of ecosystems --> increased vulnerability to natural hazards (e.g. floods, landslides) (UNDRR, 2024) • loss of biodiversity --> degradation of ecosystems --> change in disease vectors and human-wildlife interactions --> increased risk of zoonotic diseases emerging (EEA, 2023; JRC, 2025)

Unequal exposure and impacts (risk inequalities):

• Agricultural sector particularly exposed to direct impacts from biodiversity loss and weakened ecosystems (EEA, 2025) • Financial stability is highly vulnerable to nature-related risks. Studies show that roughly 75% of bank loans in the euro area are extended to companies highly dependent on ecosystem services meaning that ecosystem degradation poses systemic risks to the financial sector (JRC, 2025) • Degraded ecosystems lose their capacity to buffer against hazards. The loss of coastal habitats and coral reefs increases the risk from floods and hurricanes for people living within coastal 100-year flood zones (IPBES, 2019)

Magnitude, likelihood and uncertainty:

Magnitude (limited; critical/substantial; catastrophic): Critical / catastrophic	**Magnitude basis:** (JRC, 2024; WEF, 2025)
Likelihood (unlikely; about as likely as not (33-66%); likely): High-impact, low probability for overall ecosystem collapse; high likelihood of overall decline	**Likelihood basis:** (JRC, 2025; IPBES, 2019)
Confidence levels (high / medium / low) and sources of uncertainty: High uncertainty (JRC, 2025) • Incomplete data • Ecosystem complexities - numerous interdependencies and processes	

• Ecosystems exhibit non-linear responses to change

• Technological/ methodological limitations, limiting the the ability of models to capture the complexity and dynamics of biodiversity-related risks.

• Spatial and temporal variability: biodiversity and ecosystem processes vary across different geographic locations and time scales

• Biodiversity - climate change nexus: climate change is a major driver of biodiversity loss; uncer-tainties related to future climate scenarios

• Socioeconomic factors: human activities, policy decisions, and economic developments might influence biodiversity outcomes (JRC, 2025)

Timing:

Onset: gradual

Time horizon: already occuring

Duration: chronic

Trend: increasing

Geography:

Geographic scale: global

Geographic contexts: all ecosystems

Interlinkages:

Interlinkages to other systemic risks (shared risk pathways):
Risk_02: Risk to economy and financial systems from loss of ecosystem services; Risk_04: Risk to ecosystems from intensive agriculture and soil degradation ; Risk_06: Risk to resilient ecosystems, nature protection, climate resilience and restoration from hot and dry weather (heat stress, drought, wildfire); Risk_08: Risk to food systems from pollinator loss; Risk_14: Risk to health, economy, wellbeing from chemical pollution; Risk_15: Risk to wellbeing, health and mental health from biodiversity loss / loss of nature; Risk_16: Risk to marine food systems from overfishing and invasive alien species

Cascading & compounding mechanism(s):
• Ecosystem disruption --> zoonotic spillover --> public health strain (IPBES, 2019)

• Loss of carbon sinks --> accelerated climate change (EEA, 2023)

• Increased occurrence of natural disasters due to weakened natural disaster resilience (deforestation, loss of coastal mangroves...) (JRC, 2025)

• Food shortages and loss of livelihoods as a consequence of decline in fisheries and agriculture (JRC, 2025)

• Freshwater: degradation of ecosystems like wetlands and forests compromises water purification processes, leading to reduced access to clean drinking water and increased waterborne diseases (JRC, 2025)

• Air quality: loss of vegetation diminishes air filtration capabilities, resulting in higher concentrations of pollutants and allergens, which can exacerbate respiratory conditions such as asthma. (JRC, 2025)

Examples / case studies:

References:

EEA (2023). The importance of restoring nature in Europe. https://www.EEAeuropa.eu/en/analysis/publications/the-importance-of-restoring-nature-in-europe; IPBES (2019). Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. IPBES secretariat, Bonn, Germany. 1144 pages. ISBN: 978-3-947851-20-1; JRC (2025). Analysis of Risks Europe is Facing: An Analysis of Current and Emerging Risks (No. EUR 40352). European Commission, Joint Research Centre. https://doi.org/10.2760/0176850; World Economic Forum. (2025). The Global Risks Report 2025. https://www.weforum.org/publications/global-risks-report-2025/; EEA (2025). Protecting and restoring Europe's wild pollinators and their habitats. https://www.EEAeuropa.eu/en/analysis/publications/protecting-and-restoring-europes-wild-pollinators-and-their-habitats; United Nations Office for Disaster Risk Reduction (UNDRR). (2024). Nature for Resilience: Policy Brief. UN Office for Disaster Risk Reduction. https://www.undrr.org; JRC (2024). Cross-border and emerging risks in Europe: Overview of state of science, knowledge and capacity. Publications Office. https://doi.org/10.2760/184302; Van Der Sluijs, Jeroen P. (2020) 'Insect Decline, an Emerging Global Environmental Risk'. Current Opinion in Environmental Sustainability 46: (39–42. https://doi.org/10.1016/j.cosust.2020.08.012.

Risk ID: Risk_18

Risk to economy and financial systems from changing weather patterns, water stress and drought

Systems affected: ECON

Water stress affects approximately 20% of European territory and 30% of the population every year, figures likely to increase due to climate change (EEA, 2024b). The average annual economic loss caused by droughts in the EU and the UK between 1981 and 2010 was estimated at approximately EUR 9 billion per year. Extreme events in recent years suggest this figure is now much higher; for example, the continent-wide drought and heat event in 2022 alone cost up to EUR 40 billion (EEA, 2024). More frequent climate extremes can result in reduced tax revenues, increased government expenditure (e.g., for disaster recovery or social costs), lower credit ratings, and increased costs of borrowing and pose a substantial threat to property and insurance markets (EEA, 2024). Droughts and heat stress are a major challenge to the agricultural sector, leading to crop failures, reduced yields, and substantial economic damage (EEA, 2024). They also strain the energy sector, water-intensive industries and river transport. Climate-related financial risks disproportionately affect low-income households, small and medium-sized enterprises (SMEs), and local economies reliant on ecosystem services. or example, low-income households face higher risk due to reduced financial resilience and increased sensitivity to rising food and water prices.

Impacts rarely occur in isolation but are the result of compounding or cascading risks. For instance, a persistent lack of precipitation combined with higher-than-average temperatures leads to severe drought (meteorological drought), which is worsened by increased evapotranspiration (agricultural drought) (JRC, 2024). Climate hazards act as risk multipliers further affecting the resilience of systems that are already weak due to non-climatic factors (e.g. unsustainable water management, pollution, aging infrastrcuture) (EEA, 2024). A disruption originating in one system quickly transmits risk to others, causing a chain of system failures.

Drivers:

Primary environmental driver: climate change	**Primary environmental driver (subcategory):** changing weather patterns, water stress, drought	**Other environmental drivers:**
Non-environmental drivers (STE(E)PV): (T) Ageing and poorly maintained infrastructure; Leakages in public water supply infrastrcuture; physical alterations of waterways; (Econ) intensive water consumption in agriculture and other sectors (public water supply, industry, energy production); (P) water management practices poorly adapted to rapid environmental changes; (S) Existing socio-economic inequalities and disparities in wealth and access to resources determine the vulnerability of populations to climate impacts; Workers whose occupations require them to work outdoors, such as those in agriculture and construction, face disproportionately high exposure to heat stress, which affects labour productivity and contributes to economic risk;		

Pathways:

Direct pathways:	**Indirect pathways:**
• Rising temperatures and droughts -->crop failures / reduced yields --> increased food prices and volatility --> increased credit risks to financial institutions from agricultural borrowers (EEA, 2024; JRC, 2024) • Drought --> reduced hydropower generation --> reduced energy output, impacting profitability of energy companies (JRC, 2024) • Low water levels in inland waterways --> Severe impediment to inland navigation, disrupting freight transport and leading to economic losses across countries (EEA, 2024b) • Reduced water volume --> increased pollutant concentration --> Deterioration of public water supply and risks to water-intensive industries dependent on fresh, clean water (EEA, 2024)	• Power outages / energy supply shortfalls --> secondary disruptions across economic sectors --> wider economic and financial impacts • Losses suffered by frims (e.g. due to crop failures) --> incrreased probability in loan defaults --> increased credit risk for financial instituions --> tightening of credit conditions for overall economy (EEA, 2024) • Increased frequency and severity of events --> insurers may raise premiums or withdraw coverage, increasing the protection gap (uninsured losses) --> risk is transferred to households and businesses, potentially amplifying economic instability --> pressure on public finances (EEA, 2024) • Large-scale climate-disruptions lead to increased government expenditure for recovery and disaster relief, coupled with reduced tax revenues from affected regions/sectors

Unequal exposure and impacts (risk inequalities):

• Southern Europe is identified as a hotspot region particularly exposed to the increasing impacts of heat and prolonged droughts. This region faces critical risk levels from heat and drought impacts on agricultural production, outdoor wor and summer tourism as well as critical risk of crop failures and reduced yields during years of prolonged drought and excessive heat (EEA, 2024)

• Northern Europe, which historically had ample water is also recently experiencing water stress (EEA, 2024). Drying due to enhanced evaporation occurs even in regions with an increase in annual precipitation. It has resulted in summer drying in western and northern Europe (EEA, 2024)

• Economic sectors dependent on water resources and stable climatic conditions are acutely impacted. This includes agriculture, energy and transport sectors (EEA, 2024)

Magnitude, likelihood and uncertainty:

Magnitude (limited; critical/substantial; catastrophic): From limited in the near term to critical in the long-term for all Europe or risk to population and economic sectors due to water scarcity. From substantial in the near term to catastrophic in the long-term for Southern Europe for risk to population and economic sectors due to water scarcity	**Magnitude basis:** EEA, 2024
Likelihood (unlikely; about as likely as not (33-66%); likely): Likely for risk to population and economic sectors due to water scarcity: all Europe and southern Europe: water scarcity is already impacting society during drought periods, in particular in southern Europe.	**Likelihood basis:** EEA, 2024
Confidence levels (high / medium / low) and sources of uncertainty: Medium for risk to population and economic sectors due to water scarcity: all Europe and southern Europe (EEA, 2024) Overall confidence in the assessment of current water security risks in Europe is high, grounded in extensive empirical evidence, observed climate impacts, and a strong scientific basis supported by IPCC assessments and national and regional research. Confidence in future risks is also substantial but more conditional, as it depends on addressing remaining uncertainties, particularly around localised impacts, groundwater dynamics, water quality, infrastructure vulnerability, and complex socio-environmental interactions through improved uncertainty analysis, modelling ensembles, and cross-border research (EEA, 2024).	

Timing:

Onset: gradual **Time horizon:** already occuring **Duration:** chronic **Trend:** increasing

Geography:

Geographic scale: EU-wide, Southern Europe particularly affected **Geographic contexts:** all

Interlinkages:

Interlinkages to other systemic risks (shared risk pathways): Risk_02: Risk to economy and financial systems from loss of ecosystem services; Risk_06: Risk to

resilient ecosystems, nature protection, climate resilience and restoration from hot and dry weather (heat stress, drought, wildfire); Risk_07: Risk to food systems from extreme weather events (incl. drought, water stress and heat stress); Risk_08: Risk to food systems from pollinator loss; Risk_11: Risk to energy transitions and industrial transformation from heat stress, water stress and drought

Cascading & compounding mechanism(s):

- Prolonged drought can make subsequent heavy rainfall worse as dry, compacted soil repels water, increasing surface runoff and intensifying pluvial or fluvial flooding. This compounding of hazards leads to multiplied impacts and catastrophic consequences (EEA, 2024)

- Drought-induced low flows in rivers increase the concentration of pollutants (including nutrients and salts), deteriorating water quality. This is compounded by high temperatures, which facilitate toxic algal blooms, leading to ecosystem collapse (e.g., the Oder River disaster in 2022). Water contamination cascades into public health risks and severely disrupts the use of water resources by utilities and industries (EEA, 2024)

Examples / case studies:

References:

EEA (2024b). Europe’s state of water 2024: The need for improved water resilience. https://www.EEAeuropa.eu/en/analysis/publications/europes-state-of-water-2024;

EEA (2024). European climate risk assessment. Publications Office. https://data.europa.eu/doi/10.2800/8671471;

JRC (2024). Cross-border and emerging risks in Europe: Overview of state of science, knowledge and capacity. Publications Office. https://doi.org/10.2760/184302

Risk ID: Risk_19

Risk to economy from extreme weather events incl. flooding

Systems affected: ECON

Extreme weather events pose escalating risks to Europe's economies, with floods representing one of the most damaging hazards (EEA, 2024). The economic consequences are already substantial: between 1990 and 2020, floods caused an estimated EUR 170 billion in economic damage across Europe (Paprotny et al., 2023). Single events can be particularly destructive. The catastrophic floods that struck Germany, Belgium, and the Netherlands in July 2021 alone resulted in estimated losses of EUR 44 billion (EEA,2024).

Floods can follow different patterns. Almost 49% of major flood events in Europe have been caused by short but intense rainfall, and these events account for 56% of flood-related fatalities (EEA, 2024). Due to heavy rainfall, rivers can swell and cause fluvial floods, groundwater can rise to surface levels, and dams can fail, causing major destruction. Coastal storms (such as Xynthia, Daniel, and Hans) and amplified by sea level rise, cause major damage to densely populated and economically active coastlines.

Flood pathways often link physical damage to broader economic and societal consequences. Floods can cause widespread destruction of buildings, as well as critical infrastructure (including water and sanitation), directly reducing economic output, imposing large repair costs and potentially disrupting essential services. Besides assets loss, asset values are increasingly exposed in central and Southern Europe because over 60% of bank loans are granted to companies in regions where ecosystems can no longer provide adequate flood protection (ECB, 2025)

Impacts on transport and energy infrastructure, can disrupt mobility and supply chains, amplifying business losses at regional and national scales (JRC, 205; EEA,2024; ECB, 2025). Similarly, direct damage to crops reduce agricultural productivity affecting food markets and rural livelihoods (ibid).

As climate change accelerates, high-intensity rainfall events are expected to become even more frequent (JRC, 2025). This could have major impacts on the financial sector, with increased frequency of floods resulting in increases in insurance prices and premiums, and potentially undermining EU emergency response capacity (EEA, 2024). There is an estimated €23 billion gap per year to adequately address flood risks in the EU (ECB, 2025). There is uncertainty remaining regarding the predictability of extreme weather events, including floods, and a high degree of complexity associated with assessing compounded risks (ibid).

Drivers:

Primary environmental driver: climate change	**Primary environmental driver (subcategory):** extreme weather event	**Other environmental drivers:**
Non-environmental drivers (STE(E)PV): (P) ineffective planning in flood prone areas; regulatory and enforcement gaps failing to incorporate future climate risks; reactive approaches to managing flood risks resulting in maladaptation (Econ) Insufficient investment and maintenance of infrastructure leading to adaptation deficit; financial risks in the property and		

insurance markets (affordability of flood insurance); high proportion of loans granted to companies in areas prone to flood risks (S) social inequality increasing vulnerability to flood risk (T) aging infrastructure; climate projections are difficult to integrate into planning and policy making decisisons.

Pathways:

Direct pathways:	**Indirect pathways:**
• Floods --> widespread damage to residential and non-residential buildings and critical infrastructure --> economic loss • Flooding --> impacts to transport infrastructure • Floods-->direct damage to crops and soil erosion --> loss of agricultural productivity (JRC, 2025; EEA, 2024) • Floods --> damage to critical infrastructure of water and sanitation sysetms like sewage treatment plants --> damage to drinking water infrastructure (EEA, 2024, EEA, 2024b) • Floods --> damage to cultural heritage and historical sites --> impact on the tourism sector (JRC, 2025; EEA, 2024b)	• Floods --> damage to energy production and distribution infrastructure --> leading to disruptions in electricity and gas supply --> potential impacts on energy security (EEA, 2024) • Floods --> damage to transport infrastructure (road and railway networks) --> disruption to transport system --> economic losses due to discruption of business activities (EEA, 2024; JRC, 2025; ECB, 2025) • Increased likelihood of floods --> rise in the price of insurance and reinsurance coverage and premiums increasing for customers--> financial impacts on livelihoods with higher impact on lower income households. (EEA, 2024) • Floods--> soil erosion and run-off in agricultural soils --> water pollution in rivers and lakes (nutrient run-off) (EEA, 2024b) • Flooding--> contaminatior of water supplies and soils with pathogsns (related to sewage) or chemicals from sediments --> economic costs for remediation and treatment costs (EEA&JRC, 2025) •floods can cause disruption of energy production, agriculture, inland shipping -->can transmit beyond primary production affecting manufacturing supply chains and raising operational costs across the real economy (ECB, 2025)

Unequal exposure and impacts (risk inequalities):

• Heavy rainfall is expected to be more frequent with climate change, with high confidence in northern Europe and Alpine regions, but less clear

patterns in western and central Europe (EEA, 2024). Decreased flood frequency in eastern Europe.

• Coastal floods will be more frequent due to long term sea level rise --> increased risk for coastal cities and regions in the long term (EEA, 2024)

• Floods may also become a major source of financial vulnerability for European

small and medium-sized enterprises (SMEs) (flood risk is priced into higher interest rates on new loans) (EEA, 2024)

• Urban areas are at particular risk from extreme precipitation (EEA, 2024)

• Low income households and disadvantaged groups are particularly affected by climate related weather extremes like floods (EEA, 2024) Low prosperity might hinder adaptability required to recover from a flood.

•Asset values are increasingly exposed in central and southern Europe because over 60% of bank loans are granted to companies in regions where ecosystems can no longer provide adequate flood protection (ECB,2025) Asset values are increasingly exposed in central and southern Europe, where the gap between the demand for flood protection and what the ecosystem can provide is most severe.

Magnitude, likelihood and uncertainty:

<table>
<tr><td>Magnitude (limited; critical/substantial; catastrophic): Critical

• The annual expected damage from coastal flooding in EU Member States and Norway has been projected to increase from EUR 1 billion in 2020 to EUR 1 trillion by 2100 under a high-emissions scenario (EEA, 2024)</td><td>Magnitude basis:
EEA, 2024</td></tr>
<tr><td>Likelihood (unlikely; about as likely as not (33-66%); likely): Likely

Attribution studies: climate change makes heavy rainfall more likely in Europe (EEA, 2024). For example, climate change made heavy rainfall 10 times more likely in 2023 in Greece, Bulgaria and Türkiye (EEA, 2024)</td><td>Likelihood basis:
EEA, 2024; JRC, 2025</td></tr>
<tr><td colspan="2">Confidence levels (high / medium / low) and sources of uncertainty: Medium to high (JRC,2025)</td></tr>
</table>

• Current climate risk assesments tend to be inherently conservative and systematically underestimate overall risk levels (EEA, 2024)

• Assessments often fail to capture risks associated with climate variability (such as extreme weather events), and assess complex cascading risks and compound effects (EEA, 2024) (e.g. explore the role of a drought preceding floods)

• Lack of EU-scale assessments of pluvial flooding with lack of harmonised data across countries (EEA, 2024)

• Uncertainty regardng cascading impacts on transport infrastructure and services dute to the absence of comprehensive sectoral risk assessments (EEA, 2024)

Timing:

Onset: sudden

Time horizon: already occuring

high impact (direct and indirect economic losses) expected from floods over the next 10 years (JRC, 2025)

Duration: chronic

Trend: increasing

Geography:

Geographic scale: global

Geographic contexts: all

Interlinkages:

Interlinkages to other systemic risks (shared risk pathways):
Risk_01: Risk to ecosystems, and human systems including food and energy security, health, and economic stability from the Atlantic meridional overturning circulation (AMOC) collapse; Risk_02: Risk to economy and financial systems from loss of ecosystem services; Risk_05: Risk to energy transitions and industrial transformation from extreme weather events including flooding ; Risk_10: Risk to human health from climate change ; Risk_20: Risk to energy transitions and industrial transformation from soil degradation and loss of ecosystem services

Cascading & compounding mechanism(s):
• Infrastructure failure: Infrastructure assets are often part of a network where a disruption to one asset can quickly cascade and affect other sectors and assets (EEA, 2024)

•Floods impacts can be exacerbated by long period of droughts. Droughts lead to soil compaction, reducing its capacity to absorb rainfall (EEA, 2024)

•The EU Solidarity Fund (EURF) could potentially be depleted due to excessive mobilisation (used 107 times between 2002 and 2022) (EEA, 2024). This could hinder Member States' financial capacity to recover from extreme weather events, including floods.

•Land use change (in particular urbanisation with soil sealing, altered farming practices, narrowing and alteration of riverbeds) has led to reduced space for water drainage (EEA, 2024)

•Sea level rise has increased the likelihood of coastal floods. The 1-in-100-year extreme flooding levels reach 2.5 to 5.0 meters in the Western Atlantic coast of Europe, the UK, and North Sea coast (EEA, 2024)

•Population growth --> increase in the number of households and rise in GDP --> more omes that are more valuable are subject to damage from flood risk (EEA, 2024) About 100,000 people per year are exposed to coastal flooding and economic damage is EUR 1.4 billion (EEA, 2024)

•Climate change drives hydrological extremes, which means that the same regions can be vulnerable to both floods and water scarcity/droughts. This makes the agricultural sector particularly vulnerable (EEA, 2024b)

•Increased flood risk could lead to tipping points where house prices collapse abruptly (EEA, 2024) (ie. in Rotterdam under a very high sea level rise scenario and the market replies with stark increase in prices).

Examples / case studies:
Floods in Slovenia in August 2023: 90% municipalities reported damage to infrastructure, The government estimates the total direct damage was EUR 9.9 billion (16% of GDP). There was severe damage to local and regional road networks and to supply networks

References:
EEA (2024b). Europe’s state of water 2024: The need for improved water resilience. https://www.EEAeuropa.eu/en/analysis/publications/europes-state-of-water-2024; EEA & JRC (2025). Zero pollution monitoring and outlook 2025 (No. 13/2024). https://data.europa.eu/doi/10.2800/6470682; EEA (2024). European climate risk assessment. Publications Office. https://data.europa.eu/doi/10.2800/8671471; JRC (2025). Analysis of Risks Europe is Facing: An Analysis of Current and Emerging Risks (No. EUR 40352). European Commission, Joint Research Centre. https://doi.org/10.2760/0176850; Paprotny, D., et al., 2023, An improved database of flood impacts in Europe,

1870—2020: HANZE v2.1, preprint, ESSD — Land/Hydrology (https://essd.copernicus.

org/preprints/essd-2023-321/); ECB, 2025 Nature at Risk: Implications for the Euro Area Economy and Financial Stability. nos. 978-92-899-7518–6, European Central Bank, 2025, https://doi.org/10.2866/3014103. Occasional Paper Series.

Risk ID: Risk_20

Risk to energy transitions and industrial transformation from soil degradation and loss of ecosystem services

Systems affected: ENER

Biomass is a critical element in achieving the EU's climate mitigation targets, primarily through its use in bioenergy and as a substitute for carbon-intensive fossil fuels and materials (EEA, 2023a). In 2021 biomass made up 56% of renewable energy consumed in the EU (EEA, 2023a). However, soil degradation and the associated loss of ecosystem services pose a significant risk to energy transitions and industrial transformation by undermining the natural resource base of the bioeconomy (EEA & JRC, 2024). Soils are the largest terrestrial carbon pool, and maintaining soil organic carbon (SOC) is essential for climate regulation. Yet more than 60% of Europe's soils are affected by degradation, reducing their capacity to deliver key ecosystem services and weakening climate mitigation efforts (EEA & JRC, 2024; Ferrerira et. al., 2022).

Land use competition further amplifies these risks. Policies that promote increased biomass extraction for bioenergy compete with food production, ecological restoration, and the retention of forest biomass for carbon sequestration. For example, expanding bioenergy crops can drive land-use change from permanent systems such as forests or perennial grasslands to rotational cropping, leading to SOC losses and biodiversity impacts (EEA 2025c, EEA 2023a). Climate change adds additional pressure by altering growing seasons, suitable cultivation areas, and biomass productivity. While warmer conditions may enable northward expansion of some tree species and energy crops, southern Europe is expected to face declining forest suitability and reduced crop yields due to increasing heat and water stress, alongside heightened forest fire risks that threaten biomass supply (EEA, 2019).

Drivers:

Primary environmental driver: environmental degradation	**Primary environmental driver (subcategory):** soil degradation	**Other environmental drivers:** land degradation; loss of ecosystem services
Non-environmental drivers (STE(E)PV): (S) Consumption patterns; e.g. a cultural shift towards healthier, plant-based diets impacts food systems (agricultural practices and food processing) as well as energy systems (available land for biofuel production) (EEA, 2025c); (T) use of larger and more efficent machinery in agriculture and forestry - driving force behind soil compaction; (Econ) Economic competition and demand for food and commodities necessitate agricultural intensification, impacting soil health; (Econ) profitability of crop and timber production dictates machinery choices and harvest methods, often incentivizing cheaper, damaging practices over sustainable land management (EEA & JRC, 2024); (P) Specific policy targets (e.g. renewable energy targets / EU's climate commitments) create direct demand signals for biomass as a substitute for fossil fuels; conversely, policies governing resource management or nature restoration introduce targets that reduce land available for biomass supply		

Pathways:

Direct pathways:	Indirect pathways:
• Soil carbon loss and ecosystem degradation --> reduced resilience of biomass supply --> volatility in energy and material inputs (EEA, 2023a) • Soil sealing and compaction reduce the soil's infiltration capacity --> higher rates of surface runoff during precipitation events --> increased flood peaks and higher risks of landslides --> direct physical damage to critical energy infrastructure (EEA & JRC, 2024; EEA, 2025a). • Degradation of carbon-rich soils --> terrestrial carbon sinks become active emission sources ---> emissions can offset the carbon savings gained from using bioenergy or bio-based materials, effectively stalling the progress of the energy transition toward climate neutrality (Smith et. al., 2021).	• Soil degradation and ecosystem carbon loss --> weakened LULUCF carbon sink --> increased mitigation pressure on energy and industrial sectors (EEA, 2023a) • Reduced domestic biomass availability (due to soil degradation or land protection for restoration) --> increased reliance on global biomass markets --> externalisation of environmental pressuress to non-Eu countries --> greater vulnerability to trade shocks and supply-chain disruptions (JRC, 2023a, EEA, 2025c)

Unequal exposure and impacts (risk inequalities):

• Southern Europe and the Mediterranean is a "hotspot" for desertification and drought, with over 25% of land at high risk (Ferreira et. al., 2022 • Northern and Central Europe may experience short-term yield gains for some crops as growing seasons become longer. However, they also face growing risks, including permafrost thaw in high-latitude areas, which releases methane and can damage infrastructure, as well as more frequent storms and heavy rainfall that increase soil erosion (EEA & JRC, 2024). • Sector impact: direct loss of soil fertility and biodiversity leads to persistent yield gaps, primarily affecting the supply of cereal crops (wheat, maize) used for both food and bioenergy (EEA, 2023a)

Magnitude, likelihood and uncertainty:

Magnitude (limited; critical/substantial; catastrophic): Critical in mid-term: scenarios estimate a 40-70% shortfall in the supply of biomass required for energy and materials by 2050	**Magnitude basis:** EEA, 2023a

Likelihood (unlikely; about as likely as not (33-66%); likely): Likely (already occuring): At least 61% to 63% of EU soils are already in a degraded state; rates are projected to increase by 13–22.5% in EU agricultural lands by 2050 due to evolving climatic and land-use factors.	**Likelihood basis:** EEA & JRC, 2024
Confidence levels (high / medium / low) and sources of uncertainty: High confidence (EEA & JRC, 2024, Table 3, p. 90) • Current assessments indicate that at least 61% of EU soils are degraded, but this figure is likely an underestimate due to significant data gaps and uncertainties, particularly regarding soil contamination, subsoil compaction, and the cumulative effects of multiple, overlapping degradation processes. (EEA & JRC, 2024) • Many countries lack comprehensive data on soil health (EEA & JRC, 2024) • A significant "gap" exists in biomass accounting; the use of 20% of all agricultural biomass is currently unknown, lost, or discarded (EEA, 2023a)	

Timing:

Onset: gradual **Time horizon:** already occuring **Duration:** chronic **Trend:** increasing

Geography:

Geographic scale: global; EU-wide **Geographic contexts:** forest; agricultural; coastal

Interlinkages:

Interlinkages to other systemic risks (shared risk pathways): Risk_01: Risk to ecosystems, and human systems including food and energy security, health, and economic stability from the Atlantic meridional overturning circulation (AMOC) collapse; Risk_02: Risk to economy and financial systems from loss of ecosystem services; Risk_05: Risk to energy transitions and industrial transformation from extreme weather events including flooding ; Risk_10: Risk to human health from climate change ; Risk_19: Risk to economy from extreme weather events incl. flooding **Cascading & compounding mechanism(s):** • As the availability of fertile land declines, competing demands for biomass intensify among

food production, nature restoration, and the growing policy-driven use of biomass for energy and bio-based materials. (JRC, 2023a)

• Soil compaction and sealing reduce water infiltration, which increases surface run-off and exacerbates flood peaks and landslides. These intensified hazards cause direct physical damage to critical energy infrastructure, such as electrical substations, transmission lines, and pipelines (EEA, 2019)

• Soil degradation can create a feedback loop in which soils shift from absorbing carbon to releasing it. This adds to greenhouse gas emissions, contributing to climate change, which then increases the risk of extreme events such as droughts and wildfires that further damage soil health and reduce biomass productivity. (JRC, 2023a, EEA & JRC, 2024)

Examples / case studies:

References:

EEA & JRC (2024). The state of soils in Europe. JRC Publications Repository. https://doi.org/10.2760/7007291; EEA. (2023a). The European Biomass Puzzle. https://www.eea.europa.eu/en/analysis/publications/the-european-biomass-puzzle;

Ferreira, C. S. S., Seifollahi-Aghmiuni, S., Destouni, G., Ghajarnia, N., & Kalantari, Z. (2022). Soil degradation in the European Mediterranean region: Processes, status and consequences. Science of The Total Environment, 805, 150106. https://doi.org/10.1016/j.scitotenv.2021.150106

EEA (2025c). Imagining a sustainable Europe in 2050. https://www.EEAeuropa.eu/en/analysis/publications/imagining-a-sustainable-europe-in-2050

EEA. (2019). Adaptation challenges and opportunities for the European energy system. https://www.eea.europa.eu/en/analysis/publications/adaptation-in-energy-system

Smith, J., Farmer, J., Smith, P., & Nayak, D. (2021). The role of soils in provision of energy.

JRC (2023a). Biomass production, supply, uses and flows in the European Union. JRC Publications Repository. https://doi.org/10.2760/811744

8.2 ANNEX 1A – Environmental Risk Database

The Annex 1A is available for download on the IEEP website at this link: https://ieep.eu/wp-content/uploads/2026/05/ANNEX-1A-Risk-Fiche-Database-Ecologic-IEEP-2026.xlsx

8.3 ANNEX 2 - System Network Diagrams

This annex is available for download at this link: https://ieep.eu/wp-content/uploads/2026/05/ANNEX-2-System-Network-Diagrams-IEEP-2026.pdf

8.4 ANNEX 3 – Risk Driver & Governance Implication System Diagrams

Risk drivers

The risk-constellation diagram illustrates how multiple, interacting environmental drivers pose risks to achieving secure and sustainable food systems.

- **Climate change** drives extreme weather events, drought, water stress and heat stress. In addition, AMOC collapse would be a major tipping point, leading to catastrophic disruptions.
- **Biodiversity loss** results in loss of ecosystem services for the food system, including pollinator loss.
- **Environmental degradation**, especially soil degradation, negatively affects the quality and quantity of agricultural yields.

Many of these drivers interact in ways that amplify risks. For example, degraded soils are less likely to withstand extreme weather events and drought. The connections outside the diagram border signify the explicit links between environmental drivers.

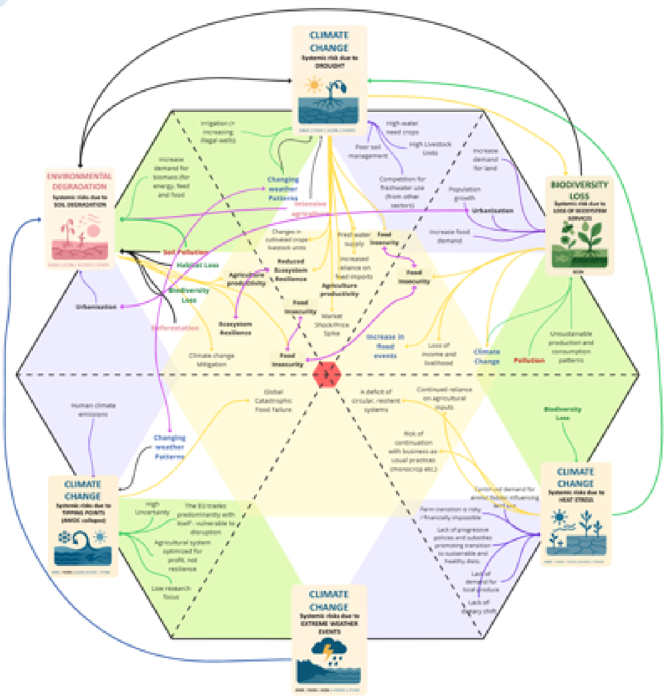
Non-environmental drivers such as urbanisation and dietary choices interact with environmental drivers, compounding the risk. For example, loss of agricultural land to development and higher shares of meat in peoples' diets put added pressure on agricultural lands and drive conversion of natural habitats, with negative effects on biodiversity and ecosystem services.

Potential impacts

The central area of the risk-constellation diagram shows the potential impacts of complex and systemic risks for the food system. If these risks are not addressed, profound impacts could materialize. For example:

- **Ecosystem resilience** could decline, with negative impacts for food production and the natural environment.
- **Food insecurity** increases, as harvests become less reliable due to increased frequency of shocks and decreased resilience to such disruptions.
- **Unsustainable practices** such as continued reliance on agricultural inputs and further intensification of agriculture could become the means of coping with short-term uncertainties, if the transition to a resilient and sustainable food systems has been inadequate.

Secure and Sustainable Food Systems



Governance Implications

The systemic network diagram highlights several potential impacts, including a decline in ecosystem resilience, food insecurity, and unsustainable practices such as continued reliance on agricultural inputs and further intensification of farming. Using the risk constellation, we can identify patterns and interconnections across different environmental risk drivers. This analysis can facilitate discussions on potential solutions and guide transformations in current governance mechanisms.

Raising Awareness and Education
Engaging stakeholders and promoting awareness through education can help shift consumption demands and better align food production with sustainable practices. Allow for the production of food that is more resilient to climatic risks.

Fostering Traditional Farming practices
Traditional farming practices are increasingly being lost to intensive agricultural methods. However, in many areas, these traditional approaches are informed by local ecological knowledge accumulated over generations. Supporting such practices can enhance ecosystem health, maintain key ecosystem services, and reduce soil degradation. In turn, this can decrease reliance on intensive agriculture and help reduce the environmental pressures and risks associated with it.

Decentralizing Food Production
Decentralizing food production can strengthen local resilience, reduce pressure on ecosystems, and improve food security by shortening supply chains.

Case Study

Environmental, Social, and Economic Regeneration of the Steppe Highlands, Southeastern Spain (AlvelAl)
This case study examines the development of AlvelAl, an association established in 2015 to promote the environmental, social, and economic regeneration of the Steppe Highlands. It illustrates a growing interest in local food systems as a resilience strategy, emphasizing regional farming and shorter supply chains as pathways for sustainable transformation.

Risk drivers

The risk-constellation diagram illustrates how multiple, interacting key environmental drivers pose risks affecting energy transitions and industrial transformation.

- **Climate change** drives extreme weather events, drought, wate stress and heat stress. AMOC collapse would bring catastrophi disruptions to industrial and economic activity.
- **Environmental degradation**, especially soil degradation, negatively affects the quality and quantity of agricultural yields
- **Biodiversity loss** results in loss of ecosystem services that support the economy, especially the agricultural sector and food system.

Many of these drivers interact in ways that amplify risk. For example, more extreme weather causes droughts, floods, ecosystem damage and soil degradation. The connections outside the diagram border signify the explicit links between environmental drivers.

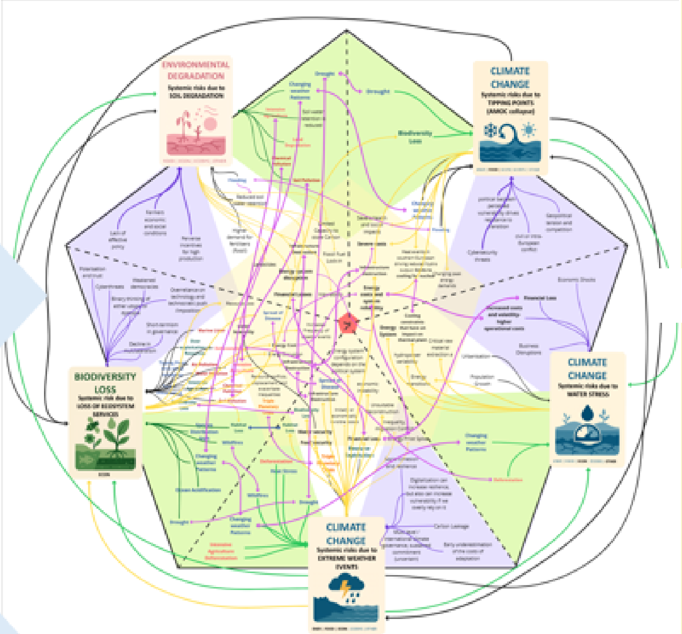
Non-environmental drivers such as the transition to renewable energies interact with environmental drivers, compounding the risk. For example, while renewable energies are essential to addressing climate change, they are more dependent on weather and hydrological conditions than fossil-based energy sources. Geopolitical instability, cyber threats and other non-climatic pressures interact with environmental drivers to amplify risks.

Potential impacts

The central area of the risk-constellation diagram shows the potential impacts of complex and systemic risks for energy transitions and industrial transformation. If these risks are not addressed, profound impacts could materialize. For example:

- **Fossil fuel lock-in** could result if the energy system is not made more resilient to extreme weather events and disruptions such as cyberthreats and geopolitical instability.
- **Reliability and resilience of energy systems** could decrease due to damage to physical infrastructure, disrupted supply chains, droughts and system instability, driving **energy costs** higher.
- **Increased land-use competition and further biodiversity lo** could result where increased biomass extraction competes wit food production, ecological restoration, and the need for carbon sequestration in soils and forests.
- **Cascading effects throughout the economy** could occur due to the central importance of both energy and ecosystem services for economic activities.

Energy Transitions and Industrial Transformation



Governance Implications

The systemic network diagram highlights several potential impacts, including fossil fuel lock-in, reduced reliability and resilience of energy systems, increased land-use competition, and further biodiversity loss. It also points to cascading effects across the broader economy.

Using the risk constellation approach, it is possible to identify patterns and interconnections among different environmental risk drivers. This type of analysis can support informed discussions on potential solutions and guide necessary transformations in existing governance mechanisms.

A key transition involves **moving from a centralized, fossil fuel–dependent energy model to a more decentralized and participatory system.** Energy communities—operating at local or regional scales—represent decentralized, self-organizing governance structures that generate and manage energy collectively. At the same time, the increasing frequency of droughts, heatwaves, and flash floods poses significant risks to conventional power plants, particularly those that rely heavily on water for cooling.

Strengthening institutional support is essential to enable these transitions. While renewable energy systems are critical for addressing climate change, they are also more dependent on weather and hydrological conditions than fossil-based energy sources. This makes adaptive governance and robust support frameworks especially important.

Case Study

Energy communities in Poland demonstrate the potential of participatory, decentralized energy governance to enhance local autonomy, strengthen social cohesion, and accelerate renewable energy adoption. However, scaling these initiatives effectively requires coherent policy support, clear long-term strategies, and targeted capacity-building.

8.5 ANNEX 4 – Case Study Assessment Criteria

Criteria for Transformative Resilience Governance Case studies

The following governance criteria have been defined using the EEA 2024 Report entitled Governance in Complexity AND the EEA Report on transformation resilience (EEA 2024) (*especially the transformation capacities*.)

There are a total six principles. Each principle is followed by a checklist. The goal is exploring the different case studies documentation using the checklist to explore if/how it fulfils the different criteria. This is a qualitative assessment - it does not have quantitative indicators/KPIs associated at this stage

1. **EXPERIMENTATION AS A TRANSVERSAL PRINCIPLE**

- This phase is looking for an inbuilt openness of the case study to embrace 'failures and opportunities to learn. Transformation governance is by its nature flexible and innovative so the case study must have a dedicated process and resources to allow for and even facilitate this process.

Criteria 1.1 – Openness to experimentation & innovation
Aim: Explores the extent to which the case study (institution or governance process) allows, normalises, and learns from trial-and-error and innovation, including the acceptance of things that did not go as planned.
Questions to answer:

1) *Are 'failures', unintended consequences, lessons learned explicitly documented and shared?*
2) *Was there evidence for or a 'defined process' by which the stakeholders had the capacity to be creative and innovative?*

Indicators/Sources to look for - Project documents, internal reports, staff surveys, meeting minutes or specific reference or evidence of learning and embracing things that do go so well. Experts can also look for an explicit document that is used to record the outcomes that may include such trials and/or failures. It could also be useful to look at the participation/co- creative processes that underpin some case studies, and these can serve as clear test beds for innovation and sharing lessons learned. Specific words such as 'failures', 'unexpected,', 'lesson learned', 'recommendation' 'innovation', and 'creativity' can also be used to find this information.

Criteria 1.2 – Feedback & quality of learning
Aim: Explore whether the case study has dedicated feedback loops that can be used to facilitate iterative learning, not just isolated outcomes. Also, there is a need to check the clarity, credibility, and accountability of pathways through

which participation influences outcomes, which is critical in governance of complexity.

Questions to answer:

1) *Does the case study feature explicit and operational feedback loops that reinforce lessons learned from experimentation?*
2) *How well (if at all) are those lessons learned integrated and considered going forward?*

Indicators/Sources to look for: Evaluation reports, policy revisions, learning repositories. The expert can also look for evidence of timely feedback loops throughout the case study's life span. Specific words such as 'feedback', 'iteration' can also help here. But the goal is to see if these aspects were indeed evident: the key is not just about recognising that things didn't go well but using that to inform outputs and developments going forward.

Criteria 1.3 – Institutional support & supporting capacities

Aim: Explore the extent to which the case study [re]allocates space, resources, leverages 'stranded assets thinking' and defines who is in charge for the case study in a specified timeframe. *Do not look for future proofing here but instead focus on the project timeframe.*

Question to answer:

1) *Are there explicit resources formally allocated for experimentation in the case study?*
2) *Has there been a clear reorganisation/reallocation of resources and supporting capacities to facilitate lessons learned?*
3) *Has there been an assessment of 'stranded' or wasted assets*

Indicators/Sources to look for- In this checklist we are looking to see if the case study has outlined resources allowing experimentation, innovation, learning and applying lessons learned. Or alternatively there was evidence of the experts' reallocating resources to account for learning. Specific words that you can look for: *Budgets, organisational charts, strategy documents. Reallocation, rethinking resources. Capacity building.*

Criteria 1.4 – Shifting norms & reviewing capacities

Aim: Evidence that case study is attempting to change *mindsets*, *norms*, status quo and the *political culture*. It is also crucial to see if public administrators and other stakeholders possess the structures, skills, and mandates to design and sustain meaningful participation and embed what is being developed and experiment into the current policy framework, practise or working culture. The worst case here is if the work exists in isolation.

Question to answer:

1) *Are creativity and reflexive practices part of the culture within the study?*
2) *Is there evidence of long-term societal behaviour changes*

3) *Is there an attempt to change ingrained policy and/or practices*

Indicators/Sources to look for: *Media analysis, internal culture surveys, case studies. Also look for Budgets, HR records, training logs, institutional guidelines, and legal frameworks.*

2. **SYSTEMS THINKING**
   - Systems thinking here refers to the understanding of interdependencies, causal pathways across disciplinary lenses. The stakeholder/project etc. should be considering cross-scale and cross-sector linkages, integrating diverse knowledge bases and supporting adaptive, multilevel and polycentric governance.

Criteria 2.1 - Recognition of system interdependencies
Aim: Explore the degree to which governance processes identify, map, and consider causal relationships, feedback loops, and cross-system and cross-scale linkages across different systems. i.e. ecologic, energy, food, society, culture and health.
Question to answer:

1) *Are cross sector and system linkages, knowledge acknowledged?*
2) *Is there evidence of reorientation of systems by building real-world contexts and anticipatory capacities?*

Indicators/Sources to look for – Here we are looking for evidence of systems thinking, not necessarily the fact that the expertise and knowledge have been included. Policy documents, strategy reports, environmental assessments. presence and frequency of system maps, causal-loop diagrams, explicit cross-impact or nexus analysis.

Criteria 2.2 – Cross disciplinary thinking
Aim: Explore how well systems thinking draws upon multiple scientific, social, and practical knowledge domains from across different disciplinary lenses.
Question to answer:

1) *Are cross sector linkages and/or knowledge acknowledged and used?*

Indicators/Sources to look for: Look for reference to different disciplinary lenses (e.g., ecology, cultural, social, economic, behavioural sciences, climate modelling, governance theory) and then the application of the thinking and results in the case study. Stakeholder rosters, assessment methodologies, tools of project teams, external review reports, and reference lists can be helpful here, too.

Criteria 2.3 – Cross scale thinking
Aim: Explore the extent to which governance integrates cross scales thinking (at the Landscape Scale) by way of example local, regional, national, EU
Question:

1) *Are cross-scale linkages, knowledge acknowledged and used?*

Indicators/Sources to look for: *Look for references to different scales and stakeholders that go beyond the focus of the case study scope. Resources that can help may be stakeholder lists, collaboration logs, memoranda of understanding, governance structures, meeting minutes.*

Criteria 2.4 – Transformation, flexibility and (appropriate) decentralisation
Aim: Transformative resilience requires flexibility and decentralization, calling for capacities that re-organize governance through collaboration, inclusive participation, embedding of activities, orchestration and leadership. In part, this can manifest in the shift towards polycentric and multi-level governance structures.
Question to answer:

1) *What type of governance structure is the case study operating within?*
2) *Is there and degree of flexibility within that governance structure?*
3) *Have absorptive capacities that need to be defined for governance components that must be maintained in any case (e.g. communication infrastructure).*

Indicators/Sources to look for - Look for references to different scales and stakeholders that go beyond the focus of the case study scope. Resources that can help may be stakeholder lists, collaboration logs, memoranda of understanding, governance structures, meeting minutes.

3. **PARTICIPATION**

Participation here refers to inclusion as a democratic right (Aarhus Convention). It refers to the need for broad, pluralistic, extended-peer-community participation, which is underpinned by co-design and co-creation, not only consultation. Transparency is a key element and should be a key aspect of the uptake of outcomes.

Criteria 3.1 – Breadth & diversity participation
Aim: Explore the degree to which participatory processes include a plurality of voices and perspectives through extended peer communities across demographics, expertise, sectors, and values.
Questions to answer:

1) *Are the right stakeholders involved at the right time, and are their voices heard and included?*

Indicators/Sources/Things to look for: This checklist focuses on the stakeholders included throughout the case study. Participant profiles, recruitment plans, outreach documentation, accessibility audits, stakeholder engagement processes and stakeholder lists.

Criteria 3.2 - Consultation to co-creation
Aim: Measures the *quality* of engagement—not only whether participation happens, but how meaningful, deliberative, and co-creative it is. Furthermore, it is important to explore the potential absorptive capacities within the case study. Absorptive capacities aim to create robust, resistant systems in which some elements can serve as a backup in times of crisis.
Question to answer:

1) *Are participatory processes meaningful (co-design or co-creation)?*
2) *Have the absorbative capacities, resources, and abilities of the stake-holders been considered and reviewed?*

Indicators/Sources to look for: This checklist is looking to see if the stakeholders were actively involved in the case study outcomes development. mini-publics, assemblies, deliberative dialogues, participatory mapping, co-design labs, shared agendas. Is there also specific evidence of that information be used and carried forward.

Criteria 3. 3 - Transparency
Aim: Explore the clarity, credibility, and accountability of pathways through which participation influences outcomes.
Question:

1) *Is the uptake pathway transparent and accountable?*

Indicators/Sources to look for – Can you clearly find the process for stakeholder engagement throughout the project, including mini-publics, assemblies, deliberative dialogues, participatory mapping, co-design labs, shared agendas. Is there also specific evidence of that information being used and carried forward.

4. **PRECAUTION**

Precaution places attention to potential harm under uncertainty or ignorance. It emphasises the need for proactive action and anticipation to prevent serious or irreversible damage and looks for careful consideration of scientific evidence of strength, risks, benefits, and distributional impacts. Attention is paid to how that precaution is operationalised through legal, procedural, and adaptive governance mechanisms

Criteria 4.1 - Assessment of uncertainty and risk
Aim: Explore how well governance processes recognise, categorise, and evaluates different types of uncertainty and potential harm.
Question to answer:

1) *Are uncertainties and potential harms explicitly assessed?*

Indicators/Sources to look for: *Here we are looking for an acknowledgement that risks evolve. Explore risk assessments, policy briefs, regulatory impact assessments, technical reports. There are also some specific words that can help here – 'generic resilience,' which refers to the building of resilience within a case study that applies to a variety of risks; it is not specific to one risk.*

Criteria 4.2 - Proactive governance & preventive action
Aim: Explores the needs of governance processes to recognise, categorise, and evaluate different types of uncertainty and potential harm. Second, we should explore preventive capacities, which aim to avoid, reduce the probability of and mitigate the impact of adverse events. Transformative resilience processes are designed to establish these preventive capacities step by step.
Question to answer:

1) *Are there measures where precaution is translated into anticipatory and preventive measures?*

Indicators/Sources to look for: *here we are looking to see if the recognition of the preventive actions has been actively integrated into measures. Look at reference to precautions within legislation, regulatory guidance, early-warning systems, programme documentation.*

Criteria 4.3 – Accountability & societal legitimacy
Aim: Explore if the precaution is socially accepted when processes are transparent, accountable, and consider distributional effects.
Question to answer:

1) *Are processes transparent, accountable, and socially legitimate and are distributional impacts and trade-offs considered?*

Indicators/Sources to look for: *public reports, consultations, impact statements, and oversight audits.*

5. **ANTICIPATION**

Anticipation here means acting in the present based on possible futures, not merely predicting them. It requires the integration of expectations, uncertainties, and long-term impacts into current decisions, as well as acknowledging that framing and imagining the future is inherently political and value laden. Finally, anticipation ensures that short-term actions align with long-term objectives. Anticipatory capacity informs supporting capacity by helping to identify the resources and systems needed to address future challenges. Supporting capacity, in turn, enables transformative capacity by providing the necessary infrastructure and tools for change.

Criteria 5.1 - Future proofing
Aim – Explore the degree to which governance processes explicitly consider long-term effects, potential scenarios, and emerging trends. A special focus on anticipative capacities which aims for early warning, impact assessment and strategy development (e.g. preparation for gradual major changes, shocks and crises).
Question to answer:

1) *Are long-term futures explicitly considered in current decisions?*

Indicators/Sources to look for - Policy documents, foresight reports, UNDP futures impact assessments, strategy plans. Also, some useful tools or references to search for can include (1) horizon scanning to identify plausible current and future events (e.g. shocks), trends (e.g. leading to stress) and issues (e.g. emerging crises), (2) anticipatory impact assessments of major changes, and (3) participatory development of shared visions of the future that allow for integrating resilience into sustainability transitions

Criteria 5.2 - Reflexivity & contextual framing
Aim - Recognition that anticipating the future involves subjective framing, social and ethical values, and reflexive evaluation of assumptions.
Question to answer:

1) *Are assumptions and scenario framings reflexively examined?*

Indicators/Sources to look for – it is one thing to identify and apply different anticipatory actions. However, it is crucial that any actions are co-created and context specific. Do the actions consider the current and future context of the case study? Look at foresight exercise reports, scenario documentation, meeting minutes, expert interviews.

Criteria 5.3 - Participation & diversity in anticipation
Aim – Explore how well anticipatory exercises involve a broad set of actors and perspectives, mitigating bias and enhancing legitimacy.
Questions to answer:
1) *Are diverse stakeholders and knowledge types included in anticipatory exercises?*

Indicators/Sources to look for - Foresight reports, participant lists, workshop outputs, policy integration documentation.

Criteria 5.4 - Alignment, coherence & adaptivity
Aim – Explore the availability and use of structured approaches and institutional frameworks to support anticipatory governance and ensure that anticipatory insights contribute to coherent, adaptive, and sustainable governance strategies. Furthermore, adaptive capacities aim to adapt systems to major changes. Systems that are desirable in terms of long-term sustainability transitions and that can be reconfigured incrementally in times of shock and crises must be defined and addressed.
Question to answer: –

1) *Do anticipatory insights inform adaptive, coherent, and sustainable governance strategies?*

Indicators/Sources to look for - Foresight reports, participant lists, workshop outputs, policy integration documentation.

6. **CARE**
   - Care means attending to relational, contextual, and ethical dimensions of governance. The recognition that responding to diverse needs of humans, animals, ecosystems, and communities. Finally, staying responsive and adaptive in the face of indeterminacy, rather than relying solely on predefined plans or universal procedures

Criteria 6.1 - Responsiveness to needs
Aim – Explore the degree to which governance actors and processes actively observe, respond to, and prioritise needs of affected entities (people, ecosystems, communities).
Questions to answer:

1) *Are the needs of humans, animals, ecosystems, and communities actively assessed and addressed?*

Indicators/Sources to look for - Needs assessments, community reports, policy documentation, program evaluations.

Criteria 6.2 - Relational & Ethical Framing
Aim - Care involves acknowledging that attention to some issues may deprioritise others and that sustainability transitions have differential impacts.
Question

1) *Are ethical, relational, and moral considerations incorporated into framing and decision-making?*

Indicators/Sources to look for - Needs assessments, community reports, policy documentation, program evaluations.

Criteria 6.3 - Recognition of Trade-offs
Aim - Care involves acknowledging that attention to some issues may deprioritise others and that sustainability transitions have differential impacts.
Questions to answer:

1) *Are trade-offs and distributional impacts recognised and mitigated where possible?*

Indicators/Sources to look for - Impact assessments, policy reports, stakeholder consultation outcomes, ethical reviews.

8.6 Annex 5 – Transformative Governance Case Study Fiches

Case Study Risk Fiche NO. 1

Case Study : Rotterdam Resilience Strategy

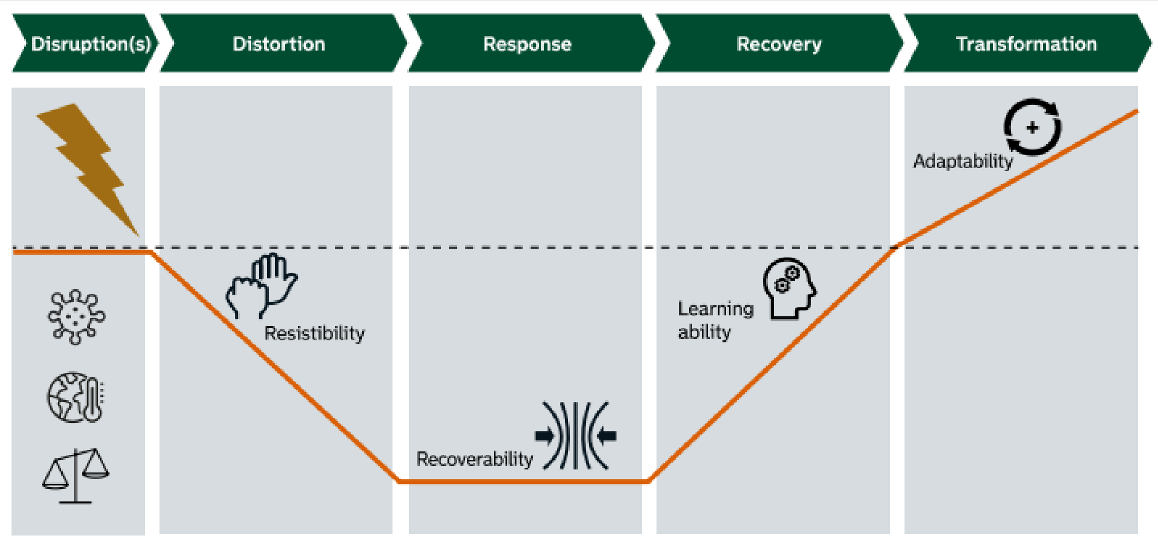
Note: The Rotterdam Case Study Fiche was not validated external by an expert. It is the authors interpretation.

System: Resilient ecosystems, nature protection, climate resilience and restoration.

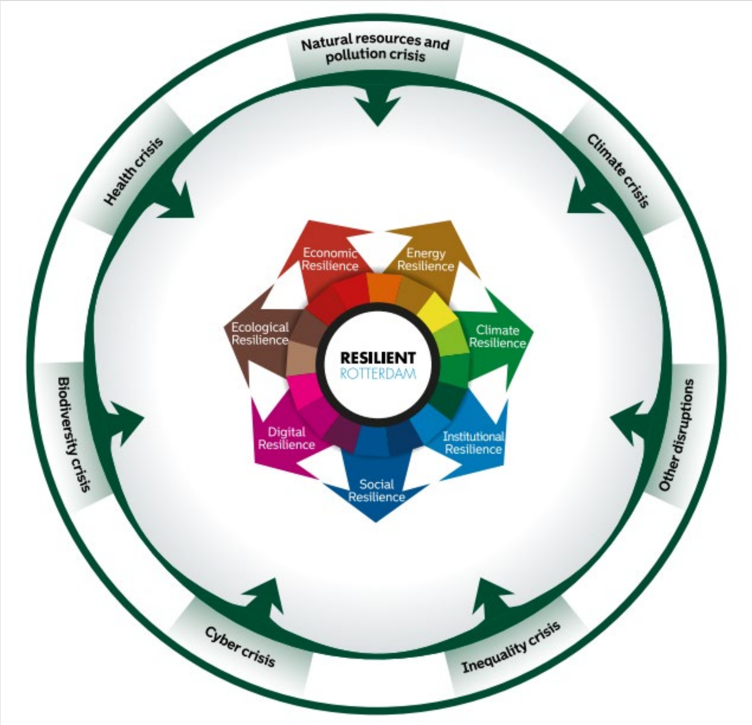
Context: Rotterdam is a city in the Netherlands that, since 2016, has been committed to understanding and strengthening its institutional resilience in response to three major planetary crises: the climate crisis, the biodiversity crisis, and the natural resources and pollution crisis. The city defines resilience into four characteristics: Resistibility, Recoverability, Learning ability and adaptability. This fiche focuses on the Rotterdam's resilience approach, focusing on the most recent iteration of the Rotterdam Resilience Strategy (2022–2027) core elements and governance. The strategy adopts a systems-based approach that prioritises governance reform, neighbourhood-scale planning, and the strengthening of local networks. Central to this approach is the lived experience of communities, positioning residents at the heart of resilience-building efforts in preparation for compounding and interconnected planetary crises.

Location: *Rotterdam, Netherlands.*	**Scale:** *City scale*	**Timeframe:** *2022-2027*
Responsiveness to systemic risks: The city of Rotterdam is facing a myriad of compounding risks, including rising sea level, heat waves, droughts, and socioeconomic inequality. The Rotterdam case aligns with the system of resilient ecosystems, nature protection, climate resilience, and restoration as rivers from environmental drivers are a central part of the city's Resilience Strategy. However, its Resilience Strategy goes beyond environmental risks and drivers. It adopts a systems approach to institutional Resilience that connects environmental, social, and economic dimensions through the ethos of bolstering institutional resilience to a myriad of crises.		

Images:



The phases of a crisis and the skills required to be resilient that are defined by the city of Rotterdam. This process underpins how the city stakeholders define resilience and seek transformational change. (Rotterdam Resilience Strategy, page 22) [1]



The conceptual model of Rotterdam's seven resilience themes to anticipate the known and currently unknown crises. (Rotterdam Resilience Strategy, page 28) [1]

1) **Evidence of Experimentation -** Refers to the inbuilt openness to embrace failures and opportunities to learn. Flexibility and innovation are crucial to effective transformation and therefore a dedicated process, resources and capacities must be allocated to facilitate experimentation.

Rotterdam is widely recognised as one of Europe's most innovative cities, particularly in urban design and resilient public policy. The Resilience Strategy Rotterdam 2022–2027 [1] **positions experimentation and innovation as both practical tools for embedding resilience into policy and implementation, and as core principles underpinning the city's resilience vision.** The strategy describes the development of a self-reinforcing "Resilient Rotterdam Ecosystem", in which knowledge development, policymaking, innovation, pilot projects, knowledge exchange, and city branding mutually reinforce one another, generating further learning and innovation. This process has contributed to the establishment of a strong and recognisable "resilient" identity among city stakeholders.

Pilot projects are identified as key instruments for experimentation and learning and are implemented across different districts of Rotterdam [1]. A prominent example is **the Resilient BoTu pilot** [2], **launched in 2019, which aims to support the neighbouring districts of Bospolder and Tussendijken in becoming Rotterdam's first "resilient district"**. The project combines transformative infrastructure investments with social programmes addressing debt, access to education, employment opportunities, and housing quality. It provides a concrete illustration of how experimentation and learning are operationalised at neighbourhood level and connected to broader city-wide resilience objectives.

Learning and adaptation are central to Rotterdam's resilience approach. **The strategy defines four key capabilities—resistibility, recoverability, learning ability, and adaptability—emphasising that knowledge gained from past crises and interventions should actively inform future decision-making**. Rotterdam's resilience trajectory began prior to the current strategy, notably with the city **explicitly built on lessons from previous strategy iterations and from changing global conditions, including the COVID-19 crisis.** Evaluations of the 2016–2021 resilience strategy highlighted the importance of a structured and integrated approach, while earlier pilot projects, such as Resilient BoTu2028 [2], generated insights that shaped subsequent actions. The strategy is supported by **strong institutional capacity and cross-departmental engagement. Initiated by the Municipality of Rotterdam**, it involved contributions from multiple sectors, including Urban Development, City Management, Social Development, Services, Work and Income, Administrative Affairs, and Corporate Support, as well as partners across the city. This broad involvement underlines the legitimacy of the strategy and reflects the integration of resilience across policy domains. The **appointment of a Chief Resilience Officer** [3] **further institutionalises resilience within the city's governance structure, supported by a dedicated resilience team and allocated resources for implementation.** Rotterdam's resilience work has also facilitated access to additional resources and funding, both internally and externally. The city has leveraged its resilience profile to participate in European programmes such as LIFE Urban Adapt [4] and LIFE@Urbanroofs [5], aligning its long-term strategy with broader EU priorities, including the European Green Deal. This positioning has contributed to international recognition, including Rotterdam's placement among the top five finalists for the European Capital of Innovation (iCapital) Award [6].

Shifts in norms and perspectives underpin Rotterdam's resilience approach. **Water is increasingly framed as an opportunity, reflecting a broader change in how environmental challenges are understood and addressed**. **Resilience is increasingly embedded as a guiding philosophy across Rotterdam's policy**

landscape, including in the Strategy on Spatial Planning and the Environment and the Safety Programme ensuring it is not treated as a standalone concept but as a cross-cutting principle shaping decision-making.

This approach is reinforced through a multi-year knowledge agenda, developed collaboratively with research and practice partners to generate both substantive and methodological insights. An example of this is in **The Resilient Delta Initiative (RDI)** [7] **which plays a central role in this learning ecosystem**. As a long-term partnership platform, the RDI supports Resilient Rotterdam through an integrated knowledge agenda addressing major societal and resilience challenges at both city and delta scales. By pooling resources, co-financing activities, and jointly generating knowledge, the RDI strengthens Rotterdam's capacity to address complex resilience challenges in a coordinated and sustained manner.

2) Systems Thinking - Refers to the understanding of interdependencies and causal pathways across disciplinary lenses. It focuses on cross-scale and cross-sector linkages, integrating diverse knowledge bases and supporting transformative, flexible and appropriately decentralised governance structures.

The Rotterdam Resilience Strategy is explicitly designed using a **systems-based approach**. Rather than addressing risks in isolation, the city developed an initial long list of potential crises and associated risks, drawing on national and international risk assessments. This comprehensive mapping exercise enabled the identification of interconnections, cascading effects, and long-term vulnerabilities across environmental, social, and economic domains. The strategy further recognises that interventions designed to prepare for specific crises often contribute to multiple forms of resilience. This systemic understanding is reflected in the use of current and target scenarios, which explicitly map how different types of crises can trigger, amplify, or interact with one another. By making these interdependencies visible, the strategy supports anticipatory planning and more integrated resilience interventions, including consideration of causal relationships, feedback loops, and nexus points between risks.

The strategy also demonstrates strong cross-disciplinary thinking. Resilience is structured across distinct but interconnected lenses—Climate, Ecological, Energy, Social, Economic, and Digital—each addressing urgency, guiding policy documents, objectives, current conditions, and strategic choices. This structure allows different disciplinary perspectives to be unpacked while supporting their integration into a coherent analytical framework. The development of the strategy itself was cross-disciplinary and collaborative, involving contributions from multiple municipal clusters, including Urban Development, City Management, Social Development, Services, Work and Income, Administrative Affairs, and Corporate Support, as well as external partners. **This collaborative process has contributed to the emergence of the self-reinforcing "Resilient Rotterdam Ecosystem", which functions as a platform for shared knowledge generation, innovation, and learning among stakeholders.**

While the Rotterdam Resilience Strategy operates primarily at the city scale and is led by the Municipality of Rotterdam, **it explicitly recognises the importance of multiple spatial scales. The strategy aims to strengthen resilience across the entire city, with particular emphasis on communities and neighbourhoods, reflecting the understanding that resilience is ultimately realised locally**. At the same time, the strategy is informed by, and aligned with, regional, national, and international policy frameworks. It references a wide range of higher-level policy instruments and is explicitly linked to the Sustainable Development Goals (SDGs) [8], reinforcing coherence across scales and situating Rotterdam's approach within a global sustainability agenda. A key objective of the 2022–2027 strategy is to scale up lessons learned from pilot projects, experiments, and knowledge exchange processes so that insights from local initiatives inform broader structural change across the city.

The strategy is **supported by an explicit governance structure designed to ensure long-term implementation and adaptability.** While decentralised in the sense that it is locally designed and tailored to Rotterdam's context, the resilience strategy does not operate in isolation. It is closely connected to policy objectives and governance frameworks at other scales, including national policies and international agendas such as the SDGs. **A central driver of this approach is the city's ability to align and coordinate a wide range of stakeholders, which enhances credibility, access to resources, and institutional legitimacy. This is particularly evident in the strategy's emphasis on "spin-offs" within its knowledge agenda—ideas, innovations, and lessons learned that have emerged from resilience work and evolved into new initiatives, further strengthening Rotterdam's resilience governance framework**.

2) **Participation -** refers to the need for transparent, broad, pluralistic, extended-peer-community participation, which is underpinned by co-design and co-creation, not only consultation.

Rotterdam places strong emphasis on collaboration and broad stakeholder participation as a core element of its resilience approach. The Rotterdam Resilience Strategy consistently highlights that complex resilience challenges cannot be addressed by single actors or sectors alone and require co-creation across multiple stakeholders. Collaboration functions both as a governance principle and as an operational mechanism, enabling integrated and inclusive resilience outcomes. **The city demonstrates broad stakeholder involvement across municipal departments, citizens and community groups, design and architecture professionals, industry, and academic institutions.** These multi-actor collaborations foster innovation, knowledge exchange, and co-creation, resulting in context-sensitive and socially embedded resilience interventions.

Rotterdam adopts a combined bottom-up and top-down consultation approach. Residents engage with the city through a variety of mechanisms, including the digital platform 'My Rotterdam', which allows continuous sharing of ideas, feedback, and concerns directly with municipal authorities. Complementing this, the city has introduced a governance layer between local communities and the municipal government: 39 neighbourhood council representatives—one per district—act as communication channels, ensuring that local perspectives inform city-level decision-making. The city also operates a participatory budgeting process, enabling community members to vote on local priorities and secure funding for grassroots initiatives aligned with the city's broader resilience and sustainability objectives.

4) Precaution - focuses on **preventing serious or irreversible harm under uncertainty by encouraging proactive action based on careful evaluation of scientific evidence, risks, benefits, and fairness**, and by applying precaution through legal, procedural, and adaptive governance tools.

A cornerstone of the Rotterdam Resilience Strategy is the principle that "a resilient city should be as well prepared for the unexpected, yet unknown, threats as possible." This philosophy reflects a deep appreciation for uncertainty and the systemic nature of risk. The strategy embeds this understanding within its systems change approach, which distinguishes three levels of intervention: structural, relational, and transformative. Structural interventions include policies, strategies, and budgets; relational interventions focus on networks, connections, and governance processes; and transformative interventions address behaviours, mindsets, and institutional culture. Resilience is therefore pursued not in response to specific hazards alone, but through the systemic enhancement of capacity across these levels.

Under each of the seven resilience themes, **the strategy maps current and target scenarios, including known risks and potential disruptions yet to be fully identified**. For example, geopolitical crises may trigger economic instability and population movements, with cascading social and infrastructural effects. The explicit inclusion of the "unknown" motivates proactive resilience-building across the city.

Proactive governance is central to Rotterdam's approach. **The strategy seeks to anticipate and prevent potential shocks, making resilience a guiding principle in urban policy.** For instance, in economic policy, the strategy states: "We will therefore be proactively steering towards resilience as a precondition and as one of the guiding principles for the city's economic policy. This new economy, aimed at broadening innovation and human capital, creates new employment opportunities for everyone. This will ensure a resilient economy also contributes to a socially resilient Rotterdam." [1]

Accountability and societal legitimacy are also key elements. **The Municipality of Rotterdam acts as the lead coordinator of the strategy while integrating contributions from multiple sectors and stakeholders**. The strategy clearly identifies responsible actors for each resilience theme and clarifies where accountability lies for facilitating and implementing interventions. Residents, referred to as "Rotterdammers," are positioned at the centre of the strategy, reinforcing community involvement and local relevance. The strategy defines its scope explicitly, focusing on city-level and community resilience across seven key themes, while excluding domains such as healthcare and terrorism, which are managed by other organisations. Lessons from the COVID-19 crisis inform interventions addressing social, economic, and ecological impacts.

Finally, Rotterdam seeks to scale up resilience by applying lessons from past projects and pilot initiatives, including the *Water Square* [8], Floating Pavilion [9], and BoTu2028 [2] programme**. Work occurs along two complementary tracks: enhancing the resilient living environment through policy integration, awareness-raising, monitoring, and innovative projects such as multifunctional roofs and floating buildings; and collaborating with social organisations and businesses to strengthen social resilience, capacity, and engagement.** The strategy emphasises "Resilience by Design," embedding resilience principles into urban planning, adapting existing infrastructure, creating synergies, and prioritising long-term, strategic interventions to ensure the city becomes more adaptable, sustainable, and prepared for future challenges.

3) **Anticipation – Refers to acting now based on possible futures by incorporating uncertainty, values, and long-term impacts into decisions, aligning short-term actions with long-term goals**, and enabling transformation by identifying and providing the capacities and resources needed for change.

The Rotterdam Resilience Strategy is forward-looking and practical, combining theoretical insights with actionable measures to prepare the city for both known and unforeseen crises. As the Mayor notes, "Spatial, social, and economic resilience is needed to make Rotterdam resilient and to keep it resilient on all fronts. That's why we decided to extend our strategy to climate, economic, social, energy, ecological, and digital resilience. Good coherence between these themes will result in a future-oriented city." [1]. Anticipation is central to the strategy. Rotterdam addresses seven major crisis areas—climate, biodiversity, pollution and resource depletion, inequality, cyber threats, health, and unknown or emerging crises—through seven corresponding resilience themes. **While the exact nature and impact of future crises cannot be fully predicted, preparing for both known and potential threats allows the city to respond more effectively when disruptions occur.** The strategy is also reflexive and context-specific. It is reflexive in that it adopts an adaptive approach capable of responding to unanticipated crises, and context-specific in that it is tailored to Rotterdam's existing governance structures, projects, and capacities. It outlines key policy documents and objectives across the seven resilience themes and establishes collaborative structures to identify and respond to community needs in real time. Importantly, the approach is not prescriptive: rather than imposing fixed goals or rules, it provides guidance and scaffolding to strengthen and enhance the city's existing, inherent resilience.

4) **Care –** Refers to the **paying attention to relationships, context, and ethics by responding to the diverse needs of people, ecosystems, and communities, while remaining flexible and adaptive** in the face of uncertainty rather than relying only on fixed plans or rules.

The Rotterdam Resilience Strategy is built around a systems-based approach that prioritises governance reform, neighbourhood-scale planning, and the strengthening of local networks, tailoring resilience to the city's unique needs. **Central to the strategy are the 'Rotterdammers' themselves: rather than imposing resilience from the top down, the approach seeks to understand and build on the capacity of communities. Initiatives such as Happy Streets address local needs while fostering wellbeing, social cohesion, and a sense of belonging.** Dedicated Resilience Officers coordinate these efforts, ensuring that interventions respond to community priorities, while creative and cultural approaches—including the involvement of poets and storytellers—empower residents to share experiences and amplify local voices.

The strategy embeds a relational and ethical perspective, recognising that many citizens are sceptical of government. By giving residents a greater role in designing, implementing, and monitoring resilience projects, governing bodies place trust in local communities, reinforcing both ethical responsibility and social legitimacy. Local involvement ensures that resilience initiatives are effective, contextually grounded, and socially accepted. Trade-offs are explicitly recognised. The strategy carefully defines its scope, acknowledging that not all challenges can be addressed within a single framework. For example, it incorporates lessons from the COVID-19 crisis to inform planning while excluding areas beyond its mandate, ensuring focus, coherence, and realistic, actionable interventions. This approach enables the city to prioritise resources, balance competing needs, and strengthen resilience in ways that are both effective and socially responsible.

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Case Study Risk Fiche NO. 2

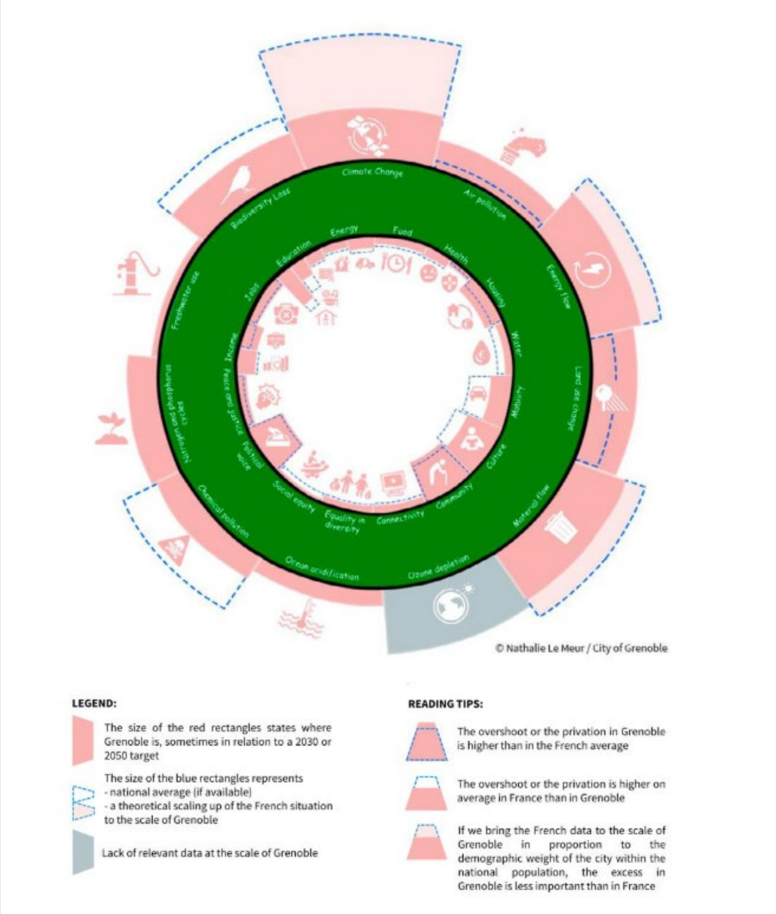
Case Study: Doughnut Economics – City of Grenoble, France.

System: Resilient & Competitive Economic and Financial Systems & Resilient ecosystems, nature protection, climate resilience and restoration.

Context: The **case study fiche focuses on the application of Doughnut Economics in the city of Grenoble** in France. Doughnut Economics is a visual framework for sustainable development. It was developed by economist Kate Raworth and defines a safe and just space for humanity by balancing social foundations (such as health, equity, and well-being) with ecological ceilings that must not be exceeded [1]. The framework highlights the need to address economic and environmental challenges within planetary boundaries while meeting the needs of all citizens. Grenoble adopted the approach in 2022 as the foundation of its 'Grenoble 2040' approach, guiding the cities transformation considering different crisis and integrating environmental and social dimensions into governance.

Location: *Grenoble, France*	**Scale:** *Local/City*	**Timeframe:** *2022-ongoing*
Responsiveness to systemic risks: Grenoble's implementation of Doughnut Economics is designed to address key systemic environmental risks that threaten long-term urban resilience and local population well-being. **By embedding ecological ceilings into local policy frameworks, the approach directly responds to risks associated with biodiversity loss, recognising the dependence of economic and social systems on healthy ecosystem services.** In parallel, the model informs climate policy by addressing systemic risks linked to water stress and the increasing incidence of extreme weather events, guiding public investment, land-use planning, and resource management toward climate adaptation and resilience.		

Images:



Grenoble data portrait (2022). Nathalie Lemeur, Grenoble city Council.

1) **Evidence of Experimentation**: Refers to the inbuilt openness to embrace failures and opportunities to learn. Flexibility and innovation are crucial to effective transformation and therefore a dedicated process, resources and capacities must be allocated to facilitate experimentation.

Grenoble has been experimenting with Doughnut Economics since 2022 through the launch of 'Grenoble 2040'. This project aims to put the city on a path towards a liveable, sustainable, and crisis-resilient future. Applying the principles of Doughnut Economics across all aspects of city management has required the city to move away from conventional approaches, such as prioritising growth in gross domestic product (GDP), and to explore new governance, planning, and decision-making methods. **Grenoble was among the first European cities to develop a "Doughnut diagnosis", assessing the city's performance in relation to planetary boundaries** [2]. The methodology was supported by the Doughnut Economics Action Lab (DEAL, co-founded by Kate Raworth) and inspired by other cities such as Brussels [3]. The implementation of the doughnut diagnosis was itself experimental and therefore after December 2022, when the initial diagnosis was completed, a second version published in 2025 updating indicators with more recent data.

Building on the diagnosis, the city began shifting its strategic priorities and developed innovative tools to guide the transition. **Notably, Grenoble introduced a project assessment method that contributes to achieving sustainable environmental targets and social thresholds.** This tool has supported informed decision-making and enabled the financial prioritisation of more than 200 projects in 2025[4]. To further strengthen its evidence base, **Grenoble is developing new accounting methodologies to improve information systems related to environmental (water, soil, biodiversity, climate) and human factors** [5]. To support the methodologies is the **creation of a transparent data observatory.** Data collection is supported by close cooperation between Grenoble City Council, the Community Centre for Social Action (CCAS), and public policy observation and evaluation units, enabling the centralisation of key demographic, social, and environmental data for the Grenoble area.

The Doughnut approach has benefited from strong political and administrative support. The city **dedicates one full-time staff member to coordinating the deployment of the approach.** To ensure alignment across municipal action, all local authority action plans are being reviewed to create cross-cutting **"Doughnut maps"** [8], supporting coherence between strategic objectives, project selection, and budget allocation. Furthermore, the Doughnut project manager works closely whit the various departments of the local authority, as each **city department has designated a "transition referee" tasked with developing and supporting transition approaches.** Finally, to enhance communication and transparent between stakeholders the city departments, elected officials, and technical teams collaborate on shared tools, including the Doughnut Portrait and the project assessment tool. Finally, **an Interdisciplinary Committee meets several times per year to discuss assessment** results and support cross-departmental coordination.

Beyond tools and governance, Grenoble is actively working to shift organisational norms and practices. **The city is also exploring ways to phase out so-called "negative commons". For example, as obsolete or unsustainable infrastructure when planetary limits are considered**. In this context, Grenoble has begun testing **ecological redirection protocols** with the support of the Origens Medialab [9], initially focusing on public swimming pools and their environmental footprint. Since 2017, Grenoble has also applied ecological redirection internally through the Bifurcations RH project [10], which aims to align organisational culture and working practices with planetary boundaries. As part of this initiative, a survey of green spaces employees was conducted in 2023–2024 to better understand how transition is experienced in day-to-day work. This work informed the development of a practical guide for green spaces staff, with similar initiatives underway in other technical teams.

Finally, the Doughnut Portrait was conceived not only as an analytical tool but also as an awareness-raising instrument, fostering reflection on planetary boundaries and social wellbeing within the administration and beyond. Grenoble has also developed activities applying Doughnut Economics concepts to broader societal issues, such as racial discrimination [6] and the future of European policy [7].

2) **Systems Thinking:** Refers to the understanding of interdependencies and causal pathways across disciplinary lenses. It focuses on cross-scale and cross-sector linkages, integrating diverse knowledge bases and supporting transformative, flexible, and appropriately decentralised governance structures.

System thinking is exemplified across the city of Grenoble's application of ~~the~~ Doughnut Economics. First, in the ***Donut Portrait of Grenoble developed in 2022*** **reviewing city performance across a wide range of social and environmental indicators in critical urban systems**. Followed by the cities **project assessment tool emphasises systems thinking in decision-making, assessing projects across six systems—Climate Change, Biodiversity & Ecosystems, Resource Management, Human Health, Social Cohesion, and Social Justice—using 36 indicators**. Demonstrating the cross-sector linkages of the approach. Building on this, the city of Grenoble contains to explore the linkages between different systems interactions between different systems. By way of example, the city of Grenoble developed a “portrait” of Grenoble’s 16 neighbourhoods, to reveal social and environmental inequalities, focusing on exposure (to extreme weather, pollutants, urban heat islands), accumulation (of social, economic, and environmental problems), and access (to aid, facilities, and amenities) [11]. Furthermore, in practice the city reports demonstrate an understanding of key Doughnut literature and the integration of supporting tools [12]. Rather than start from nothing the experts in Grenoble leverage the experiences from a Brussels pilot and the ecological transition analysis grid of Métropole Grand Lyon, combined with expertise from the Doughnut Economics Action Lab (DEAL) and Grenoble has incorporated a policy-based version of the EU Green Taxonomy system and EU CSRD standards to guide the approach.

Interestingly to **help bridge some of the ‘gaps’ in city scale data, the city aimed to compare Grenoble’s situation to national data, adapting methodologies where direct comparisons were not possible due to differences between urban and rural contexts**. In such cases, national data was scaled down to represent Grenoble’s context [12]. Also, Grenoble’s administration is working to decentralise responsibilities and empower various scales of government. **The mayor has delegated certain responsibilities to deputy mayors and councillors, increasing autonomy, and implemented a system of collective governance. Dedicated bodies, including working groups and an Interdisciplinary committee, manage cross-cutting issues**. Crucially, however, decentralisation remains a work in progress as the underlying governance structure remains mostly hierarchical.

Finally, Grenoble also aims to **evaluate its broader global impact, reviewing social, trade, and environmental effects.** This includes analysing where consumed products are produced, connected communities (diplomatic relations, migration, minorities), and environmental consequences of lifestyles and economic models (resource extraction, pollution, waste exports) on populations, including impacts on health, resources, and child labour. **As the administration states: *“Grenoble is an important public player with local aspirations and global responsibilities in today’s interconnected and interdependent world”*** [12]. The city participates in a network of “Doughnut Cities,” collaborating with other municipalities that have integrated Doughnut Economics via DEAL.

3) **Participation:** Refers to the need for transparent, broad, pluralistic, extended-peer-community participation, which is underpinned by co-design and co-creation, not only consultation.

Beyond aligning city management with planetary boundaries, the Doughnut concept has been used to broaden citizen participation in Grenoble. **The city's Doughnut Portrait was designed as a stakeholder engagement tool, helping people understand the concept and engage with it**. Grenoble organised various **workshops inviting citizens to reflect on what transition means** and dedicate events such as the 2023, "Cities in Transition Biennial" around the theme *Révolutionnons demain* [Let's revolution tomorrow] [13], featuring **innovative educational and interactive activities to include participation from groups usually distant from such issues, such as a 'transition wheel' modelled on a 'wheel of fortune'.** In fact, The Cities in Transition Biennials, has been held in Grenoble since 2017, **providing regular open partnerships among researchers, citizens, and stakeholders and helping shape the city's approach to Doughnut Economics.**

Grenoble also experimented with **involving citizens in co-creating transition pathways through the Citizens Doughnut participative workshops, ~~the 'Citizens Donut' project~~, where residents could discuss the Doughnut approach together.** The initial ambition of co-creating a Grenoble citizen portrait was discontinued due to timeline constraints. However, public participation is also being supported through resources allocation, including *Budgets Participatifs* [Participative Budgets] [14], the Fonds de *Participation des Habitants* [Community Participation Fund] [15], and *Chantiers Ouverts du Public* [Open Public Worksites] [16]. The Participative Budget allocates €1.8 million every two years to projects submitted by residents, who vote to decide funding. The Community Participation Fund provides financial support for residents to carry out projects benefiting their neighbourhoods.

The city's **project assessment tool was developed in co-creation with multiple city departments.** From indicator development to implementation, project leads from technical departments collaborate with department heads from Sports, Cultural Affairs, Education, and Youth, among others, to exchange perspectives. Finally, transparency is also central to the project. Indicators in the Doughnut Portrait were selected openly by local authority staff. In 2024, **the city published its first report on implementing Doughnut Economics, transparently discussing methodological biases, references used, and steps for improvement** [12]. Additionally, Grenoble invests in communication and accessible reporting, such as a comprehensive report (+300 pages) justifying local urban planning rules [18], available on the city's website.

4) **Precaution:** Focuses on preventing serious or irreversible harm under uncertainty by encouraging proactive action based on careful evaluation of scientific evidence, risks, benefits, and fairness, and by applying precaution through legal, procedural, and adaptive governance tools.

Grenoble's territorial resilience strategy explicitly identifies and categorises a wide range of environmental, social, and economic risks. It recognises uncertainties linked to climate change, such as heatwaves, flooding, and resource stress, as well as social vulnerabilities and economic transitions, **integrating these considerations into long-term planning and policy priorities**. Risks are not treated as static: the resilience framework is adaptive, with ongoing monitoring and updates allowing governance processes to respond to evolving conditions and emerging threats. Beyond addressing specific hazards, **Grenoble emphasizes generic resilience measures, including strengthening social cohesion, diversifying local economies, enhancing ecosystem health, and improving governance coordination, all of which increase the city's capacity to cope with multiple, unforeseen challenges.**

To support proactive governance, **Grenoble has developed a series of strategies across critical urban systems, aiming to guide the city along a resilient trajectory**. Key documents include the Air Energy Climate Action Plan 2023–2027 [19], Plan for the Promotion of Socially and Ecologically Responsible Purchasing 2023 [20], Cultural Charter for Transitions 2023 [21], Local Healthcare Plan 2024–2028 [22], Biodiversity Strategy and Action Plan 2020–2030 [23], and Greening Strategy and Action Plan 2020–2030 [24]. These strategies are closely aligned and cross-referenced, with all integrating the Doughnut perspective. Each time a strategy or action plan is updated, a Doughnut Portrait of the instrument is developed, allowing for clear visualisation of strategic actions and gaps [4].

Finally, accountability and societal legitimacy are central to Grenoble's approach. **Citizens are increasingly being engaged in the city's transition through events, public consultations, and communication activities. A key experiment was the Citizen Workshops on Ecological Redirection, launched in 2021** [25]. Six groups, each representing a sector of activity and composed of 22 randomly selected residents, worked over six months to design recommendations and concrete actions for the city. Their outputs were compiled into a roadmap, which was then submitted to elected officials and relevant city teams to inform policy and implementation.

5) **Anticipation:** Refers to the ability to act now based on futures by incorporating uncertainty, values, and long-term impacts into decisions, aligning short-term actions with long-term goals, and enabling transformation by identifying and providing the capacities and resources needed for change.

Grenoble's administration is guided by strategic documents that define a trajectory compatible with planetary boundaries and social basic needs beyond 2030, including the Territorial Resilience Strategy [26]. Resilience is defined as the city's ability to maintain its means of action, strengthen bonds of solidarity among residents, and promote their development. The strategy aims to preserve, develop, and grow these multiple bonds to secure the region's essential resources. Based on a diagnosis conducted in 2022–2023, 53 risks were identified across four categories: major risks, institutional dysfunction, economic disruption, and social safety net collapse. **From this analysis, 28 measures were defined to future-proof the city.**

A central pillar of Grenoble's resilience strategy is building collective capacity and extending networks of solidarity. The strategy seeks to reinforce collaboration at all scales to strengthen social cohesion and resilience. Actions include developing tools to support participatory democracy during crises, mapping solidarity networks, creating a mutual aid platform, and reinforcing cooperation between non-profit organisations during the biennial Cities in Transition festival. The second pillar focuses on preserving the capacity of inhabitants to respond to crises, ensuring citizens' basic needs are secured. This involves raising awareness of risks, anticipating supply chain disruptions, building first aid and mental health capacities, and organising events such as the annual Day on Resilience.

Participatory democracy is central to Grenoble's approach, and citizen involvement has been tested and expanded over several years. Initiatives such as the **Participative Budgets and Community Participation Fund (mentioned earlier) illustrate how residents participate in resource allocation.** The resilience strategy was developed based on interviews with employees across all city departments, providing an interdisciplinary understanding of the risks impacting the city. Anticipatory exercises, previously performed within the administration, are being extended to include citizens through awareness-raising activities and crisis simulation exercises. Grenoble's territorial resilience strategy functions as an institutional framework that integrates foresight into formal decision-making. Anticipatory insights, drawn from interdisciplinary interviews, risk analyses, and resilience planning exercises, inform governance strategies that align social, environmental, and economic objectives rather than treating them in isolation. This approach ensures coherence, adaptability, and alignment between long-term sustainability goals and concrete policy actions across city departments.

6) **Care –** Refers to paying attention to relationships, context, and ethics by responding to the diverse needs of people, ecosystems, and communities, while remaining flexible and adaptive in the face of uncertainty rather than relying only on fixed plans or rules.

In Grenoble, governance processes actively observe and respond to the needs of people, communities, and ecosystems through formal, integrated mechanisms. **Social and health needs are systematically addressed through public procurement rules that include social inclusion, gender equality, and anti-discrimination criteria, as well as food policies prioritizing local, sustainable, and organic supply chains, with a municipal objective of 100% organic food** [27]. Health and well-being needs are further addressed through initiatives such as the Charte de l'Habitat Durable et Santé [charter for sustainable housing and health] [28], the Strategy on Environmental Health [29], and the Health-Promoting Neighbourhoods program [11], which embed health considerations into urban planning. Grenoble's resilience strategy is explicitly structured around citizens' needs and strengthening solidarity, demonstrating a governance approach that translates identified priorities into coordinated action.

Ethical, relational, and moral considerations are explicitly integrated into governance processes. The city's public project assessment tool systematically incorporates social and environmental indicators, including impacts on citizens, health, and equity, ensuring that trade-offs and potential inequalities are considered in project prioritisation. This ethical framing is reinforced by Grenoble's eco-health (éco-santé) strategy and the Health-Promoting Neighbourhoods approach, which recognize moral responsibilities related to well-being, environmental justice, and care for vulnerable populations.

Finally, Grenoble's project assessment tool also provides a structured mechanism to identify and document trade-offs in municipal projects. By integrating environmental, social, and health indicators—including impacts on vulnerable groups—the tool highlights how prioritising certain objectives may generate unequal or competing effects. All municipal strategies currently under revision are assessed using the Doughnut framework, which visualizes potential "blind spots" where social or ecological dimensions could be deprioritized. This visualisation helps decision-makers identify trade-offs and distributional effects, supporting transparency and, where possible, the mitigation of negative impacts arising from competing priorities.

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Case Study Risk Fiche NO. 3

Case Study : Energy communities / energy clusters in Poland

System: *Energy transition and industrial transformation*

Context: Energy communities in Poland are legal frameworks that allow citizens, municipalities, and businesses to collectively produce, manage, and consume energy, primarily from renewable sources. These initiatives aim to decentralize the power sector, shifting the paradigm from large-scale, state-owned monopolies to localized, democratic systems that prioritize social and environmental benefits over profit. While the legal framework allows various actors to start these projects, the initiation of energy communities is predominantly driven by local authorities and business entities [1]. Polish energy communities operate within three primary governance frameworks, each promoting different levels of decentralization.
(1) **Energy Clusters**, first introduced in 2016 are legal agreements rather than legal entities. A cluster operates within a defined geographical area, typically not exceeding five municipalities or one county [2]. An energy cluster must include at least one entity with a controlling link to a local government, i.e. either a local government unit itself, a municipal company established by it, or a capital company majority-owned (over 50%) by such public entities. They function as regional platforms for coordinating energy generation, balancing, and demand management [3].
(2) **Energy Cooperatives:** These are formal legal entities based on democratic principles, such as "one member, one vote," which ensures that decisions are governed by the collective interest rather than profit maximization. They are restricted to rural or urban-rural areas [4,5] and must produce energy primarily for the collective's own needs. As of February 2026, over 630 cooperatives were registered in Poland [6].
(3) **Citizen Energy Communities**, introduced in the 2023 amendment of Energy Law as an implementation of article 16 of the Internal Electricity Market Directive (IEMD). These communities can be established by individuals, local governments, or companies and are designed to deliver environmental, economic, and social benefits to both their members and local areas, while supporting sustainable development and local energy self-sufficiency. Although the scope of activities of Citizen Energy Communities under Energy Law is broader than that of Energy Cooperatives, Citizen Energy Communities do not have a dedicated support scheme or economic incentives that would make this form of energy community attractive to promote broader uptake: as of February 2026, only three Citizen Energy Communities were registered in the official register of the Energy Regulatory Office (URE) [7].

The legal framework for Polish energy communities is based on both earlier domestic legislation and the subsequent transposition of EU law. The concepts of Renewable Energy Community (REC) under RED II and Citizen Energy Community (CEC) under the IEMD were formally transposed into Polish law through amendments to the Energy Law Act. The provisions introducing the Citizen Energy Community entered into force in August 2024. Rather than creating two separate legal forms corresponding strictly to REC and CEC, the Polish legislator opted to consolidate elements of both EU concepts within a single legal definition. Simultaneously, energy cooperatives and energy clusters were introduced earlier, in 2016, prior to the adoption and transposition of RED II and the IEMD. These forms were not conceived as a direct implementation of the EU REC/CEC framework. Instead, they represent autonomous domestic legal constructions that nevertheless functionally align with the broader concept of energy communities [See also: 21, 22].

Location: *Poland*	**Scale:** *Local / regional*	**Timeframe:** *2016-ongoing*

Responsiveness to systemic risks: Polish energy communities serve as a multifaceted response to a contemporary "polycrisis" characterized by overlapping climate, economic, and geopolitical threats. By transitioning from a centralized, fossil-fuel-dependent model to a decentralized and participatory one, these communities aim to provide a resilient and sustainable alternative to Poland's traditional energy structure. Many Polish initiatives are founded specifically to combat smog emissions caused by traditional coal heating, which significantly degrades local public health. The increasing frequency of droughts, heatwaves, and flash floods poses a risk to conventional power plants that require large amounts of water for cooling. Localized solar and wind sources are more resilient in these conditions.

Images:

The opening of photovoltaic farm in Lądek-Zdrój Energy Cooperative. The cooperative in Lądek-Zdrój was explicitly founded to counter deepening energy poverty triggered by the 2022-23 crisis. Source: GALERIA / KALENDARIUM - Lądecka Spółdzielnia Energetyczna

1) **Experimentation -** Refers to the inbuilt openness to embrace failures and opportunities to learn. Flexibility and innovation are crucial to effective transformation and therefore a dedicated process, resources and capacities must be allocated to facilitate experimentation.

Polish energy communities form part of an effort to reshape the country's power sector from a centralized, coal-dependent monopoly to a decentralized, participatory model. Literature highlights a proactive effort to combat the "legacy of mistrust" associated with collective action and cooperatives, which often carry negative historical connotations in Poland [8]. However, this effort currently exists in a state of tension between pioneering grassroots activity and institutional barriers. Energy communities represent a participatory approach to the energy transition, promoting democratic governance, local empowerment, and community-led sustainability rather than profit maximisation. Their focus is on producing, distributing, and using mainly renewable energy for the benefit of their members, which encourages cooperation, trust, and solidarity among local residents and strengthens civil society. At the same time, energy communities enhance local energy autonomy and resilience by decentralising energy production, reducing reliance on centralised and vulnerable supply chains, and enabling faster adaptation to energy shortages, price fluctuations, and infrastructure disruptions [9].

Sources describe some *participatory processes functioning as experimental laboratories*: for example, in Krakow, participatory workshops, commissioned by the city and led by an association CoopTechHub, were conducted, involving residents, scientists, and businesses to co-create specific models for "collective prosumers". These sessions served as a test bed to identify site-specific barriers, such as roofing limitations and heritage conservation rules [10]. However, interview evidence highlights that such experimental processes have often not translated into sustained institutional outcomes. In Krakow, despite extensive participatory workshops and co-design efforts, no energy community was ultimately established. This reflects broader structural constraints rather than a lack of local initiative. Despite amendments to the Renewable Energy Sources Act, Energy Cooperatives are still not permitted to operate in urban areas: this would be contingent on Poland requesting European Commission's approval for the use of net metering in urban areas, a step which has not yet been taken.

In combination with this, literature points to some evidence of *efforts to reinforce learning from local experimentation*. An **EU-/German-funded project RENALDO provided hands-on expert support to six selected municipalities** in the Podlaskie and Kujawsko-Pomorskie regions, helping them prepare the establishment of pilot Energy Cooperatives. This included detailed assessments of local energy demand and renewable resource potential, identification of optimal technology configurations, and preparation of complete founding and registration documentation. By working directly with local authorities and stakeholders, the project translated the concept of energy cooperatives into concrete, operational initiatives. The project also contributed to broader institutional learning and capacity building. Through the development of practical guidance materials, legislative recommendations, and the organisation of workshops and conferences, the project created a structured platform for knowledge exchange and reflection. Lessons from the pilot municipalities were documented and disseminated, supporting other local governments interested in establishing Energy Cooperatives and informing discussions on regulatory improvements. iLessons learned and unintended consequences are increasingly being documented through academic research and documentation efforts of NGOs. For example, case studies are documenting unintended consequences, such as the billing complexity and unfavourable attitude of distribution network operators.[1] iWhile energy communities are often treated with caution by the wider public, many local governments expressed confidence in Energy Cooperatives as credible and stable organisational forms. Dedicated funding from the Recovery and Resilience Plan (KPO) has been used to support *extensive knowledge-building efforts, including workshops, educational programmes, and awareness-*

raising activities aimed at broadening understanding of energy communities. These initiatives have engaged not only traditional energy stakeholders but also less conventional actors, such as cultural institutions and faith-based organisations. According to interview evidence, these efforts have contributed to increased awareness and interest, indicating early signs of impact, even if broader acceptance and scaling remain constrained by unresolved legal, financial, and regulatory uncertainties. *Lessons learned from field experimentation* have influenced subsequent policy and project decisions: Based on specific recommendations and evidence from NGOs, experts, and cooperatives, the Polish government nearly doubled the funding for energy communities in the Recovery and Resilience Plan (KPO), increasing it to approximately 192 million euros (total) to better match identified needs [11]. In Krakow, lessons from stakeholder workshops were used to create specific models for different *podmioty* (entities) that are intended to serve as examples to duplicate for schools, housing cooperatives, and public buildings [10].

It is worth noting that as an adjacent development, Poland has seen a rapid expansion of bottom-up renewable energy, driven mainly by household photovoltaics. This "PV revolution" has reshaped public attitudes and created a growing group of energy-aware citizens [8]. While the prosumer boom helped normalise self-generation and renewable energy use, it did not translate into widespread bottom-up formation of energy communities. In practice, physical people are often excluded from Energy Cooperatives and Clusters, and the offer is rarely communicated or tailored to citizens. Moreover, local authorities often perceive private individuals as introducing governance risks (e.g. "one member, one vote") and demand-side uncertainty due to irregular and difficult-to-predict consumption patterns. Despite the formal transposition of EU directives, support mechanisms for Citizen Energy Communities remain weak and unattractive. Existing instruments such as feed-in tariffs, feed-in premiums, or auction systems do not provide dedicated or meaningful advantages for citizen-led initiatives. As a result, genuinely citizen-driven energy communities remain marginal.

2) **Systems Thinking -** refers to the understanding of interdependencies and causal pathways across disciplinary lenses. It focuses on cross-scale and cross-sector linkages, integrating diverse knowledge bases and supporting transformative, flexible and appropriately decentralised governance structures.

There are emerging examples of *recognition of system interdependencies* being utilised to navigate the interconnections between energy, society, and the environment, but the practical implementation remains fragmented.

For example, Energy Cooperatives in rural areas can support the *circular economy* by utilizing agricultural by-products (e.g., corn silage, manure, and wood waste) for biogas production, linking the food system directly to local energy and waste management systems [12]. Governance goals frequently include the *improvement of air quality (reducing smog)* and *eliminating energy poverty*, which explicitly links energy transition to public health and social welfare systems [1, 12]. In light of the increasing frequency of extreme weather events such as droughts, heatwaves, and floods, as well as worsening air quality, stakeholders in Małopolskie Voivodeship recognised the need to transform its energy system to *enhance resilience and environmental sustainability*. Climate change not only compels stakeholders to reduce greenhouse gas emissions but also fosters a new regional mindset that links energy policy with security and quality of life [13]. The planning process for energy clusters sometimes involves land management assessments, such as repurposing closed landfills or mining regions, integrating *energy infrastructure with ecological reclamation* [14]. In response to the war in Ukraine and the 2022 energy crisis, governance has shifted from purely environmental goals to building *anticipatory capacities for energy security*. Energy communities have been framed as resilient alternatives to centralized systems that are vulnerable to geopolitical shocks or large-scale blackouts [5, 11, 15].

There are emerging examples of different disciplinary perspectives being applied to inform decision-making and innovation such as involvement of R&D partners in energy clusters [1], or the active involvement of universities, local governments, local businesses, and specialised firms, particularly within energy clusters and some energy communities. These configurations function as informal platforms for expert knowledge sharing and collaborative problem-solving, linking scientific, technical, administrative, and practical perspectives in the design and operation of local energy solutions.

When it comes to *a cross-scale interaction*, EU directives provide the strategic impetus, national legislation creates the enabling (or hindering) framework, and local municipalities act as the primary engines of implementation. However, experts note a superficial transposition of EU law into national legislation, resulting in a fragmented regulatory environment that lacks the clarity necessary for widespread adoption. Although national-level political support for energy communities has been periodically signalled, most notably through commitments to expand their number and their inclusion in national strategic documents such as the National Energy and Climate Plan (NECP), interview evidence suggests that these declarations have not yet translated into a coherent, stable, and enabling regulatory framework.

Polish energy communities are driving a shift *from a historically centralized power sector toward a decentralized, polycentric model* [5, 11]. While the literature identifies significant potential for transformative resilience, this is often constrained by a "systemic lock-in" caused by centralized legacies and administrative complexity [8, 11]. The Polish energy system remains highly centralized, with state-owned energy monopolies and Distribution System Operators (DSOs) often viewing local initiatives as potential disruptors to the status quo rather than partners [11].

3) **Participation -** refers to the need for transparent, broad, pluralistic, extended-peer-community participation, which is underpinned by co-design and co-creation, not only consultation.

Energy communities *have the potential to be inclusive and participatory, but in practice, their accessibility is limited*. Although formally designed to enable citizen participation, energy community frameworks in Poland are rarely oriented towards individual households. Participation often requires prior technical, legal, and organisational capacity, making strong engagement from local leaders, awareness-raising, and targeted training essential. In practice, many energy communities (particularly Energy Cooperatives and Clusters) do not admit physical persons at all, reflecting governance preferences and concerns about demand-side uncertainty rather than citizen unwillingness. Participation is further constrained by formal legal and administrative requirements, such as registration, contracts with distribution system operators, and permits for renewable energy installations. There is also concern that, in the absence of clear regulatory safeguards, energy communities' risk being instrumentalised by larger market actors. Some Cooperatives and Clusters remain closed to new members or are dominated by medium-sized enterprises, creating tensions with EU principles of openness, voluntariness, and democratic governance [5]. In addition, financial barriers remain significant, as cost savings typically materialise only during the operational phase.

To address these challenges, there has been *a number of projects to develop capacity building of various actors as means to support participation of a wider diversity of actors in the creation of energy communities*. This includes projects like RENALDO or capacity building efforts and roundtables conducted by EKO UNIA. In some initiatives (e.g. in Krakow), participation has been highly meaningful. Residents, building managers, and scientists participated in workshops to co-create models for "collective prosumers" [10]. While these processes demonstrate the potential for co-design and social learning, they have not consistently translated into sustained institutional participation or the establishment of citizen-led energy communities.

4) **Precaution -** focuses on preventing serious or irreversible harm under uncertainty by encouraging proactive action based on careful evaluation of scientific evidence, risks, benefits, and fairness, and by applying precaution through legal, procedural, and adaptive governance tools.

Energy communities are framed as "strategic pillars of adaptive capacity." Their decentralized structure makes the power system less vulnerable to large-scale grid failures, cyberattacks, or deliberate attacks on centralized infrastructure. By creating self-balancing areas that integrate generation, consumption, and storage, communities reduce dependence on global energy market fluctuations and external raw material supply disruptions [5, 9, 11].

When it comes to accountability and societal legitimacy, the literature highlights that while energy communities aim for social benefit, they face significant trade-offs regarding equity and inclusivity: transformative energy actions are currently perceived as exclusive, led primarily by individuals with high socioeconomic capital. Those facing energy poverty often lack the representation or resources to participate, although communities are theoretically designed to reduce energy exclusion [8]. Stakeholder support is largely dependent on the visibility of success stories and the involvement of local authorities. Municipalities are viewed as the most credible and trustworthy entities to initiate energy communities, acting as guarantors of stability and mediators between residents and the state [10, 16]. The administrative complexity of establishment procedures and unstable legislation acts as a major deterrent.

5) **Anticipation –** refers to acting now based on possible futures by incorporating uncertainty, values, and long-term impacts into decisions, aligning short-term actions with long-term goals, and enabling transformation by identifying and providing the capacities and resources needed for change.

The Polish updated draft NECP (2025) [17] frames local energy communities (including Energy Clusters, Energy Cooperatives, and Citizen Energy Communities) as an important element of the national energy transition. It emphasises their role in decentralisation, renewable energy uptake and local energy independence. The strengthened focus on local balancing and system flexibility reflects an anticipatory understanding of a future electricity system characterised by high shares of variable renewables, increasing electrification and growing grid congestion. The document estimates that around 1000 energy communities could be operating by 2030, although this figure is indicative and not a target of the plan. Overall, the NECP recognises the strategic relevance of energy communities and outlines supportive measures, but lacks a detailed long-term pathway beyond 2030, limiting the clarity of its transformational trajectory.

In response to the war in Ukraine, the governance narrative has shifted from primarily environmental goals toward energy sovereignty. Anticipatory measures now focus on building autonomous energy systems to safeguard against grid instabilities, cyberattacks, and large-scale blackout [8, 9, 18], although this association is more rhetorical as there is no formal structural connection between energy communities and energy security governance and long-term strategic planning.

6) **Care -** means paying attention to relationships, context, and ethics by responding to the diverse needs of people, ecosystems, and communities, while remaining flexible and adaptive in the face of uncertainty rather than relying only on fixed plans or rules.

The very concept of local energy community is based on the (moral) necessity to ensure "energy sovereignty" and protect the community from global price shocks. This includes a moral responsibility to save the planet for future generations [5, 19]. By legal definition, the primary objective of these communities must be to provide environmental, economic, or social benefits to their members rather than generating financial profit [15].

The "one member, one vote" principle in Energy Cooperatives is a formal mechanism that aims to ensure community needs are prioritized over the interests of large capital holders [15]. Energy communities operate on a non-profit basis, with financial surpluses reinvested locally rather than distributed to investors or large energy companies. These funds support community renewable energy projects, energy efficiency improvements, and other local initiatives such as cycling infrastructure, LED lighting, or public spaces. As a result, energy communities strengthen local economies, create jobs, raise environmental awareness, foster social cohesion, and improve quality of life and local infrastructure [15, 20].

Addressing energy poverty is a primary motivator for several initiatives, such as the Sąsiedzi Social Cooperative, which provides free electricity to municipal residential buildings to support vulnerable citizens. The cooperative in Lądek-Zdrój was explicitly founded to counter deepening energy poverty triggered by the 2022-23 crisis [20].

The literature highlights that while energy communities should aim for social benefit, they face significant trade-offs regarding equity and inclusivity: transformative energy actions are currently perceived as exclusive, led primarily by individuals with high socioeconomic capital. Those facing energy poverty often lack the representation or resources to participate, although communities are theoretically designed to reduce energy exclusion [8]. Energy poverty is not formally linked to energy communities in Polish legislation or in the official policy narrative and remains largely absent from the strategic framing at the national level.

Neska et. al. (2025) caution that the large-scale expansion of renewable energy communities may increase the prices for those that do not participate in them: it can affect the stability of the centralised energy system, which must continue to provide backup when local generation is insufficient or during outages. As participation in energy communities grows, the financial burden of sustaining the central system risks falling disproportionately on less affluent and energy-excluded groups, making well-designed regulatory safeguards essential to avoid energy injustice [8].

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Case Study Risk Fiche NO. 4

Case Study : Room for the River Programme

System: Resilient ecosystems, nature protection, climate resilience and restoration

Context: *Room for the River* is a Dutch government programme that was rolled out between 2006 and 2015 (with an extension until 2022) and funded 39 flood safety projects along the river system across the country, with a total budget of € 2.3 billion. The program marked a departure from the Netherlands' traditional infrastructure-centric solutions for flood control (like dikes, seawalls, and flood barriers) towards an integrated, nature-based approach to reduce flood risks. This shift in Dutch flood risk management happened after the Rhine and Meuse rivers swelled to near-disaster levels in 1993 and in 1995, and 250,000 residents and nearly one million livestock needed to be evacuated. Since a failure of the flood-safety infrastructure can result in catastrophic impacts, the Room for the River program aimed to achieve more flexibility to adjust to future uncertainties by providing more space for rivers through river widening. The program had two explicit objectives: (i) flood safety, and (ii) the enhancement of spatial quality, i.e., planning flood protection measures in a way is integrated with the existing landscape and built environment and aims at enhancing the recreational and aesthetic quality of the space (Van Herk et al, 2014) [1]. Currently, a follow-up program - Room for the River 2.0 – is being launched. It continues the strategic approach of the first Room for the River program by implementing nature-based solutions while improving spatial quality in a collaborative process. However, an important update to the first programme is that it responds to emerging climate-related issues, namely both extreme high and low water, and riverbed erosion (Room for the River 2.0) [2]. The 2.0 program has set itself the objective to preserve and enhance five key river functions: (i) safe/high water discharge, (ii) navigability, (iii) freshwater availability and drinking water supply, (iv) nature and ecological water quality, and (v) spatial economic development and spatial quality. The 2.0 program runs continuously and includes a longer research phase of around a decade preparing the decision-making before the implementation of measures will start (expert interview) [3].

Location: *The Netherlands*	**Scale:** *National /Regional*	**Timeframe:** 1999-2006: initiation phase; *2006 -2022: program phase; 2025 – ongoing: follow-up program 'Room for the River 2.0'*
Responsiveness to systemic risks: The Room for River programme responds to flood risks due to high water levels in rivers – related to more frequent and heavier rainfall because of climate change, or changes upstream that lead to higher discharges in the Netherlands. As a result, it aligns with the system of Resilient ecosystems, nature protection, climate resilience and restoration. The Room for River 2.0 is especially interesting as it is an extension of the original room for River strategy in the Netherlands that is considering the changing global perspective. By investing in a sustainable, resilient future for its rivers, ensuring that these vital waterways continue to serve both the environment and the economy, even in the face of a changing climate.		

Images:

1) **Evidence of Experimentation -** Refers to the inbuilt openness to embrace failures and opportunities to learn. Flexibility and innovation are crucial to effective transformation and therefore a dedicated process, resources and capacities must be allocated to facilitate experimentation.

The Room for the River programme adopted a strong learning-by-doing and experimentation approach, most notably through so-called frontrunner projects. **These projects were ahead of others in terms of planning and implementation, and the lessons derived from them were systematically transferred to subsequent projects** (Van Herk et al., 2014) [1]. Across the 39 individual projects, experimentation was deliberately embedded in the programme design. Projects were organised into sequential tranches, allowing lessons from earlier phases to inform later ones regarding hydraulic, morphologic and ecological effects, construction time, and market approaches (Zevenbergen et al., 2015) [4]. **At the individual project level, learning based on stakeholder feedback and new insights into effectiveness was translated into iterative design adaptations.** For example, following the first tranche, the design for lowering groynes along the Waal River was adjusted to improve outcomes (Zevenbergen et al., 2015) [4]

At the programme governance level, learning was integrated through the continuous adaptation of organisational structures and processes. **Initially, the programme followed an approach of "controlled trust", whereby the central programme directorate monitored progress but did not intervene in individual projects, which were led by regional authorities**. This approach was later revised when it became clear that many projects faced similar technical and project-control challenges. In response, the programme directorate shifted towards a more proactive role, providing facilitation and support to regional projects (Van Herk et al., 2014) [1].

The transfer of knowledge from frontrunner projects to other projects was supported through multiple mechanisms, including the exchange of personnel, shared guidelines**, and network and training events. In some cases, team members from frontrunner projects worked part-time on other projects to directly transfer experience and expertise** (Van Herk et al., 2014) [1]. Specific task forces operating at programme level further supported the dissemination of lessons learned (Zevenbergen et al., 2015)[4]. **Based on these experiences, guidelines were developed for spatial quality planning, soil movement planning and groyne information systems, while uniform management structures were established across the 39 projects to facilitate horizontal learning between team members in similar roles** (Van Herk et al., 2014) [1].

Institutionally, the Dutch Ministry of Infrastructure and Water Management held overall responsibility for the programme, with **Rijkswaterstaat acting as the programme directorate**. A total of 19 partners—including provinces, municipalities, regional water authorities and Rijkswaterstaat—cooperated in implementation. **Organisational structures at the interface between the programme directorate and regional projects were adapted to embed facilitation and support capacities through centrally positioned stakeholder managers**. These were reinforced through the involvement of knowledge, stakeholder management and project-control departments, transforming programme-level monitoring into a more collaborative governance structure (Van Herk et al., 2014) [1].

Overall, the Room for the River programme marked a fundamental shift away from traditional infrastructure-centric flood control towards nature-based water management, while elevating spatial quality to a priority alongside flood safety. Embracing experimentation, learning and stakeholder involvement became the new standard for flood risk management in the Netherlands And shaped the approach of the Delta Programme on Flood Risk Management, the Netherlands' long-term policy framework on flood safety, which shares core features such as systems thinking, stakeholder participation, and continuous experimentation and learning (Zevenbergen et al., 2015) [4].

2) **Systems Thinking -** refers to the understanding of interdependencies and causal pathways across disciplinary lenses. It focuses on cross-scale and cross-sector linkages, integrating diverse knowledge bases and supporting transformative, flexible and appropriately decentralised governance structures.

Room for the River adopted an integrated approach that considered the river as a broader system, recognising the interdependencies between water and land-use functions, including socio-economic and physical characteristics across spatial scales and their relationship to the discharge regime. This systemic perspective was reflected in the consideration of multiple, interdependent effects of the implementation of measures, such as flood safety, transport capacity, recreation, water supply, economic activity, spatial aesthetics, and water quality (Zevenbergen et al., 2015 [4]; expert interview) [3]. The programme addressed these interdependencies through an integrated system perspective that assessed the combined effects of different measures on flood levels along the river. This was supported by a computational planning tool for flood management, which was used in stakeholder co-creation processes. The tool enabled users to select combinations of available measures and immediately visualise the outcomes of their implementation, supporting informed dialogue and joint decision-making (Zevenbergen et al., 2015) [4]. Stakeholder discussions were further informed by learning about opportunities to combine recreational, nature, industrial, and urban development policy objectives, demonstrating cross-disciplinary integration in both analysis and practice (Van Herk et al., 2014) [1].

Room for the River is considered the first programme in the Netherlands to adopt a multi-level governance approach in which national government agencies (notably Rijkswaterstaat, the executive agency of the Dutch Ministry of Infrastructure and Water Management), regional authorities (provinces and regional water authorities), and local governments (municipalities) actively collaborated to reduce flood risk while enhancing spatial quality. **The explicit inclusion of spatial quality as a programme objective stimulated the integration of flood protection measures with local and regional investment agendas** (Zevenbergen et al., 2015) [4].

This cross-scale approach was operationalised through a combination of centralised steering and decentralised decision-making. A central programme office at the national level established decision frameworks, monitored progress, evaluated designs, and supported regional projects through guidelines, expert knowledge, and community-building activities. At the same time, regional and local governments, together with local stakeholders, were responsible for formulating and deciding on project designs, allowing flood risk measures to be closely linked to local needs such as urban development, landscape quality, and the provision of natural and recreational areas (Zevenbergen et al., 2015) [4].

3) **Participation -** refers to the need for transparent, broad, pluralistic, extended-peer-community participation, which is underpinned by co-design and co-creation, not only consultation.

The Room for the River programme placed strong emphasis on broad and diverse participation, facilitated through both informal and structured engagement mechanisms.

The Programme Directorate enabled the participation of farmers and residents through so-called "kitchen table meetings": small, informal group discussions held literally at residents' kitchen tables. **This approach aimed to lower barriers to participation, build trust, and move away from abstract public hearings towards more personal, dialogue-based engagement.** These meetings provided a space to speak directly with affected landowners and inhabitants, explain proposed measures, listen to concerns and preferences, and negotiate tailor-made solutions.

Beyond local residents, Room for the River fostered the development of a broad professional community spanning national, regional, and local public organisations, as well as NGOs, academic researchers, and private stakeholders. **This community brought together expertise from different disciplines, including flood risk management, spatial planning, agriculture, and nature conservation, supporting integrated and informed decision-making** (Zevenbergen et al., 2015) [4].

The programme adopted a participatory planning approach that enabled consultation to evolve into co-creation. Stakeholder engagement was organised through two main structures: a national steering group composed of representatives from water boards, municipalities, and NGOs, and regional steering groups and stakeholder platforms that formulated regional advice for the national level. **Co-creation was further supported through interactive workshops** with regional and local stakeholders, where two key tools were used. A **physical design table displaying the topography of river stretches allowed**

participants to draw proposed river-widening measures, while the "Planning Kit" computer programme calculated and visualised the hydraulic effects of these measures on river levels in real time. This interactive process generated a large pool of proposals in the early phase of the programme, from which approximately 40 measures were ultimately selected for implementation by committees composed of local and regional authorities (Zevenbergen et al., 2015 [4]; Van Herk et al., 2014[1]).

Transparency played a central role in building legitimacy and trust throughout the process. The Planning Kit — also referred to as the "box of blocks"— proved essential in facilitating discussions during collaborative planning, design, and decision-making. Its transparent and accessible visualisation of the hydraulic consequences of different combinations of measures helped stakeholders understand trade-offs, fostered trust, and strengthened commitment to the final decisions (Van Herk et al., 2014 [1]; Zevenbergen et al., 2015[4]).

In the Room for the River 2.0 program, stakeholder participation will be concentrated in the implementation-design phase, where measures are going to be elaborated in accordance with decisions made by the Ministry and Rijkswaterstaat following expert consultation (expert interview) [3].

4) **Precaution -** focuses on preventing serious or irreversible harm under uncertainty by encouraging proactive action based on careful evaluation of scientific evidence, risks, benefits, and fairness, and by applying precaution through legal, procedural, and adaptive governance tools.

Different measures were analysed to see if they could retain their functionality and performance under any future scenario, and how much extra space would be needed in the longer term to cope with higher discharges due to projected climate change. While the measures implemented in the first Room for the River program were not based on these higher discharge levels, spatial planning reservations were made for future measures accordingly (expert interview) [3]. An assessment was carried out to see how much space would be needed to accommodate the passage of 18.000m 3 /s in the river systems in the future instead of the 16.000m 3 /s for which the program measures were designed, and at what cost. The objective of 16,000 m^3/s discharge capacity of the river system after program implementation had been based on extreme flood estimates at the time (the), corresponding to a very rare high-water event (about a 1:1250-per-year probability, the flood protection standard at that time). **Knowing that the peak river discharge could increase further due to climate change , potentially to around 18,000 m^3/s by the end of the century, mainly due to more intense rainfall, and less buffering of precipitation in the form of snow in the Rhine basin**, hydrological projections were updated to reflect more extreme future conditions (Zevenbergen et al, 2015)[4].

In the later Delta Program, climate change-related sea level rise scenarios were included in modelling and planning to link river discharge, estuarine water levels, and coastal impacts. In addition, it was estimated how much extra space for the river in the flood plains of the Rhine would be needed under higher future discharges (Zevenbergen et al, 2015) [4]. The Delta program had a stronger emphasis on proactivity, and protection standards were adapted to longer time horizons, including to foresights for 2100, and even 2200. This also included raising awareness of existing embankments being less secure than expected due to the risk of subsurface flow beneath the embankment structure (expert interview) [3].

Finally, in the Room for the River 2.0 program, additional future uncertainties are being addressed. Riverbed erosion, an issue that had not been tackled in the first program, can have long-term implications for navigation, groundwater levels, agriculture, the foundation of houses, etc. (expert interview) [3].

In the initiation phase of the program, two independent organisations were commissioned to evaluate the program objectives to strengthen accountability and legitimacy (Van Herk et al, 2014) [1].

An independent expert panel on spatial quality -the so-called Quality Team - was established to produce independent recommendations and safeguard the program's objective on spatial quality on an ongoing basis (Van Herk et al, 2014) [1]. The interdisciplinary team peer reviewed the designs and plans and worked unrestrained by formal governmental or institutional opinions (Klijn et al, 2013) [5].

In addition, societal legitimacy was achieved through comprehensive involvement and good compensation for households that needed to be relocated, and for farmers whose agricultural land was impacted by the measurements (Van Herk et al, 2014 [1]; Quadros Aniche, 2017 [4]).

5) **Anticipation -** means acting now based on possible futures by incorporating uncertainty, values, and long-term impacts into decisions, aligning short-term actions with long-term goals, and enabling transformation by identifying and providing the capacities and resources needed for change.

The original Room for the River programme did not centre on formal long-term scenario planning, aside from assessments related to higher future discharge quantities. **However, in the follow-up programme, Room for the River 2.0, scenario work is explicitly embedded in the analytical foundation. This includes the use of climate scenarios from the Royal Netherlands Meteorological Institute (KNMI), alongside hydraulic and morphological modelling** that show the relation between climate and river discharges, to assess future river discharge scenarios. Since there are different climate change scenarios, and all of them work with ranges, the program looks at the entire range of potential effects, including scenarios that could imply river discharges far beyond 18,000 m3/s, and might be as high as 22,000 m3/s (expert interview) [3]. Potential impacts also depend on the measures that will be taken by countries upstream the water catchment, e.g., embankments being installed in neighbouring Germany. Managing these uncertainties necessitates preserving adaptive capacity. Adaptive policy pathways depending on discharge levels and climate scenarios are being created to address these uncertainties (expert interview) [3].

Room for the River 2.0 examines the impacts of these scenarios on riverbed erosion, flood risk, freshwater availability, navigability, and nature. Importantly, the programme adopts a very long-term perspective, looking ahead to 2100 and even 2200, to avoid measures that could lead to long-term lock-ins (Deltares, 2025) [5].

The preparatory approach to decision-making within Room for the River 2.0 demonstrates reflexivity through the examination of multiple "working hypotheses," informed by existing knowledge on riverbed erosion solutions and discharge distribution under high and low flow conditions. Lessons from earlier impact studies are explicitly incorporated into the assessment of the consequences associated with different potential choices, allowing the programme to reflect on experience while adapting to future uncertainty (Deltares, 2025) [7].

There is evidence that Room for the River 2.0 engages a broad range of actors in reviewing and discussing research results, including actors across multiple governance levels, knowledge institutions, and sectoral stakeholders. However, neither the first Room for the River program nor the follow-up program included participatory processes in the scenario work itself, i.e., the development of scenario assumptions or modelling frameworks.

Overall, the modelling and assessment of different working hypotheses within the context of long-term scenario analysis are explicit steps used to support alignment, coherence, and adaptive decision-making in the Room for the River 2.0 programme, ensuring that future interventions remain flexible and robust under conditions of deep uncertainty.

5) **Care -** means paying attention to relationships, context, and ethics by responding to the diverse needs of people, ecosystems, and communities, while remaining flexible and adaptive in the face of uncertainty rather than relying only on fixed plans or rules.

Some projects, such as the Room for the River Waal project in Nijmegen, brought significant transformations to the landscape and required the relocation of families living in the area. In these cases, high levels of social acceptance were achieved through intensive citizen participation in stakeholder engagement processes, the provision of fair financial compensation for relocated households, and the creation of new spaces for living, recreation, and culture to be enjoyed by residents (Quadros Aniche, 2017) [6].

After 2010, the needs of agriculture and farmers gained greater prominence within the programme. Solutions were increasingly developed to protect or compensate agricultural land within project areas. For example, farmers affected by the construction of a bypass through farmland were compensated through the acquisition of additional agricultural land outside the project area (Van Herk et al., 2014) [1].

Economic considerations also played a role in responding to societal needs. The Dutch Central Planning Bureau conducted cost–benefit analyses based on direct implementation costs and direct benefits in terms of prevented flood damage. Some projects, such as those along the Waal at Nijmegen, demonstrated positive cost–benefit outcomes, indicating economic justification. These analyses also showed that, in certain river branches, the Room for the River approach was likely to be more expensive than traditional flood protection measures (Zevenbergen et al., 2015) [4]. This is unsurprising, as simply strengthening embankments is always the cheaper option – even though it implies the risk of catastrophic impact in case the infrastructure fails. Thanks to an inducive political environment, there was also a willingness to pay for nature restoration at the moment of program inception (expert interview) [3]. While cost–benefit analysis informed project prioritisation and design, there is no evidence that individual projects were cancelled on a cost basis. The fact that funding for large government programs in the Netherlands is allocated long-term, including in the case of a change of government, also resulted in planning certainty. Overall, decision-making involved balancing trade-offs between flood safety, spatial quality, and cost (Nieuwe Instituut, 2026) [8].

In the Room for the River 2.0 program, which looks at scenarios of potentially very high river discharges due to future impacts of climate change, requiring a lot of additional space for the river, trade-offs regarding the use of scarce space in the NL might become a central topic (expert interview) [3].

At the project level, environmental impact assessments and social cost–benefit analyses were systematically conducted to support informed decision-making and to account for both environmental and social implications of the interventions.

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Fiche Author: Isabella Wedl

Case Study Risk Fiche NO. 5

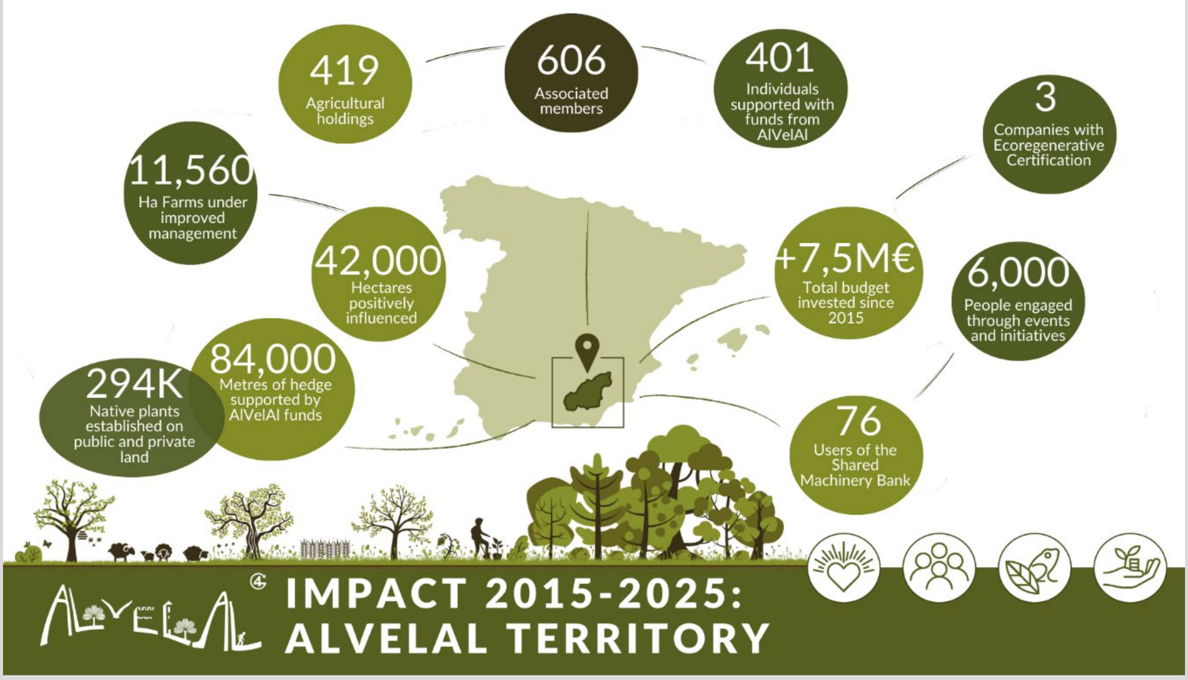
Case Study : Environmental, social and economic regeneration of the Steppe Highlands in southeastern Spain (AlVelAl)

System: Secure & sustainable food systems

Context: AlVelAl is an association established in 2015 promoting the environmental, social and economic regeneration of the Altiplano Steppe in Southeastern Spain. Under the 'AlVelAl' acronym lie 5 regions of the Altiplano Estepiario in the Southeast of Spain: Altiplano de Granada, Los Veléz, Alto Almanzora, Guadix and the Northwest of Murcia. The territory is marked by a myriad of interacting climate including desertification, biodiversity loss. Compounding this, the area is facing the effects of depopulation, and extensive agriculture and livestock farming prevail. AlVelAl aims to revive the region by applying the innovative '4 returns framework'. The 4 returns framework focuses on the combined return of inspiration, social return, natural return and financial return to the region in the hope of transforming the region into a regenerative landscape, tackling the environmental drivers from climate change and undoing some of the other social drivers that are affecting the region. The fiche focuses on the 4 returns framework and the ongoing efforts of the experts on the ground. For more Information on what AlVelAl's mission is visit here, YouTube video here. And a podcast explaining their story here (in Spanish).

Location: *Steppe Highlands in Southeastern Spain (Altiplano de Granada, Los Vélez, Alto Almanzora, Noroeste de Murcia and Guadix)*	**Scale:** *Local/Regional*	**Timeframe:** *Since 2015 and ongoing. Their vision is to have a regenerative landscape by 2034. New vision for 2050.*
Responsiveness to systemic risks: The AlVelAl case study aligns with several of the identified systemic risks from the research, particularly those related to environmental degradation, biodiversity loss, and climate change. The AlVelAl region is especially affected by systemic risks linked to soil degradation, drought, loss of ecosystem services, heat stress, and extreme weather events. Further compounding these challenges are a range of social and economic drivers, including depopulation and intensive agricultural practices.		

Images: (source: AlVelAl)



1) **Evidence of Experimentation -** Refers to the inbuilt openness to embrace failures and opportunities to learn. Flexibility and innovation are crucial to effective transformation and therefore a dedicated process, resources and capacities must be allocated to facilitate experimentation.

Through its work in southeastern Spain, the **AlVelAl association aims to build a young and revitalised highland region that values its natural and cultural resources, supports a professionalised organic farming sector, and provides opportunities for businesses and restoration initiatives** [1]. A central element of their vision is a **transition to regenerative agriculture**, designed to improve soil health, biodiversity, water retention, and carbon sequestration. This is achieved by **helping farmers access finance for implementing practices within the regenerative protocol** and providing access to research and innovation projects, which typically cover the costs of practice implementation. Through engagement in projects such as Farms4Climate, Pasture+, and GOV4ALL, AlVelAl enables land managers to learn from experimentation and share experiences with other stakeholders. Beyond agricultural sites, the association experiments with regenerative techniques in natural areas, **including innovations such as the use of drones for aerial seeding in hard-to-access degraded sites** [2]. Implementation of these practices follows an iterative process, with feedback continuously integrated and practices evolving over time to adapt to local conditions and a changing climate.

AlVelAl initially developed outside formal institutional support, but its legitimacy has grown through engagement with a wide range of actors. Institutional collaboration includes local councils, natural parks, universities, and regional and national authorities. **Municipalities provide meeting spaces and may establish contracts for advice or support with restoration activities, while**

natural parks provide sites for hands-on interventions. AlVelAl prioritises training, awareness-raising, and capacity building, participating in events and dissemination activities with the Spanish Ministry of Agriculture, Food and Fisheries (MAPA) and regional and local governments. The association also facilitates access to public (e.g., EU programmes) and private funding, and brokers collaboration among land managers through shared machinery, common production centres, training, and knowledge exchange.

Committed to transforming environmental, social, and cultural landscapes, **AlVelAl applies the 4 Returns framework to guide interventions at multiple, interrelated levels.** Regenerative agricultural practices are translated into actionable steps to mobilise collective action [3], and the association has created an Ecoregenerative certification (Certificación Ecoregenerativa) to recognise and encourage farmers adopting these practices. Beyond agriculture, the 2018 "Destino AlVelAl" project, in partnership with TUI Care Foundation, promotes regenerative tourism, demonstrating how tourism can support territorial regeneration while connecting agriculture and gastronomy.

2) **Systems Thinking -** refers to the understanding of interdependencies and causal pathways across disciplinary lenses. It focuses on cross-scale and cross-sector linkages, integrating diverse knowledge bases and supporting transformative, flexible and appropriately decentralised governance structures.

AlVelAl's work recognises the interconnections between environmental, social, and economic systems. Its focus on regeneration extends beyond soil and food systems to address challenges such as depopulation, water scarcity, desertification, and economic development, creating new business opportunities for farmers and other stakeholders [1]. **For example, the association supports farmers in commercialising products and developing regenerative enterprises**, such as Almendrehesa (2016), which brings together over twenty producers of certified, high-quality almonds using organic regenerative agriculture.

The association embraces a cross-disciplinary approach, recognising that regenerative agriculture and landscape restoration can generate social, economic, and environmental benefits simultaneously [4]. To achieve this, AlVelAl collaborates with a **diverse network of stakeholders, combining traditional knowledge with innovative practices**. Decisions within specific disciplines are made by consent, while cross-disciplinary issues are addressed at the "higher council" level, bringing together technical teams and the board of directors [3]. Art and culture are also integrated to strengthen social cohesion and create collective memory [3].

Operating across three provincial boundaries, AlVelAl's strategy encourages local initiatives while contributing to regional and international networks. The association is part of the Red de Territorios Regenerativos (Network for Regenerative Territories) and serves as a lighthouse territory, providing guidance and inspiration to eight other associated territories in Southern and Eastern Spain. AlVelAl also engages internationally, collaborating with initiatives such as Commonland and has been designated as a European Union Mission Soil Living Lab and Lighthouse (#126). Intergenerational engagement is embedded in its activities, including events targeting children and youth, such as the Re-generation Festival.

The governance model is dynamic, based on egalitarian principles and bidirectional information flow, allowing multiple perspectives to shape decisions. Team members participate in board meetings, and board members join team discussions, fostering flexibility, collective ownership, and adaptive responses to local challenges [3]. This approach supports the adoption of sustainable management practices more effectively than top-down methods, which have proven less successful in the region [5].

3) **Participation -** Refers to the need for transparent, broad, pluralistic, extended-peer-community participation, which is underpinned by co-design and co-creation, not only consultation.

The 4 Returns Framework under which AlVelAl serves as a mechanism to bring together local farmers, conservationists, government actors, and entrepreneurs to create a shared vision for the territory [10]. A key objective is to mobilise the local community and foster engaged citizens who contribute to revitalising the region. **Training, awareness-raising, and capacity building are central to this work.** Land managers and other stakeholders learn from experimentation and share experiences through research projects, open days, and advisory activities. AlVelAl currently counts over 600 members, including more than 200 farmers, businesses, municipalities, international foundations, conservationists, research institutions, and universities. Participation is open to citizens aged 14 and above, with workshops also organised in schools.

Collective action is achieved through a co-created vision and social schemes that encourage stakeholder engagement [3]. **Thoughtful governance processes have built trust and ownership among members, while surveys, often linked to Master's or PhD research, collect feedback and input from participants.** Conflicts, which can arise as membership grows and becomes more diverse, are managed through dialogue, third-party mediation when needed, and preventive measures such as early-stage dialogue and the involvement of respected leaders committed to the initiative's mission [8,9]. T**ransparency is a key principle in AlVelAl's governance. Strategic plans, external audits, and annual reports are publicly accessible via the Transparency Porta**l [7], and opportunities for involvement in projects, such as GOV4ALL, are published through open calls, ensuring wide access and accountability.

4) **Precaution -** focuses on preventing serious or irreversible harm under uncertainty by encouraging proactive action based on careful evaluation of scientific evidence, risks, benefits, and fairness, and by applying precaution through legal, procedural, and adaptive governance tools.

AlVelAl operates in a territory affected by land degradation, biodiversity loss, and depopulation, and its **co-created vision seeks to increase the resilience of soils and landscapes.** While the association **does not use predictive models, its work is informed by research from partner organisations, including universities and research groups**. Participatory governance and co-creation, through workshops and collaborative knowledge-sharing, help address uncertainties and integrate risks into decision-making.

The association's horizontal governance structure clearly distributes tasks between the Board and Technical Team, while members can propose ideas for consideration. Preventive action is embedded in its support for transitions to regenerative agriculture and sustainable business models, which mitigate environmental and climate risks. By promoting agricultural practices that restore soils and landscapes and supporting the development of sustainable business opportunities, AlVelAl strengthens the resilience of the territory. Awareness-raising activities with local authorities further contribute to preventive governance.

AlVelAl's social legitimacy is reinforced by its multi-stakeholder approach, transparent governance, and external verification of restoration efforts against the Forest Ecosystem Restoration Standard. Trade-offs are explicitly acknowledged: if a practice causes economic loss for farmers, it is not repeated in subsequent cycles, demonstrating responsiveness and adaptive management.

5) **Anticipation** – Refers to possible futures by incorporating uncertainty, values, and long-term impacts into decisions, aligning short-term actions with long-term goals, and enabling transformation by identifying and providing the capacities and resources needed for change.

AlVelAl's approach prioritises short- to medium-term actions while operating within the framing of a longer-term vision. This Vision sets measurable targets, including hectare goals for restoration and regenerative land management by 2026, with ambitions further upscaled to 2050 [1]. The focus on restoration reflects a clear intention to future-proof the territory by increasing its ecological and socio-economic resilience. Adaptive management, regular review cycles, and learning from implementation are central to this process and support continuous adjustment over time.

Reflexivity and contextual framing are embedded through participatory processes and collaborative learning. AlVelAl regularly organises workshops and strategy sessions with a broad range of actors to gather feedback, integrate local knowledge, and co-develop activities. The Vision for 2034 emerged from a co-creation process involving 30 stakeholders during a 2014 workshop using the Theory U methodology [3].

Over the past decade, AlVelAl has also worked with communities and organisations to develop a Manifesto for a Regenerative Territory. This declaration is intended as a tool for change, uniting municipalities and local communities around the revitalisation of the natural environment, society, and local economy. To date, around a dozen municipalities and several local associations have endorsed the manifesto. Alignment, coherence, and adaptivity are further supported through training and capacity-building activities for public administrations and farmers. By strengthening skills, knowledge, and shared understanding, AlVelAl contributes to increasing the territory's resilience and its capacity for transformative governance.

6) **Care -** means paying attention to relationships, context, and ethics by responding to the diverse needs of people, ecosystems, and communities, while remaining flexible and adaptive in the face of uncertainty rather than relying only on fixed plans or rules.

AlVelAl's way of working places strong emphasis on listening to farmers and other stakeholders. The association recognises that regenerative practices evolve over time in response to changing environmental conditions and practical experience, and that understanding what works and what does not is central to effective action. Members' needs are addressed through a range of activities and opportunities, including access to finance, capacity building, participation in innovation projects, and the organisation of workshops and open days. Objectives are regularly readjusted to reflect changing realities; for example, while the association initially aimed to create a new business model each year, it later prioritised strengthening existing business models as a more effective approach in a rural territory characterised by slow innovation uptake.

Relational and ethical considerations are formally embedded in AlVelAl's governance through its Equality Plan (Plan de Igualdad) [6], developed in line with Law 3/2007, and the establishment of an Equality Commission to oversee its implementation. The association commits to improving opportunities for women and men, combating discrimination, increasing women's participation across all areas, formalising inclusive and non-sexist communication, and raising awareness among members on gender equality. Measures also aim to promote a genuine work–life balance for staff, reinforcing an ethical and care-oriented organisational culture.

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Case Study Risk Fiche NO. 6

Case Study: Ireland's Action Plan on Competitiveness and Productivity

System: Resilient & competitive economic and financial systems

Context: Considering the rapidly evolving international landscape characterised by geopolitical uncertainty, rising protectionism and trade fragmentation, the Irish Government outlined an action plan [1] to enhance its competitiveness and productivity in response to the challenges that Ireland is facing. Increasing strategic efforts in six key areas (productivity, international, SMEs, competition, infrastructure and sustainability), the plan aims to make the Irish economy shock-resistant, where feasible ('controlling the controllable'), with 85 concrete actions, 26 of which are identified as priority actions. The Action Plan aims for swift implementation, with several priority measures for 2025 and 2026 already in place, as they have been designed to be timely and responsive to current needs. [2]

Location: *Ireland*	**Scale:** *National*	**Timeframe:** *The 2025 recommendations are meant to be actionable in the next 1 – 3 years with long-term objectives*
Responsiveness to systemic risks: This Case study fiche aligns with the Resilient & competitive economic and financial systems system that was defined in the project. The Action Plan supports resilience within the current growth-oriented economic model at times of greater uncertainty. It is not necessarily fuelling the need for transformative change in responses to solely climatic drivers. But instead, it provides an opportunity to explore an innovative national scale Action Plan that tackles Competitiveness and Productivity at times of uncertainty and that links directly with one of the key impacts that was identified by the experts during the workshop. Doing so sets up a governance process that embeds resilience thinking and attempts to tackle uncertainty, focuses on the security of the economic sector and could have implications on other sectors and respond to other social and environmental drivers.		

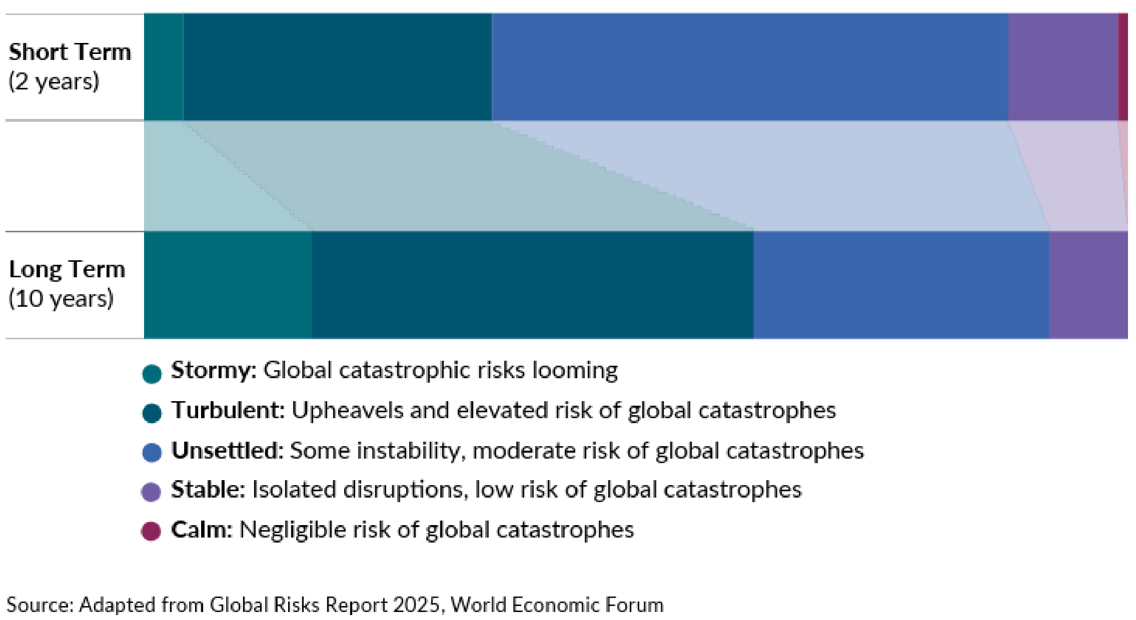
Images:

Figure 1. Six Thematic Challenges and the Actions Needed to Address Them

Theme	Number of Priority Actions	Key Focus
Productivity	5	Technological Change, Digitalisation, Skills
International	3	Market Diversification, EU Single Market, Advanced Manufacturing, Frontier Technologies
SMEs	3	Nurturing SMEs, Access to Finance, Start-Up Ecosystem
Competition	5	Simplification, Legal Reform, Domestic Competition
Infrastructure	3	Expediting Delivery, Construction Productivity
Sustainability	7	Energy, Regional Growth

Source: Action Plan on Competitiveness and Productivity, September 2025, page 6.

Figure 2. Short and long-term survey



Source: Action Plan on Competitiveness and Productivity, September 2025, page 26.

1) **Evidence of Experimentation -** refers to the inbuilt openness to embrace failures and opportunities to learn. Flexibility and innovation are crucial to effective transformation and therefore a dedicated process, resources and capacities must be allocated to facilitate experimentation.

Ireland's Action Plan on Competitiveness and Productivity focuses on strengthening adaptive or absorptive resilience, aiming to make the economy more resistant, efficient, and flexible in the face of shocks such as inflation, supply-chain disruptions, or global competition. The plan targets improvements in productivity, skills, infrastructure, innovation, cost competitiveness, and regulatory efficiency, drawing on international best practice, including the EU Draghi report on competitiveness [3], and aligns closely with Ireland's National Development Plan [4].

Each of the six thematic chapters follows a consistent approach: outlining the challenges faced, benchmarking Ireland against similar countries, and identifying realistic objectives and actions based on international examples. **Innovation, particularly in the area of productivity, is considered a cornerstone of long-term competitiveness. The plan emphasises systematic investment, coordination, and the broader adoption of innovation to close gaps with peer countries**

Implementation is supported by a robust framework and monitoring mechanisms to ensure tangible outcomes. Responsibilities, timelines, and high-level targets are clearly defined, with progress tracked along two dimensions: the effective delivery of specific actions and the strategic impact on broader goals. **Oversight is provided by the Government's cabinet committee on economy, trade, and competitiveness, producing quarterly reports from December 2025 onwards, while relevant departments coordinate annual progress reports.** [5] The National Competitiveness and Productivity Council (NCPC) continues to advise on monitoring, ensuring Ireland's performance is assessed against international peers. This approach relies on existing governmental structures and senior public service expertise, embedding accountability and learning into daily operations without creating additional entities.

The plan also addresses institutional and systemic reforms needed to support productivity and competitiveness. Under the theme "Regulating for Growth and Controlling Costs," the Government is modernising aspects of the Irish judicial system to align with international standards. Recommendations from the 'Review of the Administration of Civil Justice Report' [6] are being implemented, including simplifying procedural rules, accelerating case timelines, reducing litigation costs, and enhancing digitalisation.

Similarly, under "Increasing the State's Capacity to Deliver Infrastructure," the Government recognises challenges in recruiting specialised staff across the Civil and Public Sector. Measures such as Specific Purpose or Duration Contracts and increased flexibility across departments aim to ensure that public sector skills match needs more effectively. Together, these reforms demonstrate an approach that combines practical institutional adaptation with strategic, forward-looking governance.

2) **Systems Thinking -** Refers to the understanding of interdependencies and causal pathways across disciplinary lenses. It focuses on cross-scale and cross-sector linkages, integrating diverse knowledge bases and supporting transformative, flexible and appropriately decentralised governance structures.

Ireland's Action Plan on Competitiveness and Productivity recognises the strong interlinkages between economic stability, competitiveness, and the range of thematic priorities addressed. For example, enhancing the SME sector is seen as contributing not only to economic growth and higher living standards but also to increased resilience against international shocks. **The Action Plan promotes an SME model focused on innovation, competitiveness, and growth. Similarly, the green transition is framed as both an environmental imperative and an economic opportunity: decarbonisation strengthens resilience, supports job retention, reduces costs, and enhances competitiveness for industry and SMEs.**

Ireland's international competitiveness, particularly in attracting foreign direct investment (FDI), is also addressed through an integrated approach that combines site readiness, skills development, infrastructure investment, streamlined planning and licensing processes, and strengthened research, development, and innovation (RDI) capacity.

The Plan **demonstrates cross-disciplinary approaches, integrating emerging technologies such as artificial intelligence, quantum computing, and high-performance computing into broader innovation strategies**. Under the "Sustainability" theme, regional development and enterprise clustering are highlighted as enablers of innovation, productivity, and place-based growth. Ireland plans to establish five new national cluster organisations, including three pilot clusters to generate evidence for the continuation of the National Clustering Programme beyond 2026.

Innovation is understood as a collaborative effort involving multiple actors: Government provides strategic vision, funding, infrastructure, and national priorities; firms contribute expertise, market insight, and agility; academia and research institutions drive creativity and

discovery; and the EU strengthens the ecosystem through funding, policy alignment, and international cooperation.

The Action Plan emphasises the importance of strong interconnections across governance levels, from local authorities to national institutions, as well as European partners. Ireland's future competitiveness depends on the inclusiveness, connectivity, and dynamism of the national innovation ecosystem. Collaboration with EU partners is seen as critical to mitigating risks, supporting industrial transformation, and facilitating cross-border investment through initiatives such as Innovative Projects of Common European Interest (IPCEI).

The Action Plan is designed as a "whole-of-Government" strategy, requiring strong coordination across departments and agencies with clear accountability for outcomes. Cross-cutting responsibilities are assigned to lead departments or agencies, with measurable targets to monitor progress. The strategy aims to leverage existing structures and avoid creating unnecessary new bodies, while maintaining the flexibility to adapt to emerging challenges and opportunities across Ireland's economic, social, and environmental systems.

3) **Participation -** Refers to the need for transparent, broad, pluralistic, extended-peer-community participation, which is underpinned by co-design and co-creation, not only consultation.

The development of Ireland's Action Plan on Competitiveness and Productivity involved extensive engagement with a wide range of stakeholders. Within government, the social partnership model—which includes employers, trade unions, civil society groups, the Enterprise Forum, and the NCPC—was consulted during the initial scoping and throughout the drafting process to identify key pillars and priority issues. In addition, meetings were held with firms, local government sectors, and state agencies to ensure a comprehensive perspective.

Public consultation was also conducted through a survey, which gathered input from 168 respondents including company owners, directors, employees, and sole traders. Stakeholder engagement continues, particularly under Theme 6, "Sustainability," where local authorities are actively involved. Active fora and working groups provide ongoing spaces for stakeholders to share lessons, best practices, and insights across different aspects of the enterprise ecosystem.

Transparency was embedded throughout the plan's development. Continuous exchanges and requests for feedback ensured stakeholders could observe and contribute to the drafting process. The implementation framework reinforces accountability by clearly defining targets, roles, and monitoring mechanisms, supporting public trust while enabling progress to be tracked against the plan's goals.

4) **Precaution** -focuses on preventing serious or irreversible harm under uncertainty by encouraging proactive action based on careful evaluation of scientific evidence, risks, benefits, and fairness, and by applying precaution through legal, procedural, and adaptive governance tools.

The Government and relevant departments explicitly acknowledge a range of risks and uncertainties. Disruptions to trade flows, such as tariffs on goods, pose significant risks to Irish exports to key markets.

In addition, heavy reliance on private-sector investment in R&D exposes the innovation system to cyclical risks, as investment levels are influenced by economic conditions, firm-level priorities, and broader economic cycles. As a result, there is a recognised need for greater public funding to help stabilise long-term innovation capacity.

At the same time, climate change and environmental pressures are transforming the global economy, with decarbonisation presenting both opportunities and risks for Ireland. In this context, Ireland's strong potential in wind energy—both onshore and offshore—is highlighted. Unlocking this capacity through clear investment roadmaps and innovative funding models can enhance long-term climate and economic resilience, strengthen energy security and competitiveness, and reduce reliance on fossil fuels and associated uncertainties.

The strategy also recognises that Ireland's industrial and employment base must fully acknowledge the role of the energy transition in supporting medium-term resilience and competitiveness. For SMEs and micro-enterprises in particular, effective communication and tailored incentives are seen as essential to enabling their participation in the energy transition.

The action plan outlines several proactive governance and preventive measures. It recognises that well-designed and well-implemented regulation can improve outcomes across multiple areas, including risk reduction, while also supporting innovation and economic growth. The Government therefore commits to strengthening regulatory frameworks to secure more robust long-term outcomes.

In the international arena, reducing exposure to systemic and sector-specific risks is pursued through diversifying sources of foreign direct investment, supporting the internationalisation of Irish firms, and strengthening engagement with high-growth and emerging global markets. To support this, a new interdepartmental group on trade oversight has been established and will produce an action plan focused on market diversification.

With regard to accountability and societal legitimacy, the plan links competitiveness objectives to spatial and social equity. In addressing regional imbalances, the revised National Planning Framework (April 2025) [7] sets an explicit objective of achieving a 50:50 distribution of future growth between the Eastern and Midlands regions and the combined Southern, Northern, and Western regions. Uneven regional development is recognised as a risk that can constrain growth and exacerbate structural inequalities. Aligning climate action with competitiveness is, therefore, framed as a way to deliver economic benefits that are both environmentally sustainable and geographically inclusive.

5) **Anticipation –** Refers to acting now based on possible futures by incorporating uncertainty, values, and long-term impacts into decisions, aligning short-term actions with long-term goals, and enabling transformation by identifying and providing the capacities and resources needed for change.

"Future-proofing" is a core principle underpinning the development of the Action Plan. The plan seeks to strengthen the resilience of Ireland's economy so that it is better prepared to absorb and cope with future external economic shocks.

To support this, the plan incorporates strategic foresight through an ongoing cross-departmental exercise that develops multiple scenarios and analyses how domestic and global dynamics may interact. This foresight work is complemented by engagement with partner universities and external advisers, who provide validation and draw on international good practice.

The plan also reflects a reflexive approach by recognising the need to reduce reliance on factors that may diminish or become unavailable in the future. For example, it acknowledges that temporary revenues can no longer be relied upon to finance permanent increases in public expenditure, particularly in the context of climate change and an ageing population.

In relation to the energy and digital transitions, the plan highlights that reducing the industry's dependence on fossil fuels can protect businesses from volatile energy prices, given the lower long-term costs of renewables. Similarly, sustaining the expansion of AI and other emerging technologies will require a coordinated approach to planning for future large-scale, energy-intensive industries, ensuring alignment with renewable energy capacity while limiting additional infrastructure costs.

Under Theme 5, "Infrastructure", the plan explicitly emphasises the importance of alignment, coherence and adaptivity. Drawing on analysis by the Economic and Social Research Institute (ESRI) on population projections used in the National Planning Framework [8], it highlights the substantial future pressure on infrastructure under different migration scenarios. This reinforces the challenge of long-term planning and underlines the need for continuous investment in infrastructure to support sustainable growth.

6) **Care –** refers to paying attention to relationships, context, and ethics by responding to the diverse needs of people, ecosystems, and communities, while remaining flexible and adaptive in the face of uncertainty rather than relying only on fixed plans or rules.

The government recognises the crucial role of local authorities, identified as key actors in regional development, in delivering territory-based economic strategies, targeted infrastructure planning, and support to community groups that respond to regional and local needs. A concrete example lies in the development of the new iteration of the Regional Enterprise Plans (REPs) [9], designed to address persistent regional development imbalances in Ireland. These plans enable regions to identify their specific strengths and challenges, as well as to implement targeted initiatives that foster business growth, innovation and employment. Ireland's strategy, based on a bottom-up approach for the REP design process, is informed by the OECD recommendations on regional development policies (June 2023) [10], which suggest that regional priorities reflect local needs, while remaining consistent with international practices.

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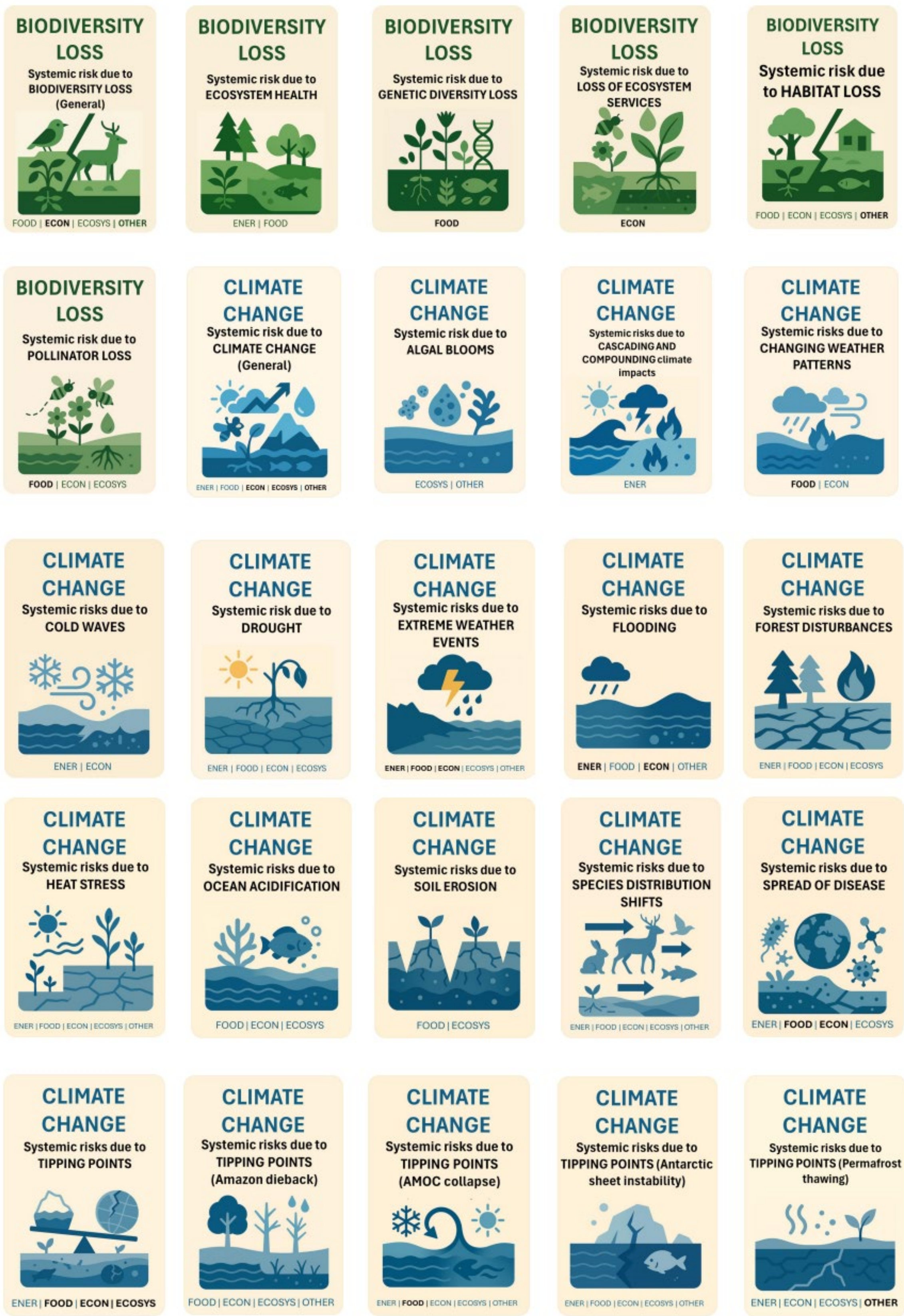
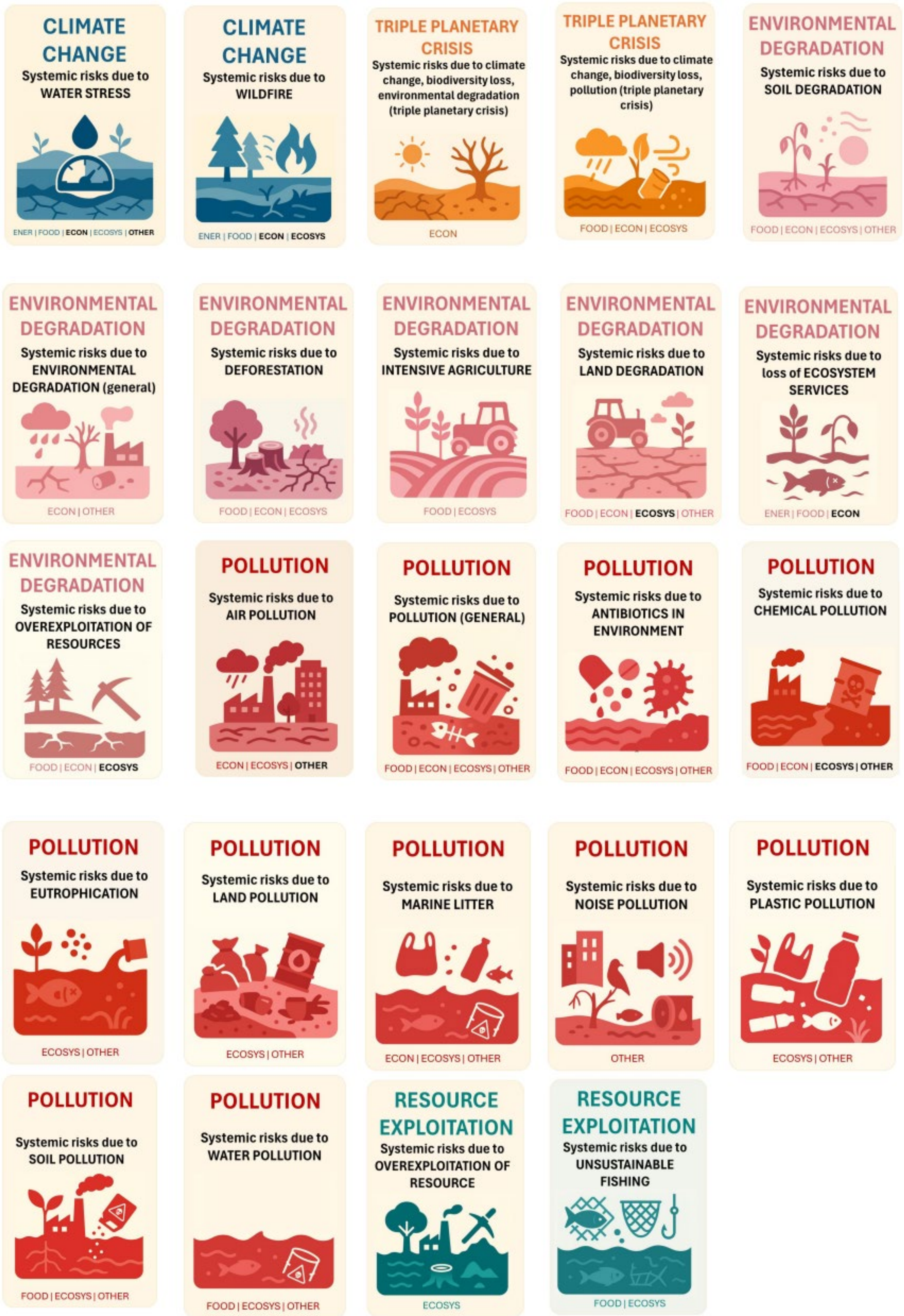
8.7 ANNEX 6 – Full Deck of Risk playing Cards





CLIMATE CHANGE
Systemic risks due to WATER STRESS
ENER | FOOD | ECON | ECOSYS | OTHER
CLIMATE CHANGE
Systemic risks due to WILDFIRE
ENER | FOOD | ECON | ECOSYS
TRIPLE PLANETARY CRISIS
Systemic risks due to climate change, biodiversity loss, environmental degradation (triple planetary crisis)
ECON
TRIPLE PLANETARY CRISIS
Systemic risks due to climate change, biodiversity loss, pollution (triple planetary crisis)
FOOD | ECON | ECOSYS
ENVIRONMENTAL DEGRADATION
Systemic risks due to SOIL DEGRADATION
FOOD | ECON | ECOSYS | OTHER
ENVIRONMENTAL DEGRADATION
Systemic risks due to ENVIRONMENTAL DEGRADATION (general)
ECON | OTHER
ENVIRONMENTAL DEGRADATION
Systemic risks due to DEFORESTATION
FOOD | ECON | ECOSYS
ENVIRONMENTAL DEGRADATION
Systemic risks due to INTENSIVE AGRICULTURE
FOOD | ECOSYS
ENVIRONMENTAL DEGRADATION
Systemic risks due to LAND DEGRADATION
FOOD | ECON | ECOSYS | OTHER
ENVIRONMENTAL DEGRADATION
Systemic risks due to loss of ECOSYSTEM SERVICES
ENER | FOOD | ECON
ENVIRONMENTAL DEGRADATION
Systemic risks due to OVEREXPLOITATION OF RESOURCES
FOOD | ECON | ECOSYS
POLLUTION
Systemic risks due to AIR POLLUTION
ECON | ECOSYS | OTHER
POLLUTION
Systemic risks due to POLLUTION (GENERAL)
FOOD | ECON | ECOSYS | OTHER
POLLUTION
Systemic risks due to ANTIBIOTICS IN ENVIRONMENT
FOOD | ECON | ECOSYS | OTHER
POLLUTION
Systemic risks due to CHEMICAL POLLUTION
FOOD | ECON | ECOSYS | OTHER
POLLUTION
Systemic risks due to EUTROPHICATION
ECOSYS | OTHER
POLLUTION
Systemic risks due to LAND POLLUTION
ECOSYS | OTHER
POLLUTION
Systemic risks due to MARINE LITTER
ECON | ECOSYS | OTHER
POLLUTION
Systemic risks due to NOISE POLLUTION
OTHER
POLLUTION
Systemic risks due to PLASTIC POLLUTION
ECOSYS | OTHER
POLLUTION
Systemic risks due to SOIL POLLUTION
FOOD | ECOSYS | OTHER
POLLUTION
Systemic risks due to WATER POLLUTION
FOOD | ECOSYS | OTHER
RESOURCE EXPLOITATION
Systemic risks due to OVEREXPLOITATION OF RESOURCE
ECOSYS
RESOURCE EXPLOITATION
Systemic risks due to UNSUSTAINABLE FISHING
FOOD | ECOSYS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