

Strengthening European Union's Future Disaster Resilience

A strategic foresight study identifying priority capabilities and
emerging technologies towards 2040

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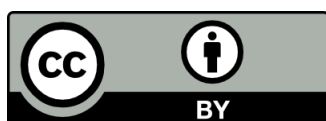
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Abstract

This report presents the results of a strategic foresight study aimed at supporting European Union policy developments and strategic planning, particularly Research & Innovation (R&I) funding in the destination *A Disaster-Resilient Society for Europe*. In the context of an increasingly complex and interconnected risk landscape, the study adopts a forward-looking and capability-based approach to strengthen the EU's preparedness and response capacity.

The analysis integrates a strategic foresight methodology combining literature review, horizon scanning, expert surveys, interviews, and participatory workshops. This multi-stage process enabled the identification, validation, and prioritisation of key operational capabilities and emerging technologies relevant for disaster and infrastructure resilience towards 2040. A total of 12 priority capabilities and 12 high-potential emerging technologies were selected through a triangulation of quantitative and qualitative evidence. The study is anchored in a capability-centred framework, placing operational needs at the core of the analysis and linking them with technological innovation and policy objectives. This approach allows for the systematic identification of capability gaps and investment priorities, while ensuring alignment between R&I activities and real-world operational requirements. At the same time, the integration of strategic foresight enables the exploration of future developments, uncertainties, and disruptive trends, supporting more anticipatory and adaptive policymaking.

By bridging the gap between policy, operations, and technological development, this report provides an evidence-based foundation for more strategic and forward-looking EU action in disaster and infrastructure resilience. It contributes to the development of a cross-cutting understanding, supports the prioritisation of investments, and strengthens the integration of foresight into long-term planning for civil security.

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Executive summary

Policy context

The European Union faces a converging risk landscape in which climate-driven hazards, an evolving security threat spectrum, and deepening structural vulnerabilities interact to produce compound scenarios that exceed the design parameters of current preparedness frameworks. The Preparedness Union Strategy (2025) and ProtectEU (2025) articulate a comprehensive response, with the Commission proposing a fivefold increase in preparedness funding to EUR 10.7 billion under the next Multiannual Financial Framework (MFF). Translating this unprecedented commitment into effective action requires a forward-looking understanding of which capabilities European societies will need and which emerging technologies can support them.

This study, conducted by the Joint Research Centre of the European Commission (JRC) in support of the Directorate-General for Migration and Home Affairs (DG HOME), provides the forward-looking, evidence-based capability and technology analysis needed to orient these investments towards the 2040 horizon. Through a structured foresight process involving over 120 experts, it identifies 12 priority capabilities and 12 emerging technologies and proposes a Framework of Core Capabilities for Disaster Resilience for their structured assessment.

Key conclusions

The study highlights the need for a systemic and forward-looking approach to disaster resilience, grounded in a capability-centred framework and supported by strategic foresight. In a nutshell:

- The risk landscape to 2040 is defined by convergence, not escalation alone. Natural hazards, security threats, and structural vulnerabilities are not independent risk categories; they interact and amplify each other, catalysed by rapid technology evolution.
- Resilience must be addressed across the disaster management cycle, with particular emphasis on anticipation, prevention, protection and preparedness, where early investments can significantly reduce future impacts.
- The absence of a common capability language in European civil security is a structural barrier to coordinated action. Disaster resilience across all hazards demands coordinated effort, yet the diverse actors involved lack a shared understanding of what capabilities are needed and where gaps exist or threaten to materialise in the future. Establishing such a common understanding is essential to reduce fragmentation and enhance interoperability. Without such a common reference, the coordinated action on which resilience depends will remain structurally constrained.
- A capability-driven approach provides the most robust basis for R&I programming. This study adopts such an approach, grounded in a cyclical logic: emerging risks (shaped by natural hazards, security threats, and structural vulnerabilities) dictate the capability needs that drive solutions, whether technological or not. Once deployed, these solutions build or reshape existing capabilities to manage risks. However, they may also create new dependencies or alter the risk landscape, thus sustaining the cycle. This iterative relationship is why capabilities, rather than specific technologies or hazards, should sit at the epicentre of investment decisions.

- *Technology is an enabler, not a solution in itself.* The 12 emerging technologies, led by advanced integrated sensing systems, AI-assisted drone detection, 3D mapping and localisation, and city-scale digital twins, scored highest when they combined multiple technological domains. Expert assessments consistently pointed to technological convergence, rather than standalone innovations, as the principal driver of future impact in this domain. However, technologies that are not interoperable, trusted, or adapted to operational constraints will not deliver their potential. Investment decisions must assess not only technological maturity but also integration into clearly defined capabilities and governance of dual-use risks, particularly around Artificial Intelligence (AI).

Main findings

The study identifies a set of priority capabilities and emerging technologies expected to play a key role in strengthening disaster and infrastructure resilience in the EU towards 2040, and proposes a capability-centred framework to support a coherent assessment of capability needs and prioritisation. The findings were derived from the convergence of quantitative survey scoring, workshop deliberation, and expert interviews validation.

Twelve priority capabilities were identified spanning all phases of the disaster management cycle and covering the full threat/hazard spectrum. Key capability areas include:

- Essential services continuity and redundancy, addressing the growing criticality of uninterrupted essential services as infrastructure interdependencies deepen
- Cross-border cooperation and multilevel coordination, addressing fragmentation and enabling joint action across borders
- Critical communications, ensuring effective information exchange during crises
- Early warning and detection, enabling timely and preventive action, as climate-driven hazards intensify and Chemical, Biological, Radiological, Nuclear and Explosive (CBRN-E) threats evolve
- Cyber resilience, responding to the expanding cyber-physical attack surface and the projected convergence of AI and quantum computing
- Citizen empowerment, strengthening community-level resilience and response capacity
- The remaining priority capabilities, namely decontamination, waste management, and restoration; resilient design; systemic risk modelling and Critical Infrastructure (CI) interdependency mapping; efficient and safe frontline operations; training; and rapid on-scene detection and monitoring, complete the full-cycle coverage from anticipation through recovery.

Twelve emerging technologies were identified, clustering around several convergent trends:

- Advanced sensing and Earth observation (satellite radar, Light Detection and Ranging (LiDAR) with Simultaneous Localization and Mapping (SLAM), thermal and hyperspectral sensors, optical atomic clocks) for real-time monitoring and early warning
- AI-enabled autonomous systems (Unmanned Aerial Vehicle (UAV) swarms for communication, search & rescue robotics, surveillance drones) for frontline operations in hazardous or access-restricted environments
- Digital twins at both city and infrastructure scale for multi-hazard simulation and power grid optimisation

— Advanced materials and biotechnology for decontamination of air, water, and surfaces

The study also identifies persistent challenges, including fragmentation across sectors and borders, limited interoperability, barriers to innovation uptake, and risks associated with increasing technological complexity and AI dual-use.

Framework of Core Capabilities for Disaster Resilience. To ensure systematic coverage of capability needs across all phases of the disaster management cycle and covering the full threat/hazard spectrum, the study developed a framework for organising core capabilities. Originally conceived as an internal structuring tool for the foresight process, the framework was enriched and refined through successive rounds of expert input. It is offered here as a contribution to the discussion on a common capability needs language for the European civil security.

Related and future Joint Research Centre work

This study builds on and complements ongoing work of DG HOME and the JRC in societal resilience and security. Future work should refine the Core Capabilities Framework through Member State consultation, test its application for gap analysis and benchmarking, and strengthen the link between foresight and R&I programming. The JRC will continue to support DG HOME and the Directorate-General for European Civil Protection and Humanitarian Aid Operations (DG ECHO) in embedding foresight and capability-based approaches into EU policy and R&I agendas.

Quick guide

The report is structured as follows: Section 1 (objectives and scope), Section 2 (methodology summary), Section 3 (relevant emerging risks), Section 4 (findings: 4.1 capabilities and 4.2 technologies), Section 5 (framework), Section 6 (recommendations), Section 7 (conclusions) and Annexes (full-fledged methodology, results, material). Readers interested in policy implications may focus on the Executive Summary and Section 6 Recommendations.

1. Introduction

Natural disasters, major accidents and deliberate attacks are expected to increase in frequency, severity and complexity across Europe. Climate change is intensifying extreme weather events. The security environment has deteriorated, reintroducing threat categories, from hybrid attacks on critical infrastructure to the prospect of armed conflict, that existing civil protection frameworks were not primarily designed to address. At the same time, the deep interdependence of critical infrastructure systems, the accelerating digitalisation of essential services, increasing urbanisation and demographic ageing are accumulating structural vulnerabilities that amplify the societal impact of any disruption. These developments are not occurring in separation; they are converging, generating compound and cascading risk scenarios that exceed the planning assumptions embedded in current preparedness instruments.

Responding to this evolving landscape, the European Commission has articulated a comprehensive preparedness agenda through the Preparedness Union Strategy (2025), the ProtectEU strategy (2025), and the Critical Entities Resilience (CER) and Network and Information Security (NIS2) Directives. Within the next Multiannual Financial Framework, the Commission proposes a fivefold increase in preparedness funding to EUR 10.7 billion, structured around the ‘preparedness by design’ principle. Translating this ambition into effective action requires a forward-looking understanding of which capabilities European societies will need and which emerging technologies can support them.

This report presents the findings of a foresight study conducted by the JRC under the guidance of DG HOME. The study covers in the first place the scope of the Horizon Europe Cluster 3¹ destination on **Disaster-Resilient Society (DRS)**² which focuses on reducing disaster losses through preventive and systemic approaches. This scope is extended to the destination **Resilient Infrastructure (INFRA)**³, on enhancing the resilience of physical and digital infrastructures, in the context of disasters. The study was designed to identify priority capabilities and emerging technologies, with the aim of informing EU policy and strategic planning with regards to research and innovation (R&I) programming.

For the purposes of this study, the term “**capability**” refers to the ability to perform the tasks necessary to deliver effect and achieve disaster and critical infrastructure resilience. It denotes competencies rather than the means through which capabilities may be delivered (tools or equipment).

Long-term R&I programming in disaster resilience requires a principled basis for selecting which capabilities matter most. This study adopts a **capability-driven approach**, grounded in the recognition that **emerging risks**, shaped by natural hazards, security threats, and structural vulnerabilities, determine the new **capability needs** that civil security apparatus must develop to

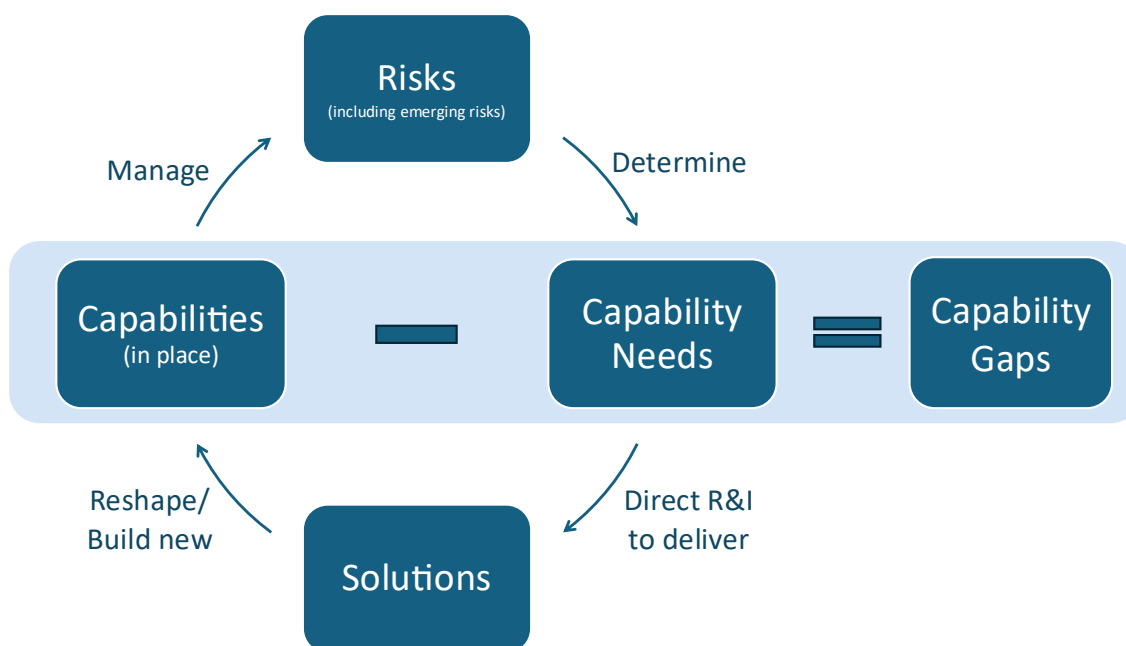
¹ See Horizon Europe [Cluster 3: Civil security for society - Research and innovation](#).

² This destination's expected outcome is that: “*losses from natural, accidental and human-made disasters are reduced through enhanced disaster risk reduction based on preventive actions, better societal preparedness, and resilience and improved disaster risk management in a systemic way.*”

³ This destination's expected outcome is that: “*[...] resilience and autonomy of physical and digital infrastructures are enhanced and vital societal functions are ensured, thanks to more powerful prevention, preparedness and response, a better understanding of related human, societal and technological aspects, and the development of cutting-edge capabilities for [...] infrastructure operators [...]*”

remain effective. Capability needs, in turn, should direct the **solutions** (technological or not). Once deployed, these solutions reshape **existing** or create **new capabilities** to manage the risks that motivated them, though they may also generate new dependencies or alter the risk landscape, sustaining the cycle. Within this cycle, capability gaps represent the deficit between identified capability needs and existing capabilities.

Figure 1. Iterative relationship between existing and emerging risks, capability needs, solutions and existing/new capabilities, in the context of R&I programming



Source: JRC own elaboration

It is this iterative relationship between risks, capability needs, and solutions that justifies placing capabilities rather than specific technologies or hazards at the centre of R&I programming (Figure 1). Technologies and policies are most meaningfully assessed not in isolation, but in terms of their contribution to the capabilities that future risk demands.

The study methodology followed a structured foresight workflow aligned with the European Commission's strategic foresight approach, proceeding through scoping, literature review, horizon scanning, expert surveys, interviews, and a participatory workshop involving over 120 experts. The process is summarised in Section 2, with a full methodological description in Annex 1.

As part of this process, the study developed a *Framework of Core Capabilities for Disaster Resilience* to ensure systematic and comprehensive coverage of capability needs across all phases and threat types. Initially conceived as an internal structuring tool, the framework was progressively enriched through successive rounds of expert validation and is presented here as a structured contribution to the broader discussion on capability planning within the EU civil protection architecture. It does not seek to replace existing instruments but to complement them by offering a cross-phase, all-hazards analytical lens that was found useful in the context of this study and may merit further examination by the wider disaster resilience community.

The report is structured as follows: Section 2 describes the methodology, Section 3 describes drivers that shape the future risk landscape, Section 4 presents the findings in two parts: priority

capabilities (Section 4.1) and emerging technologies (Section 4.2), Section 5 presents the framework of core capabilities for disaster resilience, Section 6 sets out recommendations for R&I programming and policy action, and Section 7 draws conclusions.

2. Methodology summary

Foresight Workflow

The methodology followed a structured workflow, fully aligned with the European Commission's strategic foresight approach (European Commission 2026a). The process was implemented in consecutive steps, ensuring continuity, traceability and iterative refinement of knowledge, moving from broad evidence collection to expert validation and prioritisation.

The work began with an **internal scoping phase**, carried out in collaboration with DG HOME to define the thematic boundaries, strategic priorities and analytical focus of the foresight study. This ensured early alignment with policy needs in disaster resilience.

Following the internal scoping phase, the foresight process proceeded through clearly defined stages:

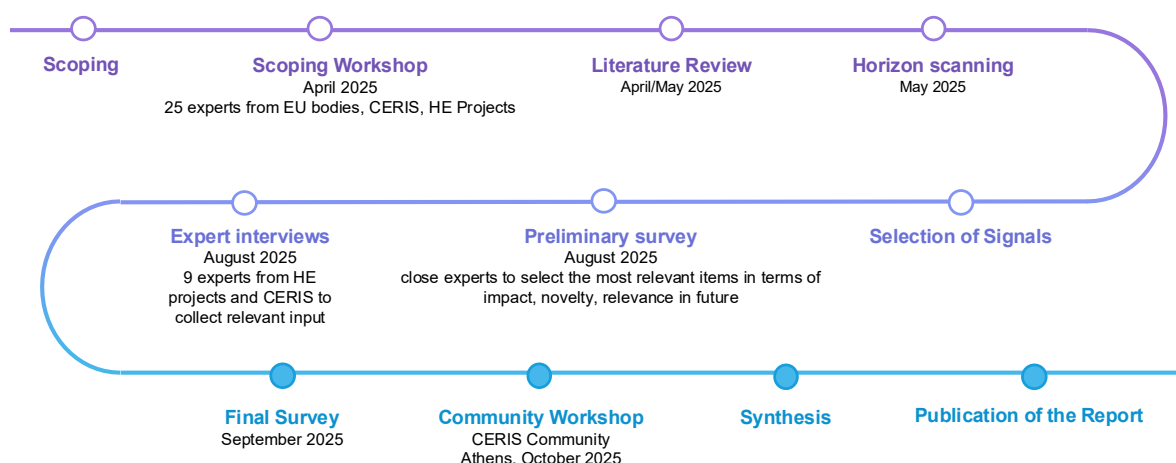
1. **Scoping Workshop** – gathering 25 experts from EU bodies, CERIS⁴ and Horizon Europe projects to validate thematic directions and scope the knowledge landscape.
2. **Literature Review** – thousands of documents were screened and filtered, resulting in 278 selected documents used as the core knowledge base for subsequent analysis. They are listed in Annex 2.
3. **Horizon Scanning** – identification and classification of 748 signals⁵, distributed as 577 emerging technologies, 149 capabilities and 22 contextual factors.
4. **Selection of signals** – The 149 capability and 577 technology signals were consolidated to 111 and 129 signals after removal of duplicates, overlaps and less relevant items.
5. **Preliminary Survey** – evaluation and prioritisation by experts of the 111 capability and 129 technology signals, resulting in 56 technology and 51 capability signals.
6. **Expert Interviews** – consultation with domain specialists and CERIS/Horizon Europe experts to refine and validate signals, resulting in the introduction of 6 additional capability signals to the final set.
7. **Final Survey** – evaluation and prioritisation of 56 technology and 57 capability signals.
8. **Community Workshop** – participatory foresight and scenario-based synthesis to analyse implications and future pathways.
9. **Synthesis** – feeding high-priority outcomes into the present Foresight Report.

This structured pipeline ensured that insights were progressively validated, refined and matured. Except for the final stage of synthesis, each output was used as the starting point for the next stage, allowing the project to converge from a broad set of early indicators into a focused set of high-priority capabilities and emerging technologies relevant for the future of a Disaster-Resilient Society and Infrastructure.

⁴ CERIS: The Community for European Research and Innovation for Security established by the European Commission gathers around 1,500 registered stakeholders (policy makers, end-users, academia, industry and civil society) and aims to facilitate interactions within the security research community and users of research outputs.

⁵ "Signals" in foresight are early indicators of potential future change.

Figure 2. Foresight study workflow

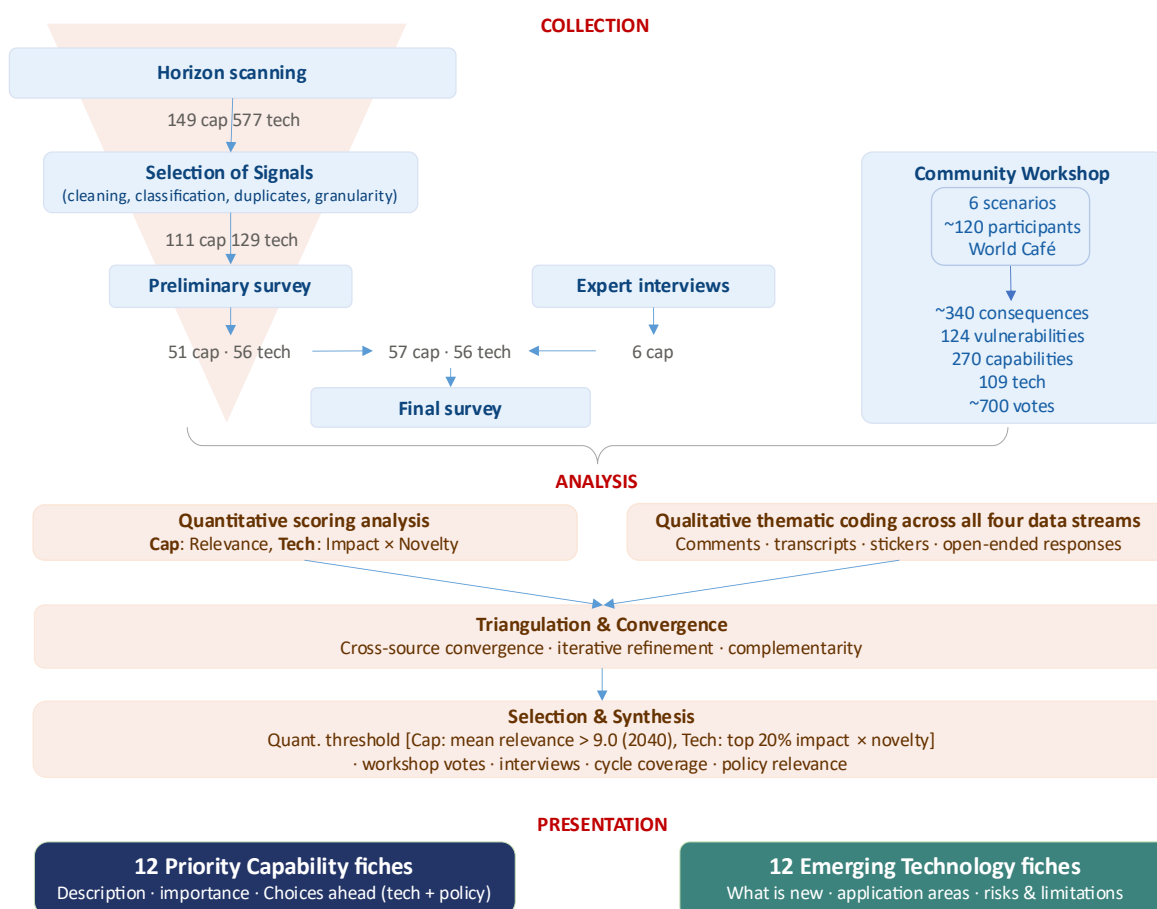


Source: JRC own elaboration

Analytical Process for the Synthesis of Findings

The analysis of results integrated data from four stages of the foresight process — the preliminary survey, expert interviews, the final survey, and the community workshop — to derive a consolidated, evidence-based prioritisation of capabilities and technologies towards 2040.

Figure 3. Analytical Process for the Synthesis of Findings



Source: JRC own elaboration

A mixed-methods approach combining quantitative scoring analysis with qualitative thematic synthesis was employed throughout.

Quantitative analysis. Capabilities were scored by mean relevance across the 2030 and 2040 horizons, with attention to overall rankings, temporal shifts in importance, and differences across disaster management phases. Technologies were assessed on impact and novelty dimensions; scores were multiplied to produce a composite ranking and grouped into six thematic clusters (Biotechnologies, Robotics & Autonomous Vehicles, etc.). Given small sample sizes, the analysis focused on central tendencies and consensus patterns rather than inferential statistics.

Qualitative analysis. Open-ended survey comments, interview transcripts, and community workshop outputs were thematically coded to contextualise the quantitative scores, identify capability gaps, and validate the capability categorization.

Community Workshop analysis. Outputs from scenario-based deliberations (World Café method) were digitised, de-duplicated, and clustered by semantic similarity, yielding approximately 270 capability entries with ~700 votes and 109 technology entries.

Triangulation. The three data streams were triangulated following principles of cross-source convergence, iterative refinement, and complementarity. A final set of 12 priority capabilities and 12 emerging technologies was selected based on: quantitative thresholds (capability relevance $\geq 9.0/10$ for 2040; technology scores in the top 20% of the impact $\times$ novelty product), workshop vote confirmation, interview corroboration, coverage across the disaster management cycle, alignment with the emerging security landscape, and policy relevance.

Presentation. This process yielded a shortlist of 12 priority capabilities and 12 emerging technologies that cover the whole disaster management cycle, reflect emerging security trends, and have clear EU policy and research and innovation relevance. Each priority signal was then packaged into a concise “fiche” that combines discrete elements that highlight its growing importance.

Methodological innovation and AI Integration

Artificial Intelligence (AI) was systematically integrated throughout the foresight process to enhance scalability, analytical consistency, traceability, and coverage across all methodological stages. The GPT@JRC platform⁵ supported literature review, horizon scanning, and data processing through large-language models, Retrieval-Augmented Generation (RAG), and controlled web-search functionalities. AI-assisted workflows enabled the extraction of candidate signals, metadata enrichment, clustering, and thematic structuring across large volumes of evidence, thereby accelerating analysis and supporting the identification of emerging technologies and capabilities relevant to disaster resilience.

At the same time, methodological robustness was ensured through continuous human oversight and expert validation at every step. AI-generated outputs were reviewed, refined, merged, or discarded by analysts and subject-matter experts, while transparency was maintained through the documentation of prompts, workflows, and validation procedures. AI therefore functioned as an analytical support tool that strengthened expert capacity without replacing human judgement.

⁶ GPT@JRC is an in-house general-purpose generative AI service that includes both open-source AI models hosted on-premises and commercial models hosted on-premises or in the cloud.

Methodological limitations

Several methodological constraints should be acknowledged when interpreting the findings of this study, primarily concerning sample sizes, expert selection, and survey design. The initial survey involved a small panel (N=7) for filtering purposes, providing indicative assessments rather than definitive rankings, while the interview round (N=9) offered qualitative depth but limited perspectives. The final survey, distributed across various networks, yielded 18 responses, enhancing robustness but reflecting a purposive sample with potential gaps in capturing the full range of views within the European disaster resilience community. Changes in the technology rating scale introduced comparability challenges, addressed through linear rescaling. The scenario-based community workshop, despite generating rich data, could be influenced by regional biases due to its location and participants, affecting deliberative outcomes and voting patterns. The iterative filtering process posed selection effects, potentially excluding relevant signals early, although interviews helped identify gaps independently. Capability and technology signals were collected in parallel to avoid constraining the technology search; however, this introduced an asymmetry that complicated the alignment of specific application areas with the prioritised capabilities.

A detailed description of the different phases and steps of the methodology and its limitations can be found in Annex 1.

3. Converging factors shaping the future risk landscape

Europe's risk landscape in 2040 will not simply be a scaled-up version of today's. It will be structurally different, defined by the simultaneous intensification and interaction of hazards, threats and societal vulnerabilities that have traditionally been treated in isolation. This chapter sets out the converging drivers that shape this landscape, providing the shared analytical context for the twelve priority capability areas examined in the sections that follow. These drivers are organised into three analytically distinct but deeply interacting categories: **hazards triggering natural & accidental disasters**, **security threats**, and **structural vulnerabilities**. What makes the horizon to 2040 distinctive is not the emergence of entirely new risk categories, but the degree to which these three dimensions are converging, each amplifying the others, to generate compound and cascading risk scenarios that exceed the design parameters of current European civil protection frameworks.

Hazards triggering natural & accidental disasters

Climate change is the principal driver of an accelerating natural hazard environment. Across Europe, the frequency and severity of flooding events is projected to increase significantly (European Environment Agency 2024; Merz et al. 2021; Voudoukas et al. 2017). Wildfires are intensifying in frequency, magnitude and geographic spread, driven by the expansion of the Wildland-Urban Interface (WUI), rural land abandonment and fuel accumulation (European Environment Agency 2024; World Bank 2025). Heatwaves and droughts are becoming more prolonged and extreme precipitation events more intense (Toreti et al. 2025). The aggregate scale of the challenge is substantial: climate change alone is projected to cause up to a tenfold increase in damage to the built environment from extreme weather by the end of the 21st century (European Environment Agency 2024). At the same time, persistent geological hazards, particularly seismic activity in Southern Europe, continue to expose significant concentrations of population to acute risk (Atalić et al. 2023).

As important as the increase in intensity is the shift in the character of hazardous events. The 2040 horizon is expected to be marked by a growing frequency of compound and multi-hazard scenarios, where hazards cascade across sectors, co-occur, or interact with human-induced incidents to produce risk configurations that cannot be addressed through single-hazard planning (Lentini et al. 2025; UNDRR 2019). Climate-driven events are already triggering technological accidents at industrial installations, with Natech scenarios emerging as a growing concern at local, national and EU level (Fujita et al. 2024). The rising likelihood of pandemics, driven by zoonotic spillover, antimicrobial resistance and the progressive compression of human-animal-environment interfaces, reinforces this multi-hazard picture with a biological dimension that operates on a different temporal and geographic scale from physical hazards (AghaKouchak et al. 2020; Fenollar et al. 2021).

Security Threats

The European security environment has deteriorated markedly over recent years, reintroducing threat categories that many civil protection and risk governance frameworks had treated as peripheral. Terrorism, encompassing attacks on public spaces, mass casualty incidents and the deliberate use of CBRN-E weapons, remains a persistent and evolving threat. CBRN-E attacks are relatively rare, but the consequences of such an attack can be devastating in terms of loss of life, physical damage, and economic disruption. International terrorist groups have already used and

sought to develop weapons of mass destruction, and state actors have employed such weapons for targeted assassinations and in civil conflicts (SIPRI 2019). Technological progress is sharpening this risk: the convergence of advances in chemistry, synthetic biology and accessible digital tools is expanding the capacity of terrorist actors to develop improvised weapons containing novel chemical or biological agents, including agents potentially engineered to target specific population groups using genome-editing (Balachandar 2021; U.S. Department of Homeland Security 2025; Urbina et al. 2022). Radicalisation pathways, already amplified through social media, are being further enabled by immersive virtual environments that complicate early detection of extremist activity and the identification of perpetrators (Awan 2017; Hupont Torres et al. 2023).

Hybrid threats constitute a second and increasingly prominent dimension of the evolving security landscape. The deliberate combination of cyber operations, disinformation and physical sabotage of critical infrastructure is progressively eroding the boundary between natural disaster management and security response. Acts of sabotage targeting European critical infrastructure increased significantly in 2024, affecting multiple EU Member States (Edwards and Seidenstein 2025; European Commission 2025b), and adversaries are known to exploit natural hazard events or Natech incidents to amplify disruption and degrade public trust in state capacity (Giannopoulos, Smith, and Theocharidou 2021). The precarious nuclear safety situation generated by armed conflict in the European neighbourhood, combined with the number of European nuclear facilities approaching or exceeding their original design lifespans (IAEA 2025; World Nuclear Association 2025), elevates radiological risk from a residual to a concrete contingency. In the cyber domain, the convergence of AI and quantum computing is projected to automate and enhance offensive capabilities, with the potential to compromise conventional encryption protocols and circumvent existing defensive mechanisms (ENISA 2025; Europol 2025; Groenland 2025; Ryan et al. 2025).

The deterioration of the European security environment has reintroduced the prospect of armed conflict on or near European territory as a plausible contingency for civil protection planning. Russia's war against Ukraine, now in its fourth year, has demonstrated in practice the devastating consequences for civilian populations and critical infrastructure of high-intensity conventional warfare, while simultaneously revealing the extent to which civilian resilience underpins national defence capacity. With the end of the Cold War, the concept of **civil defence**⁷ was gradually abandoned and is currently insufficiently integrated into national public policies (Ministre de l'Intérieur 2025). However, a growing number of Member States⁸ are now revisiting civil defence as a distinct policy objective alongside civil protection (The Government of Sweden 2025). These developments signal that civil protection frameworks designed primarily for natural disasters and industrial accidents should now consider integrating scenarios involving sustained hostile action

⁷ Defined under Additional Protocol I to the Geneva Conventions (Art. 61) as: *"the performance of some or all of the undermentioned humanitarian tasks intended to protect the civilian population against the dangers, and to help it to recover from the immediate effects, of hostilities or disasters and also to provide the conditions necessary for its survival"*. Protocol Additional to the Geneva Conventions of 12 August 1949, and Relating to the Protection of Victims of International Armed Conflicts (Protocol I), of 8 June 1977 (<https://www.ohchr.org/en/instruments-mechanisms/instruments/protocol-additional-geneva-conventions-12-august-1949-and>)

⁸ The *"European Coalition for Civil Preparedness and Resilience"* was launched in May 2025 and brings together ministers responsible for civil preparedness and resilience from Belgium, Estonia, Finland, Latvia, Lithuania, Luxembourg, the Netherlands, Poland and Sweden to strengthen cooperation and ensure preparedness for all security threats, including armed aggression.

against European territory and populations. There is a clear need to identify the priority needs of the population for civil defence and to adapt planning arrangements accordingly.

Migration is, among other factors, driven by insecurity, armed conflict and climate change in the source countries; these drivers are increasing. Migration is also weaponised in the context of hybrid threats. Large, unexpected or uncontrolled migration events may risk overwhelming coping capacity.

Structural vulnerabilities

Structural vulnerabilities determine the severity of the impact that any given hazard or threat ultimately inflicts on society, and across Europe they are accumulating.

The deep interdependence of critical infrastructure systems means that disruptions originating in one sector can propagate rapidly and non-linearly to others, generating cascading failures whose scale far exceeds the original incident (Piraina and Trucco 2022; Yadav, Chatterjee, and Ganguly 2020). Insufficient redundancy throughout these systems magnifies this dynamic: without adequate backup capacity, the failure of individual components carries disproportionate societal cost. The dependence of densely populated urban areas on complex and geographically extended supply chains simultaneously reduces the time window available to absorb prolonged service shortages, a condition that is itself a documented trigger for public panic behaviour, further amplified in a hyperconnected society (Anokhin et al. 2021; J. Wu, Niu, and Santibanez Gonzalez 2025).

The ongoing digital transformation of critical sectors is generating an expanded cyber-physical attack surface that existing governance frameworks were not designed to manage (Demertzi, Demertzis, and Demertzis 2023; Marmier et al. 2022). The same artificial intelligence technologies that enhance early warning, detection and decision support also enable autonomous offensive cyber operations, deepfake-driven disinformation at scale, and the potential acceleration of weapons development, creating a dual-use challenge that cuts across multiple capability domains. In parallel, the energy transition is introducing new risk categories, including thermal runaway in electric vehicles and toxicological hazards from alternative maritime fuels, for which response protocols remain inadequately calibrated (European Maritime Safety Agency 2025; Silva, Gomes, and Alberto 2021; Tankou 2024). Space provides more and more critical functions but is becoming increasingly threatened itself (Council Conclusions on the EU Space Strategy for Security and Defence, 14512/23, 13 Nov 2023).

Urbanisation is concentrating more people and assets in hazard-prone areas and in environments that complicate emergency access. Europe's urban population is projected to exceed 80% by 2050 (UCP Knowledge Network 2023), and the urban heat island effect, soil sealing and high population density amplify the consequences of heatwaves and floods in ways that are not captured by hazard data alone. Demographic ageing adds a further structural dimension: with the 65+ cohort approaching one-third of the EU population by 2050, European societies face a simultaneous reduction in the professional responder base and growth in the share of the population requiring support during emergencies (Curtale et al. 2025; Ueffing et al. 2022).

Most European first-responder agencies have not defined their own future capability gaps, due to a lack of resources, procedures and know-how. Moreover, first responders are usually organised regionally, with gaps and needs differing from one region to another. Thus, the Member States' first responders have agreed neither on a common set of required technologies nor on a joint methodology to define their capability gaps (European Commission 2024a).

These material vulnerabilities are compounded by a social one: public trust in national governments and institutions across the EU remains fragile (European Commission 2025i), reducing societal

cohesion at precisely the moments when coordinated response is most needed, and amplifying the destabilising effect of disinformation on crisis management. Organised crime including corruption is also a potentially increasing threat that may undermine response capabilities.

Convergence and the limits of fragmented approaches

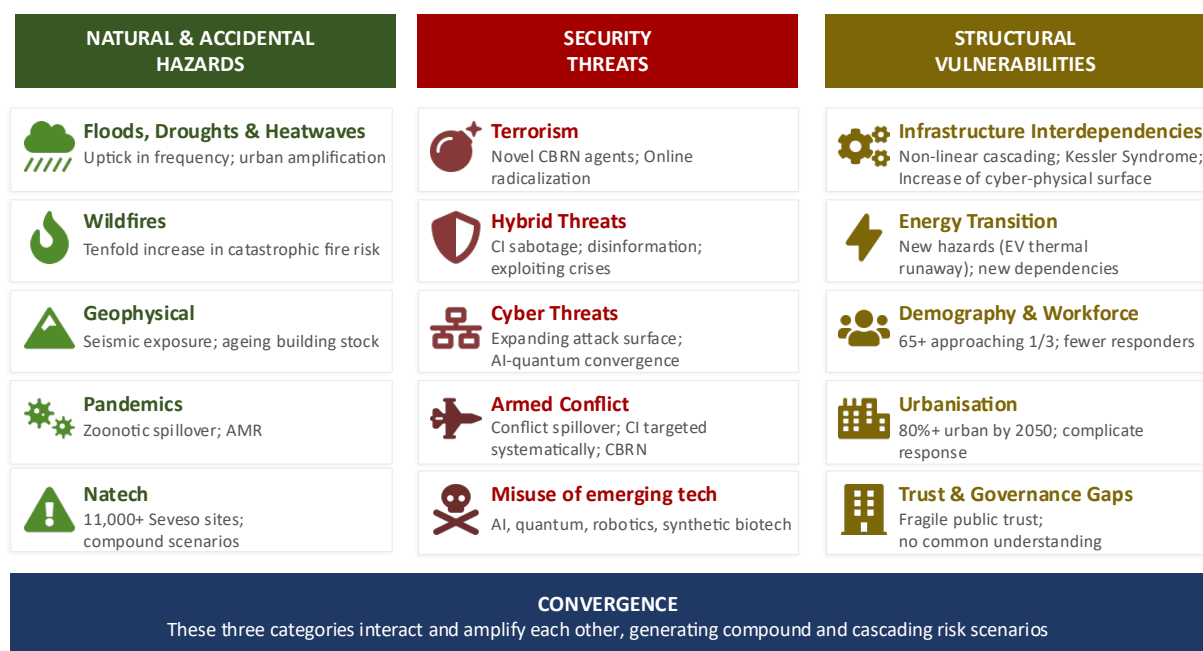
The impact of these three categories lies not in each individually but in the nature of their interactions. Compounding this convergence is the accelerating rate of change itself: the pace at which climate impacts intensify, technologies evolve, and geopolitical alignments shift is compressing the decision window available to policymakers and making anticipatory capacity a systemic necessity rather than a discretionary investment. Climate change does not operate against a stable social or security background: it degrades the physical resilience of infrastructure that is already under-maintained, progressively saturates emergency response capacity, and displaces populations in ways that generate new concentrations of vulnerability. Security threats, in turn, do not unfold in isolation from the physical environment: they are calibrated to exploit moments of maximum systemic stress, when the combination of degraded infrastructure, saturated responders and disrupted communications creates the conditions for maximum societal impact. Structural vulnerabilities, finally, are not a passive backdrop to hazards and threats but the primary mechanism by which localised incidents are transformed into cascading crises that cross sectoral and national boundaries. The interactions are bidirectional and mutually reinforcing: a flooding event that triggers a Natech accident (Natural-Hazard Triggered Technological Accident), disrupts communications infrastructure and coincides with a disinformation campaign is not an exceptional scenario for the 2040 horizon; it represents the expected operating environment (European Commission 2025h; Lentini et al. 2025; Martin-Moreno et al. 2025).

The cumulative effect is a risk environment that is qualitatively different from the assumptions embedded in most existing European planning frameworks. The relevant unit of analysis is no longer the single hazard or single threat event but the compound scenario: the intersection of multiple drivers acting simultaneously on a vulnerable and interconnected society. Multifaceted and interdependent risks, driven by diverse causal factors and producing impacts across multiple domains at once, render traditional sector-by-sector or single-risk assessment approaches structurally inadequate for informing resilience investment at the scale required (Lentini et al. 2025; UNDRR 2019).

The EU has begun to respond through instruments including the Preparedness Union Strategy (2025), ProtectEU (2025), the CER and NIS2 Directives, and the White Paper for European Defence Readiness 2030; and within the next EU MFF, built around the 'preparedness by design' principle, the Commission proposes to increase funding in this area fivefold, to EUR 10.7 billion (European Commission 2025c).

The twelve priority capabilities proposed in this forward-looking, capability-oriented analysis are intended to enable Europe to deal with this future. Figure 4 and Table 1 below map the key interactions between hazards, threats and the vulnerabilities they engage. These elements shape the future EU security landscape and determine future capability needs.

Figure 4. Overview of the risk drivers: hazards, threats and vulnerabilities.



Source: JRC own elaboration

Table 1. Risk drivers and key associated developments and implications⁹.

RISK DRIVERS		KEY DEVELOPMENTS AND IMPLICATIONS
HAZARDS TRIGGERING NATURAL & ACCIDENTAL DISASTERS		
Meteorological-Hydrological-Climatological	General	- Large-scale disasters rapidly exceed single EU MS capacity - Compound and multi-hazard scenarios overwhelm single-hazard response frameworks 11,000+ Seveso industrial sites across the EU
	Overall	- Significant increase in frequency and severity of extreme weather events across Europe - Climate damage to the built environment projected to increase up to tenfold by end of century - Extended duration strains essential services beyond their designed continuity thresholds
	Floods, droughts & heatwaves	- Uptick in riverine and coastal flooding, particularly in north-western Europe - Urban heat island and soil sealing amplify heatwave mortality and flood runoff in cities - Water scarcity
	Wildfires	Southern Europe could face up to a tenfold increase in the probability of catastrophic fires

⁹ This tabulation provides an overview of risk drivers shaping the future EU security landscape and determining future capability needs, together with key associated developments and implications; the many interactions between them are not fully captured in this linear presentation.

RISK DRIVERS		KEY DEVELOPMENTS AND IMPLICATIONS
		— EU will face extension of the fire season — WUI expansion, rural land abandonment and fuel accumulation
	Geophysical	— Ageing building stock designed under outdated parameters — High urban density in seismically active Southern European zones concentrates population exposure
	Pandemics & Epidemics	— Zoonotic spillover — Antimicrobial resistance
SECURITY THREATS		
	Overall	— VUCA (Volatility, Uncertainty, Complexity, Ambiguity) geopolitical environment. — Technological evolution (AI, quantum, drones, etc.) can be exploited for malicious use — Threats transcend national boundaries
	Terrorism	— Novel biological and chemical agents are increasingly accessible — Bioterrorism: Gene-editing technologies (Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR)-Cas9) have made it easier for non-state actors to create and disseminate biological agents — Detection of novel biological agents remains limited — Virtual environments create new pathways for radicalisation and facilitation of terrorism activities — Intersection with hybrid threats
	Hybrid threats	— Sabotage against EU Critical Infrastructure — Adversaries can exploit natural hazard events to amplify disruption and degrade state credibility — Disinformation degrades public capacity to act on factual information during crises
	Cyber-threats	— Expanding cyber-physical attack surface — AI-quantum convergence can automate attacks and compromise current encryption
	Armed conflict	— Conflict spillover in EU neighbourhood — CBRN-E risks — Large-scale population displacement — Civilian infrastructure systematically targeted during war
STRUCTURAL VULNERABILITIES		
	Overall	— Localised incidents can become cascading crises — Disruption to essential services triggers public panic — Insufficient redundancy across infrastructure systems magnifies the societal cost of any failure — Slow / limited innovation uptake — EU-wide comparability of risk data remains limited, hampering collective preparedness — Fragile public trust reduces societal cohesion at the moments coordinated response is most needed — Absence of a common EU capability framework limits mutual understanding of gaps and hampers coordinated resource allocation — Uncontrolled migration risk overwhelming coping capacity

RISK DRIVERS	KEY DEVELOPMENTS AND IMPLICATIONS
	— Organised crime and corruption undermine response capacity — Current civil protection frameworks give limited consideration to warfare
Infrastructure (Digital transformation, energy transition, interdependencies)	— Failures propagate non-linearly across interdependent sectors — Accelerating digitalisation of critical sectors continuously expands the cyber-physical attack surface — Cascading CI failure complicates and prolongs response — Cross-border supply chain complexity extends cascade risk — Emergence of quantum technology threatens the encryption on which secure transactions and communications depend — Green transition introduces new types of hazards and new dependencies (e.g. thermal runaway of electric vehicles) — Ageing European nuclear facilities approaching or exceeding original design lifespans — Growing reliance on orbital assets (exposed to Kessler Syndrome, weaponization of space) — Tensions and increasing congestion in space elevate the risk of deliberate or accidental disruption
Demography, workforce	— Ageing workforce and declining volunteer recruitment reduce operational surge capacity — 65+ cohort approaching one-third of EU population: fewer responders, more people requiring support during emergencies — Evolving threat landscape requires specialist competencies (CBRN-E, cyber, robotics)
Urbanisation	— Urban population projected to exceed 80% by 2050 — Urban density complicates emergency access and amplifies hazard consequences

Source: JRC own elaboration

4. Findings

This section presents the findings of this study. It is structured in two parts: Section 4.1 presents 12 priority capabilities identified as strategic priorities for a Disaster Resilient Society and related Critical Infrastructure Resilience towards 2040, while Section 4.2 presents 12 emerging technologies with the high potential to support resilience. The selection of these signals results from the convergence of quantitative scoring, qualitative expert input, and participatory deliberation across the full foresight process, as described in the Methodology summary above and Annex 1.

4.1. Capabilities

4.1.1. Analytical findings across the different study phases

The capability assessment across the foresight process produced a consistently high-scoring landscape: in the final survey, the vast majority of the 57 capabilities were rated between 8 and 10 on the 0–10 relevance scale for the 2040 horizon, with an overall mean of approximately 9. This concentration at the top of the scale is consistent with the design of the foresight process, in which the 57 capabilities had already been distilled from a longer list of 149 (subsequently 111) candidate capabilities through earlier expert consultation. The final-survey ratings therefore confirm the relevance of the shortlisted set. Table 2 lists the average scores of the 57 capabilities from the final survey in each phase.

Table 2. The final survey scores for capabilities per phase

2030		2040	
Phase	Average score of replies	Phase	Average score of replies
A. Anticipation	8.4	A. Anticipation	8.5
B. Preparedness	8.9	B. Preparedness	8.9
C. Response	8.9	C. Response	9.0
D. Recovery	8.9	D. Recovery	9.0
ABCD. Horizontal	8.9	ABCD. Horizontal	8.9
Total	8.9	Total	8.9

Note: Full table of average scores per signal in Annex 3

Source: JRC own elaboration (final survey results)

Expert interviews were helpful in shaping and enriching these findings. Nine interviews with specialists spanning across CBRN-E defence, civil protection and emergency management, AI and security research, and innovation ecosystems, identified recurring cross-cutting themes:

- *Citizen Preparedness and Empowerment*: This was highlighted by most interviewees as a critical gap. Empowering citizens is considered essential for effective emergency response, particularly in the first hours when professional capacity may be overwhelmed.
- *Civil-Military Coordination*: The need to clarify chains of command for escalation scenarios was emphasised, especially given the proximity of armed conflict to EU borders and the increasing sophistication of CBRN-E threats.

- *Cross-border Standardization*: There were notable examples of interoperability failures, such as incompatible fire hose couplings between Member States, divergent building codes, and fragmented risk data, highlighting the need for standardised equipment, procedures, and data.
- *CBRN-E Detection and Decontamination*: Significant gaps were identified in the detection and decontamination capabilities, particularly for biological agents. Experts see a need for miniaturised sampling tools, rapid field analysis, and updating legacy platforms like JRODOS (Java-based Real-time Online Decision Support) to incorporate real-time data and AI.
- *Technology Adoption Barriers*: The challenge of transitioning EU-funded innovations from project results to operational deployment was noted, with issues such as procurement delays and insufficient involvement of operational end-users in solution co-design.
- *Caution on AI Dependence*: Interviewees stressed the importance of science-driven systems over AI-driven ones, maintaining human involvement in critical decisions, and the risk of reduced resilience when technology fails.

The community workshop provided a complementary and independent prioritisation lens. Working under the assumption of a 2035 world with only 2025 capabilities, 120 experts explored six disaster scenarios and identified capability gaps through structured deliberation. Across all scenario tables, the exercise fostered collective thinking and generated approximately 270 capability-related entries and approximately 700 votes ensuring cross-pollination of perspectives. After de-duplication and semantic clustering, the workshop results identified 14 broad capability clusters. They are ranked by aggregate vote count in Table 3.

Table 3. Community workshop capability clusters ranked by total votes

Capability cluster	Related entries	Votes	Description
Training, Education & Exercises	30	111	Knowledge, skills and competency development; exercises, drills, lessons-learned programmes, crowd management and CBRN-E training
Citizen Empowerment & Public Communication	32	77	Public awareness, citizen preparedness, risk communication, volunteer management, community involvement in response and prevention
Detection, Monitoring & Early Warning (before and after event onset)	18	67	Early warning systems, real-time monitoring and Decision Support Systems (DSS), surveillance, threat detection (incl. CBRN-E), geohazard assessment
Critical Communications & Interoperability	16	64	Information exchange among responders and agencies; common language, unified communications, interoperable systems
Coordination	22	62	Cross-border, cross-agency and civil-military coordination; common operational picture, coordination centres, unified command, clear responsibilities, EU-level cooperation
Planning & Risk Assessment	23	61	Land-use and urban planning, risk assessment, cascading effects modelling, strategic and contingency planning, climate adaptation
Evacuation	20	50	Evacuation routes and plans, passenger localisation, shelter identification, mass evacuation, evacuation of vulnerable groups
Medical Response & Psychosocial Support	16	48	Specialised hospital units, Emergency Medical Services (EMS), triage, first aid readiness, psychological support for survivors, responders and communities

Capability cluster	Related entries	Votes	Description
Resilient Design & Infrastructure	15	42	Build-back-better, resilient critical infrastructure, building codes, nature-based solutions, infrastructure maintenance and strengthening
Frontline Operations	27	33	Search and rescue, resource deployment, logistics, drones, rescue equipment, real-time situational tools, distribution of essential supplies
Redundancy & Backup Systems	13	29	Backup power supply, modular hospitals, manual operation fallbacks, EMP (Electromagnetic Pulse) protected equipment, essential supplies reserves
CBRN-E specific	12	22	CBRN-E emergency response units, decontamination, HAZMAT (Hazardous Material) removal, biological/chemical agent detection, specialised Personal Protective Equipment (PPE)
Recovery & Lessons Learned	20	22	Environmental recovery, infrastructure restoration, post-incident analysis, regulatory updates, economic rehabilitation
Cyber Resilience	5	14	Security by design, ethical hacking, zero trust architecture, backup solutions for cyber incidents, resilient architecture
Other (unclassified)	1	1	Single item with ambiguous thematic fit
Total	270	699	

Note: Votes combine red dots (own-table priority) and black dots (visiting experts' perspective) across all six scenario tables. All entries are assigned to a thematic cluster through keyword-based classification and manual review. Related entries refer to the number of capability items per cluster, including zero-vote entries. Clusters are ranked by total vote count (red + black).

Source: Community workshop scenario boards extraction.

Notably, the workshop voting distribution by disaster management phase — 292 votes for “Before” (preparedness), 270 for “During” (response), and 137 for “After” (recovery) — reveals that experts consider pre-disaster preparedness and active response as the most intensive phases when dealing with concrete scenarios.

The final set of 12 priority capabilities was derived by identifying signals where survey (primarily scores above 9), workshop votes, and interview themes converge, considering the selection criteria described in Annex 1. The table below lists the priority capabilities and summarises the evidence base for each. The 12 selected capabilities cover all phases of the disaster management cycle from anticipation to recovery. The workshop’s emphasis on “Before” capabilities (292 of 699 votes) further validates the priority given to preparedness-stage signals such as training, resilient design, and early warning systems.

Table 4. Priority Capabilities and their converging evidence across data sources

	Priority Capability	Capability Elements (survey / workshop)	Score (Survey average Workshop votes)
1.	Essential Services Continuity and Redundancy	Continuity of essential services	9.7
		Reliable power supply	9.4
		Redundancy and backup systems for essential services continuity	9.3
		Redundancy & Backup Systems	29 votes
2.	Cross-border Cooperation & Multi-level Cross-sectoral Coordination	Data sharing	9.6
		Cross-border cooperation	9.3
		Coordination	62 votes

	Priority Capability	Capability Elements (survey / workshop)	Score (Survey average Workshop votes)
3.	Cyber Resilience	Cybersecurity measures	9.5
		Cyber incident response	9.4
		Cyber Resilience	14 votes
4.	Early Warning & Detection	Accurate early warning systems	9.5
		Early detection, monitoring & early warning (pre-event)	35 votes
5.	Critical Communications	Connectivity for first responders	9.4
		Interoperable communications	9.2
		Critical Communications	64 votes
6.	Decontamination, Waste Management, and Restoration	Restoration of the environment, livestock, agriculture	9.2
		Decontamination of areas from hazardous materials (e.g., CBRN-E)	9.2
		Hazardous waste management	9.1
7.	Resilient Design	Resilient design	9.2
		Resilient Design & Infrastructure	42 votes
8.	Systemic Risk Modelling & Critical Infrastructure Interdependency Mapping	Systemic risk modelling & Critical infrastructure interdependency mapping	9.2
9.	Efficient and Safe Frontline Operations	Efficient equipment and tools for responders' mission	9.4
		On-scene remote operations	9.1
		Protective personal equipment	9.1
		Equipment and techniques	20 votes
10.	Citizen Empowerment	Citizen empowerment	9.1
		Citizen empowerment	77 votes
11.	Training for first responders	Training should be regularly updated and effectively communicated	9.0
		Training for responders	96 votes
12.	Rapid on-scene detection, monitoring and analysis of threats, hazards, contaminants	Rapid on-scene detection, monitoring and analysis of threats, hazards, contaminants	9.2
		On-scene detection and monitoring (response-phase, field-operation level)	34 votes

Note: the score represents respectively the: a) survey average of constituent capability element relevance for 2040 and b) the votes of closest items matching the survey signal.

Source: JRC own elaboration (final survey results)

4.1.2. Priority Capabilities

Essential Services Continuity and Redundancy

Continuity of essential services (European Parliament and Council 2022) refers to the ability to maintain vital services and functions during and after disasters and disruptions. Redundancy as a key aspect of disaster resilience (Kim et al. 2025), refers to the provision of alternative or back-up means to ensure such continuity.



Why does it matter?

This capability will become increasingly critical for the EU by 2040 due to several converging factors that outline the future challenges on civil security landscape. Climate change intensifying frequency and severity of natural disasters (European Environment Agency 2024; Menoni et al. 2023), growing digitalization and over-dependence on digital technologies, increasing critical infrastructure interdependencies (Piraina and Trucco 2022), proliferation of cyber-attacks on interconnected infrastructure (Europol 2025), new dependencies and vulnerabilities due to energy transition (Silva, Gomes, and Alberto 2021), cascade risks due to complex cross-border supply chains (Menoni et al. 2023), longer recovery periods due to system complexity (Anokhin et al. 2021), are among the principal drivers of this trend.

Insufficient redundancy in infrastructure systems increases the criticality of individual components. Without backup systems, the failure of any single component would result in a greater disruption of essential services. For instance, communications and electric power systems rely on each other to function; major damage to one will disrupt the other.

Disruptions to essential services or goods are a significant trigger for public panic behaviour, a phenomenon that is demonstrably amplified and accelerated in a technologically interconnected future society (J. Wu, Niu, and Santibanez Gonzalez 2025). Urbanization tends to reduce the

inherent resilience and therefore the time window a densely populated area can effectively withstand prolonged shortages, as cities rely heavily on complex, far-reaching supply chains and critical infrastructure. This vulnerability is a growing concern, as the urbanization trend is projected to continue in Europe and globally (United Nations 2025).

Choices ahead

Technology enablers

Advanced energy storage solutions and decentralised power generation technologies will enhance power supply resilience, AI-powered predictive maintenance systems will help identify potential failures before they occur. Digital twins of critical infrastructure will enable better planning and testing of redundancy systems. Smart grid technologies will allow more flexible power distribution during emergencies. Autonomous logistics systems will improve supply chain resilience during disruptions.

Policy options

Providing several alternatives can provide built-in redundancy to infrastructure, reducing the impact of a single failure. Cross-border agreements on mutual assistance for essential service restoration, diversification and redundancy in supply chains, retrofitting infrastructure and fallback sites, EU-wide standards for redundancy in critical systems, updated business continuity plans, and incentive programs for private sector investment in backup capabilities.

Cross-border Cooperation & Multilevel Cross-sectoral Coordination

Refers to the capability to effectively synchronise efforts among critical stakeholders across geographic jurisdictions, to achieve common goals for disaster resilience.



Why does it matter?

Future major threats, risks, and crises will rarely occur in isolation. Therefore, cooperation and coordination among different sectors, levels and regions is essential to withstand and face these challenges. Considering Europe's evolving risk landscape, this capability is expected to be a critical cornerstone for determining the level of future European disaster resilience and serves as the basis for all efficient interventions. Factors such as climate change that will intensify extreme natural events, geopolitical instability that will challenge the EU's ability to face direct security threats, and growing technological interdependence are driving complex, interconnected threats and vulnerabilities that naturally transcend national boundaries, rendering isolated national approaches insufficient and fragmented actions from different sectors counterproductive (Lentini et al. 2025).

As acknowledged in (European Commission 2025h), a comprehensive picture of both existing and planned prevention and preparedness measures relevant to key risk

areas across the European Union still lacks sufficient detail and comparability for effective analysis. By knowing each other's vulnerabilities and strengths, Member States can move beyond fragmented national efforts to enable true risk-informed decision-making, optimise resource allocation, and foster a fully coordinated and robust pan-European disaster resilience framework. By strengthening coordinated, multi-level, and cross-sectoral actions across the European Union, the EU can enhance its resilience and safeguard its communities.

Choices ahead

Technology enablers

Deployed AI-powered crisis dashboards that leverage data fusion to generate real-time common operating pictures for decision-makers. These dashboards aggregate multi-modal data sources (satellite imagery, ground sensors, open-source intelligence) and apply machine learning

algorithms to correlate events, thereby reducing cognitive load on operators and ensuring a unified situational awareness across all command levels (Sun, Bocchini, and Davison 2020).

Policy options

The successful implementation of the whole-of-society and whole-of-government approach is closely connected with this capability (European Commission 2025f). A pre-established, tiered response plan (local → regional → national → pan-European) is crucial for facilitating a seamless escalation and maintaining unified command immediately following a disaster. Setting a framework of core capabilities essential for disaster resilience could optimise actions. Such framework would establish a common language and shared understanding among jurisdictions, sectors, levels, and MS, enabling a homogenous description of capability needs and further comparative gap analysis across EU. Upgrade joint mechanisms, such as EU Civil Protection Mechanism (UCPM), to ensure unity of efforts through a Unified Command structure, especially when no single MS, administrative entity or agency has primary authority and/or the capacity to manage a serious incident on its own.

Cyber Resilience

Though lacking a universal definition, refers to the capability of an entity to endure and adjust from unfavourable cyber incidents, such as cyberattacks, technical failures, and Natech events (Tzavara and Vassiliadis 2024). It encompasses cybersecurity, which focuses mainly on protecting against cyber threats (European Parliament and Council 2019).



Why does it matter?

Digital transformation of our societies will accelerate, creating new realities on all facets of our future life, particularly in critical sectors such as healthcare, energy, communication, and transportation.

Smart cities, energy transition, smart grid, quantum technology, and the Internet of Things (IoT) are some of the technological advances that will drive new cyber threats, which will be increasingly linked to geopolitical tensions (ENISA 2025; Europol 2025). The expected enormous growth of the cyber-physical attack surface, coupled with exacerbated vulnerabilities from hyperconnectivity, means cyberattacks targeting critical infrastructures can cripple essential services (Demertzi, Demertzis, and Demertzis 2023; European Commission 2023a; Marmier et al. 2022; Office of the Director of National Intelligence 2021; Oughton et al. 2019).

The convergence of quantum computing and AI is projected to automate and enhance cyberattacks, potentially compromising conventional encryption protocols and circumventing adaptive defence mechanisms, all particularly relevant with the advent of a cryptographically relevant quantum computer (CRQC) (Office of the Director of National

Intelligence 2026). Nevertheless, while roadmaps for fault-tolerant quantum computers (FTQCs) by 2030 remain optimistic, uncertainty persists over their achievable power, reliability, and wide availability within this decade (Groenland 2025; Ryan et al. 2025).

Virtual universes build on Web 4.0 will create new ways to compromise devices and damage infrastructure, cause disruptions and harm people (Hupont Torres et al. 2023). Moreover, due to the interdependency of digital systems, disruptions can have cascading effects across

interconnected networks, where a limited disturbance in one component can rapidly spiral to cause severe impacts in others (Panda and Bower 2020; Yadav, Chatterjee, and Ganguly 2020). Consequently, given the increased likelihood of persistent disruptions and the severity of their overall impact, cyber resilience is paramount.

Choices ahead

Technology enablers

Blockchain for data integrity and protection against unauthorised access, providing a decentralised method of securing critical information. AI-powered threat detection and response systems. Quantum-resistant encryption is designed to safeguard against future quantum computing threats, although it remains unclear whether it represents the optimal solution in terms of implementation costs and computational efficiency (Lewis et al. 2025). Self-healing networks that can automatically isolate compromised segments. Digital twins for testing cyber defences without risking operational systems.

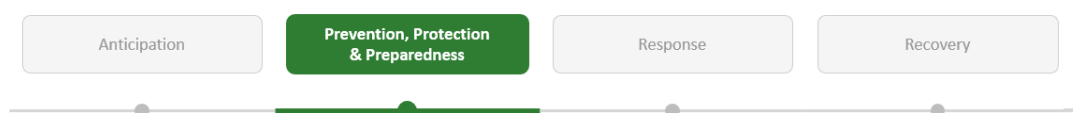
Policy options

Given the inherently cross-border nature of cyber threats, it is essential to move further towards a holistic approach shifting from cybersecurity to cyber resilience and from fragmented national to unified EU-level efforts. This transition necessitates establishing an EU comprehensive and consistent cyber resilience framework and empowering an EU agency¹⁰ to effectively coordinate response actions during large-scale incidents and crises, better allocate resources, measure vulnerabilities, and significantly improve the monitoring, collection, and exchange of operational and strategic intelligence. Addressing security issues in virtual universes, particularly those related to the prosecution of crimes, and enhancing authorities' capabilities to identify vulnerabilities (Hupont Torres et al. 2023).

¹⁰ For instance, upgrading the EU Computer Security Incident Response Teams (CSIRTs) Network (NIS2 Directive, 2022/2555) into a unified EU agency (e.g., ENISA).

Early Warning & Detection

Early Warning & Detection refers to the capability to identify potential threats and hazards proactively, facilitating timely actions to prevent incidents or mitigate their impacts. This involves monitoring and analysing indicators and patterns that signal the onset of a disaster.



Why does it matter?

The necessity for advanced early warning and detection systems for hazards and threats in Europe by 2040 will be driven by a convergence of technological, environmental, and socio-political drivers and stresses.

As climate change intensifies rising temperatures, altering precipitation patterns, heatwaves and extreme droughts, early warning systems will become increasingly vital to reduce our vulnerability (European Environment Agency 2024). For instance, the frequency and severity of flooding events are projected to increase and Europe will face a significant uptick in riverine and coastal flooding events especially in north-western regions (Merz et al. 2021; Vousdoukas et al. 2017). Climate projections indicate that heatwaves and prolonged droughts will reduce soil moisture and increase vegetation flammability, directly amplifying wildfire risk across Europe. Southern Europe could face up to “a tenfold increase in the probability of catastrophic fire events”, while fire-prone conditions are expected to extend northward into temperate and boreal regions (El Garroussi et al. 2024). A combination of drivers such as, Wildland Urban Interface (WUI) expansion, rural land abandonment, and fuel accumulation, is expected to contribute to the increase of

wildfires frequency, intensity, magnitude (European Environment Agency 2024; World Bank 2025). Occurrence of such events simultaneously, cascading or compounding, require a multi-hazard approach.

On the other hand, political crises, polarisation, regional instability, migration, and socio-economic inequalities, can fuel grievances, foster extreme ideologies and pave the way towards terrorism. The evolution and impact of these threats will be further amplified by technological advancements. Given that social media served already as breeding grounds for radicalisation (Awan 2017), the evolution of immersive technologies and virtual universes can exacerbate this

creating “dark verses” within (Hupont Torres et al. 2023). The pseudo-physical nature of entities and activities in virtual universes creates new challenges: to define the boundaries of crime, to identify the perpetrator, and to detect early extremist activity. This challenge is combined with the growing potential for terrorists to exploit advances in technology and create or deploy improvised weapons containing novel chemical or biological agents, some of which may feature modified DNA to target specific groups (Balachandar 2021; U.S. Department of Homeland Security 2025; Urbina et al. 2022), while the detection of such hazardous biological agents remains limited (Market Forecast 2023). Only in 2019, 1,733 selectors related with manuals and tutorials on Improvised Explosive Devices (IED), including CBRN-E, were detected online (EU IRU 2019). Ultimately, this evolving threat is further complicated by geopolitical tensions that can back state-sponsored terrorism or sabotage, and the diminishing barriers to international cooperation. Consequently, early detection of radicalisation online and CBRN-E hazmat will be crucial to prevent terrorist attacks.

Choices ahead

Technology enablers

The rapid evolution of novel technologies such as remote sensing using satellite-based or drones monitoring systems, remote sampling systems, fibre-sensing to detect failures in submarine cables, AI-powered detection systems, environmental sensors, IoT devices, wireless networks of sensor detectors and data fusion, presents significant opportunities for improving hazard early warning and detection (natural or CBRN-E) and reducing response timing (Di Giovanni et al. 2021; Himeur et al. 2022; Market Forecast 2023; NORDUnet 2024). Countering improvised weapons that use novel or engineered agents will require detection technologies able to identify such threats rapidly and on site, such as portable chemical sensors and biosensors, including emerging CRISPR/Cas-based platforms for biological agents (Kumar et al. 2023; Li et al. 2019). New tools and methods to detect illegal activity in virtual worlds and prosecute perpetrators will be needed.

Policy options

Enhance MHEWS (Multi-Hazard Early Warning Systems, e.g. Global Disaster Alert and Coordination System (GDACS)) components integration, through the development of open data sharing frameworks connecting various national EWS (Early Warning Systems) (UNDRR and WMO 2024). The implementation of a formal system for reporting suspicious activity, specifically concerning the development of toxic molecules lacking therapeutic intent, and targeted awareness campaigns in relevant institutions and laboratories are recommended (Urbina et al. 2022). More R&I for detection tools of biological agents (Market Forecast 2023). This approach aligns with the EU CBRN Action Plan (European Commission 2017) and draws a parallel with the requirements set forth in Regulation (EU) 2019/1148 concerning the marketing and use of explosives precursors.

Critical Communications

Critical Communications refers to the seamless, effective, and secure exchange of critical information among various organisations, agencies, and responders, across different communication systems, platforms, and protocols. Its core purpose is to enable coordinated operational activities, especially during critical incidents, emergencies, or disasters, and achieve common strategic and tactical objectives.



Why does it matter?

In disaster scenarios, the ability to exchange vital information in real-time is crucial for effective crisis management, with telecommunications infrastructure serving as the essential backbone to facilitate this process. By 2040, the EU is expected to face an increasingly diverse array of threats, influenced primarily by climate change, geopolitical tensions, and rapid technological advancements. Climate change models predict an uptick in extreme weather events and large scale disasters, such as floods and wildfires, which pose substantial risks to communication infrastructures such as extensive physical damage, disruption of service, and information overload (European Environment Agency 2024), (Menoni et al. 2023), (Baldini et al. 2014).

Furthermore, as telecommunications networks represent a prime target for hybrid operations, adversaries can exploit natural hazards or Natech events to amplify disruptions, thereby undermining public trust in the state's capacity to manage crises and provide essential services (Giannopoulos, Smith, and Theocharidou 2021). Disasters

would be more complex due to interdependencies among countries and domains, rendering isolated national approaches insufficient and fragmented actions from different sectors counterproductive (Lentini et al. 2025). No state has yet produced a cryptographically relevant quantum computer, but its eventual development would threaten the encryption on which secure digital communications depend (Office of the Director of National Intelligence 2026). Future operations necessitate interoperability not just as a technical “nice-to-have”, but as an operational prerequisite. The capability to transfer responders and share tools across EU regions in future operations fundamentally hinges on communication architecture. As frontline assets evolve into sophisticated data-gathering nodes, transferring equipment depend on compatible data streams and communication protocols. Therefore, critical communications must serve as the universal translator and connector, enabling diverse systems among Member States to dynamically handshake, authenticate, and integrate. Without this cohesive digital layer,

multinational teams remain operationally fragmented, unable to fully leverage the collective utility of their deployed assets.

These complexities require robust interoperable secure telecommunications as a foundational element for an effective crisis management across various jurisdictions and agencies.

Choices ahead

Technology enablers

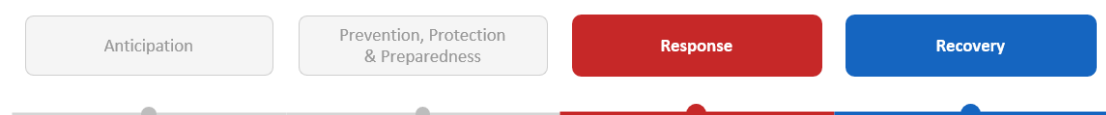
The transition from the narrowband Terrestrial Trunked Radio (TETRA), to broadband communication (such as LTE and 5G) significantly expands communication capabilities to include visuals, while retaining a hybrid architecture to ensure the resilience of the critical voice lifeline (Airbus 2025). In the event of damages to the physical communication infrastructure UAV swarms can serve as ad hoc wireless networks to cover large areas (Arafat and Moh 2019; Quero and Martinez-Carranza 2025). Conversely, to mitigate capacity overload, Cognitive Radio (CR) technology can be integrated as an intelligent system to dynamically sense and allocate unused frequencies, ensuring communication continuity (R. K. Sharma et al. 2012). The integration of novel technologies, including quantum communication, edge computing, IoTs, 6G, and satellite constellation (IRIS²/EuroQCI) enabling satellite direct-to-device services, are expected to contribute to secure and seamless operational connectivity for crisis management (European Commission 2025e; International Telecommunication Union and World Bank 2025; Maddikunta et al. 2022)

Policy options

The EU Critical Communication System (EUCCS) and IRIS² are two Commission initiatives crucial to ensuring Europe's future capacity to react to crises. EUCCS will connect the communication networks of law enforcement, civil protection and public safety responders, enabling seamless critical communication and operational mobility across the Schengen area (European Commission 2024b). The Commission is working with the EU Member States and Schengen Associated countries to establish the technical and legal base of such System. To drive this effort, DG HOME established in 2023 the Mission Critical Communication Expert Group (MCCG), bringing together experts to work towards the targeted establishment of EUCCS by 2030 (European Commission 2023b). Complementing it, IRIS² which will provide by 2030 a sovereign, secure satellite constellation (of up to 290 satellites) underpinning resilient connectivity for crisis management (European Commission 2025e).

Decontamination, Waste Management, and Restoration

This capability set encompasses the removal or neutralisation of dangerous substances, the management of hazardous waste, and the restoration of ecosystems in disaster-affected areas. This capability bridges immediate emergency response with long-term recovery, ensuring affected areas can safely return to productive use while protecting public health and environmental integrity.



Why does it matter?

The necessity of this capability is linked with the evolution of accidental and human induced disasters shaped by the convergence of climate change impacts, hybrid and conventional warfare, terrorism, aging infrastructure, urban development, energy transition, digital transformation and emerging CBRN-E threats.

More frequent and severe climate-driven events endanger over 11,000 Seveso-classified industrial establishments across the EU risking Natech accidents¹¹ (European Commission 2025g). Such establishments include chemical plants, refineries, and industrial sites situated along major river basins can be exposed to floods (Merz et al. 2021). Outbreaks of zoonotic diseases often require large-scale interventions, including livestock culling and agricultural decontamination, to control the spread and protect human and animal health (Fenollar et al. 2021). Higher contamination of freshwater increase water-borne pathogens and diseases (European Environment Agency 2024).

The precarious nuclear safety and security situation set by the war in Ukraine (IAEA 2025), coupled with Europe's numerous aging nuclear facilities, with many reactors approaching or exceeding their initial lifespan (World Nuclear Association 2025), makes the potential for nuclear accidents a significant concern. The geopolitical landscape, terrorism, and potential misuse of technology raise a persistent threat of unconventional attacks with a CBRN-E component, like the

¹¹ Technological accidents triggered by a natural hazard or disaster which result in consequences involving hazardous substances (e.g. fire, explosion, toxic release) are commonly referred to as Natech accidents.

terrorist attack with Sarin gas on the Tokyo subway (1995) (Balachandar 2021). A convergence of quantum technology and biotechnology could theoretically accelerate the development of bioweapons, although the extent of the risk and the timeframe for such advancements remain uncertain. Cyber-physical attacks on or failures of critical infrastructures such as water treatment facilities, chemical plants, or waste management systems present the risk of intentional or accidental releases of hazardous materials, such as the 2021 cyber incident on the water treatment facility in Florida, USA (Joint Cybersecurity Advisory 2021).

Factors that could amplify the impact of accidental or malicious releases of contaminants include, but are not limited to: the proximity of hazardous industrial sites to residential areas in Europe, technological advancements that may lead to new biological or chemical agents, urban environments with high population density, agricultural productivity pressures due to climate change, and the difficulty, complexity, and cost associated with remediation measures. Consequently, a substantially elevated risk environment in the future requires advanced decontamination, waste management and restoration capabilities to prevent cascading crises.

Choices ahead

Technology enablers

Nanomaterial-based technologies, bioremediation and mycoremediation approaches, advanced oxidation processes, biochar applications can reinforce this capability. Specifically, advanced materials (e.g. photocatalytic nanomaterials, metal–organic frameworks (MOFs), graphene-based filters, antimicrobial coatings) combined with emerging biotechnologies (e.g. engineered microbes, enzyme-based cleaners, and biofilms for pollutant degradation) can provide highly effective solutions for contaminant removal. (Akpaşi et al. 2023; Negro et al. 2024; G. Wu et al. 2023)

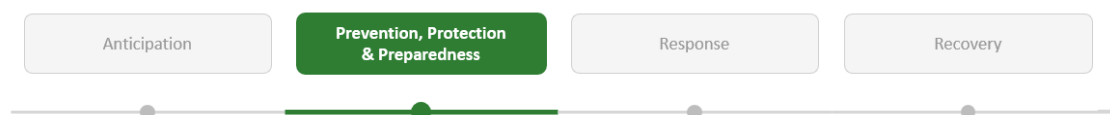
Policy options

The EU should prioritise funding for R&D initiatives focused on developing decontamination technologies for CBRN-E defence and particularly effective decontamination agents, new techniques for decontamination (Market Forecast 2023), and sustainable waste processing methods informed by best practices and lessons learned. Simultaneously, it must promote knowledge sharing through platforms such as JRC eNatech Database¹² and ensure the full implementation and sufficient functioning of frameworks (e.g., *Seveso-III Directive 2012/18/EU*, *UNECE Convention on the Transboundary Effects of Industrial Accidents*), while addressing the new challenges of industrial safety linked with climate change and the energy transition (European Commission 2025g).

¹² <https://enatech.jrc.ec.europa.eu/>

Resilient Design

This capability set encompasses the integrated capacity to design and construct, infrastructure and systems to withstand, adapt to, and rapidly recover from various threats and hazards. The term infrastructure covers all the human-made structures and spaces that provide a service, including built environment (residential, non-residential buildings and public spaces) and critical infrastructures set by the EU Critical Entities Resilience (CER) Directive (European Parliament and Council 2022).



Why does it matter?

One of the core elements that defines a society as modern is the infrastructure it depends on to function, and thus the increasing complexity of its future operation and emerging threats makes resilience an even more fundamental requirement. The confluence of climate change impacts on built environment, the aging infrastructure, the interconnected nature of the built environment, the rising urbanisation, increasing interdependencies, and evolving threats (terrorism, cyberthreats) creates an imperative for proactive resilience rather than reactive recovery.

The impact of climate change alone is projected to cause up to a tenfold increase in damage to the built environment from extreme weather by the end of the 21st century with energy, transport, water and industry sectors expected to be highly affected (European Environment Agency 2024). Specifically, severe damages are expected in health and education facilities from flooding and windstorms; railways will face a projected double or triple increase in flood risk; and ports in North and Western Europe will be more vulnerable to sea level rise and storm surges (European Environment Agency 2024).

Historical design assumptions no longer hold as climate conditions exceed parameters embedded in existing infrastructure. Europe's aging infrastructure, suffering from an adaptation deficit, is already experiencing failures (e.g. collapse of bridges, dams), increasing the risk of cascading and compound disruptions. This risk is particularly acute in Southern European regions, where persistent seismic and geological hazards, coupled with aging infrastructure and rising urbanization, endanger more people in vulnerable zones. Recent earthquakes in Croatia (2020) and Turkey-Syria (2023) underscore the devastating impacts on non-resilient structures (Atalić et al. 2023).

Modern societies will face also a widening array of human induced threats. Public spaces have been targeted by terrorists in the recent past and are exposed to future attacks (Coaffee et al. 2022). Simultaneously, the increasing digital integration of critical infrastructure creates new pathways for cyberthreats stemming from criminals or state sponsor actors. Furthermore, the space-based infrastructure underpinning modern societies, including satellite communications and Global Navigation Satellite Systems (GNSS), is exposed to emerging risks in an increasingly congested orbital environment, particularly amid rising geopolitical tensions (De Luca and Evroux 2025).

Choices ahead

Technology enablers

Technological innovations provide unprecedented capabilities for resilient design, construction, and continuous performance monitoring. Advanced materials extend infrastructure lifespan and performance under extreme conditions. Digital twins and AI-powered analytics enable predictive management and optimised interventions. Nature-based solutions offer cost-effective complementary approaches with multiple co-benefits. Biomimicry such as “sponge city” an urban design approach to mitigate flood risks (Chan et al. 2018).

Policy options

Stress-testing infrastructure or a system to extreme or adverse conditions to evaluate its robustness, limits and identify points susceptible to failure (Dannemand Anderson et al. 2023). Implementation of climate-responsive design in buildings and urban settlements, updated building codes, spatial planning, and investment in climate-proof design for new structures and retrofitting and reinforcement of existing ones are some of the priorities (European Environment Agency 2024). Embedded security-by-design concept at the very beginning of the design of infrastructures and built urban environment that are assessed as potential targets by terrorists or other malicious actors (Coaffee et al. 2022).

Systemic Risk Modelling & Critical Infrastructure Interdependency Mapping

Systemic risk modelling encompasses analytical processes for assessing risk that is endogenous to, or embedded in a system and identifying its critical vulnerabilities (UNDRR 2019). Interdependency mapping refers to the detailed representation of bidirectional relationships between critical infrastructures to understand how these systems interact, rely on one another, and collectively provide essential services and support vital societal functions (European Commission 2025d; Galbusera and Giannopoulos 2019; Rinaldi, Peerenboom, and Kelly 2001). These capabilities allow decision-makers to anticipate potential hazards, assess vulnerabilities, and formulate appropriate mitigation strategies that are responsive to the interconnected nature of modern infrastructures.



Why does it matter?

The European Union faces an increasingly complex and interconnected threat landscape as it approaches 2040. Climate change is a risk multiplier that can exacerbate existing risks and crises, threatening European prosperity and stability (European Environment Agency 2024). Hazardous events are frequently amplified by factors that initiate chains of disruption across multiple sectors (cascading risk). These events can drive feedback loops or co-occur with other incidents to create entirely new, complex threats (compound effects) (Lentini et al. 2025; UNDRR 2019). For instance, a single disruption (GNSS or electricity) can trigger a cascading traffic gridlock. This prevents emergency services from responding, creating a feedback loop that exacerbates the crisis and leads to a compound disaster if it overlaps with other hazardous incidents. Multifaceted and interdependent risks are shaped by diverse drivers that cause impacts across multiple domains as a result of complex interactions, rendering traditional single-risk assessments inadequate for capturing the full spectrum of risk (Lentini et al. 2025).

As societies become more digitally-dependent, the interconnections between cyber and physical infrastructure have created new vulnerability vectors where failures in one domain can rapidly propagate to others (Piraina and Trucco 2022). Proliferation of cyber-attacks on interconnected infrastructure systems (Europol 2025), new dependencies and vulnerabilities due to energy transition (Silva, Gomes, and Alberto 2021), cascade risks due to complex cross-border supply

chains (Menoni et al. 2023), longer recovery periods due to system complexity (Anokhin et al. 2021), collectively form a complex mesh of risk interactions. The geopolitical landscape also presents intensifying challenges to critical infrastructure security, especially through hybrid warfare. Acts of sabotage targeting critical infrastructure have increased significantly, particularly in 2024, affecting several EU Member States (European Commission 2025b). Within an increasingly volatile global landscape, these disruptions may expand in scale and sophistication, specifically targeting vulnerable points by exploiting systemic interdependencies and weaknesses.

Choices ahead

Technology enablers

Technological innovations are greatly enhancing the ability to model, visualise, and assess systemic interdependencies. Digital twins represent a transformative technology for critical infrastructure modelling, allowing realistic simulation, scenario testing, and what-if analysis (Lampropoulos, Larrucea, and Colomo-Palacios 2024). The EU's Destination Earth (DestinE) initiative exemplifies this approach at continental scale. AI is revolutionising cascading failure prediction and systemic risk assessment (Varbella, Gjorgiev, and Sansavini 2023). Overall, the high-performance computing supports complex network modelling that captures nonlinear interactions across sectors and borders, supporting a system-of-systems representation of interdependent infrastructure networks (Galbusera and Giannopoulos 2019; Ganguly and Mukherjee 2023).

Policy options

A comprehensive, integrated understanding of the diverse risks across the European Union remains limited. To complement novel technologies, strategic policymaking can play a pivotal role in reshaping disaster resilience capabilities, through: Funding for research and innovation, standardization of hazard assessment approaches across EU Member States to ensure consistency and comparability (Lentini et al. 2025), implementation of CER (Directive (EU) 2022/2557), NIS2 (Directive (EU) 2022/2555) and adaptation to emerging landscape.

Efficient and Safe Frontline Operations

This capability set concerns the ability of first responders to carry out frontline operations with maximum efficiency, speed, and safety. It encompasses the capacity to perform mission-critical tasks using appropriate equipment and instruments, to extend operational reach into hazardous or inaccessible environments, and to maintain responder safety and physical integrity. Efficient equipment becomes a force multiplier essential for effective response and this capability set serves as the operational backbone enabling responders to translate strategic plans into effective frontline operations.



Why does it matter?

The relevance of this capability has always been central to disaster management. However, the compound and cascading disasters expected to intensify by 2040 necessitate a paradigm shift in frontline operations, capitalizing on the invaluable opportunities that new technologies can provide.

Projected increases in the frequency and severity of extreme weather events across Europe – including more intense heatwaves, extreme precipitation, and prolonged droughts – will escalate acute crises such as flooding and wildfires in the coming decades. Southern Europe could face up to a tenfold increase in the probability of catastrophic fire events, with fire seasons extending by “up to two weeks” in Mediterranean regions and fire-prone conditions expanding northward into temperate and boreal zones (El Garroussi et al. 2024). These trends will place unprecedented strain on civil protection capacities, demand larger-scale and longer-duration suppression operations, and increase population exposure (European Environment Agency 2024; El Garroussi et al. 2024; Kimutai et al. 2024; Lentini et al. 2025; World Bank 2025).

Beyond climate-related risks, the EU faces a complex threat landscape comprising technological, industrial, and CBRN-E hazards. A wide range of natural, accidental, and man-made hazards increases risks at mass population concentration in urban environments. As urban density increases (United Nations 2025), emergency response scenarios grow more intricate, requiring versatile, specialised tools for operations in confined spaces (e.g., metro flooding, tunnel breaches). Urbanization especially in high-risk areas increases population exposure to seismic events, while the expansion of the WUI heightens the risk of

significant socio-economic losses due to wildfires; both necessitate larger-scale, resource-intensive operations. Novel hazards are emerging from the green energy transition, notably the proliferation of electric vehicles (Tankou 2024) and ammonia-fuelled vessels, (European Maritime Safety Agency 2025) are demanding new response equipment and protocols.

Furthermore, Europe's ageing population (Ueffing et al. 2022), creates a double-sided pressure: a diminishing pool of first responders and more vulnerable people requiring assistance during emergencies. Compound emergencies increasingly require responders to operate simultaneously across multiple fronts with finite resources. Simultaneously, the cascading risks inherent in interdependent infrastructure can cripple essential services, complicating Search and Rescue operations. Achieving efficient cross-border assistance within the EU requires high levels of interoperability, specifically regarding standardised equipment (e.g. firefighting hoses).

The evolving CBRN-E threat environment, driven by geopolitical instability and Natech events, demands enhanced protection for responders and swift response. This includes advanced Personal Protective Equipment (PPE) that balances high-level shielding with ergonomic wearability, as well as the integration of remote-operated systems to ensure safety at a distance. Cyber-physical attacks on critical infrastructure require both digital defensive tools and physical response equipment.

Consequently, responders will increasingly operate under extreme thermal stress, in contaminated environments, and in structurally unstable settings. They must ensure rapid response and manage multiple simultaneous hazards during large-scale and cross-border operations. In this context, operational efficiency of a tool is defined primarily by its reliability, versatility, and interoperability. Equipment must prioritise ruggedness, portability, and intuitive use, ensuring it remains maintainable and rapidly deployable under harsh field conditions.

Choices ahead

Technology enablers

Advances in Human–Robot Interaction (HRI), specifically cobots and robotic vision, are transforming high-risk operations. These systems interpret human intent to enable safe collaboration under difficult conditions. In disaster scenarios, specialised platforms like snake robot swarms demonstrate how human-robot synergy reduces responder exposure while extending operational reach into inaccessible areas (Moosavi, Zafar, and Sanfilippo 2024; Robinson et al. 2023). Smart PPE can reduce responder casualties, exoskeletons can enhance responders' operational ability, and edge computing allows real-time data processing without the need for central connectivity.

Policy options

Define frontline operational gaps through a rigorous analysis of past failures, accidents, and fatalities to prevent future loss. Identify the common gaps across EU Member States. Mandate the co-design of equipment by integrating first responders from the prototyping phase onward, ensuring maximum field utility and reliability. Simultaneously, expand RescEU reserves and enforce equipment standardization to catalyse interoperability, enabling international teams to transition from disjointed, parallel efforts into a unified, resource-sharing force. Reduce external dependencies for critical tools.

Citizen Empowerment

Involves equipping individuals with the skills and knowledge to respond swiftly and effectively. Prepared citizens can take immediate action to reduce impacts, implement safety measures, and support first responders, enhancing overall disaster response and community resilience. It positions the citizen not as a passive recipient of protection but as an active, informed participant in a "whole-of-society" resilience architecture, who engage in decision-making and reciprocal assistance during crises.



Why does it matter?

The EU's future risk landscape is shaped by converging threats that will increasingly overwhelm purely institutional response capacities, making citizen empowerment a structural necessity. The Sendai Framework recognises it as a guiding principle for Disaster Risk Reduction (DRR) goal, while the Preparedness Union Strategy set it as a core element of resilience. Extreme weather events, floods, heatwaves, wildfires, are growing more frequent and severe, and increasingly strike simultaneously across regions, saturating professional response capacity (AghaKouchak et al. 2020). When citizens possess the skills to act during the critical first hours of an emergency, they become a vital foundation of community resilience. Beyond self-sufficiency, residents are essential partners for first responders, providing the 'on-the-spot' knowledge and spontaneous support that can prove decisive in saving lives.

In parallel, cyber and hybrid threats are escalating sharply. State-sponsored sabotage, disinformation campaigns, and attacks on critical infrastructure can disable the systems on which emergency communication response depends on. Citizens equipped with the capacity to function during prolonged outages constitute an irreplaceable buffer. Persistent

CBRN-E threats from terrorism and industrial accidents further require that citizens understand shelter-in-place protocols and alert systems, while the growing likelihood of pandemics, driven by zoonotic spillover and antimicrobial resistance, requires widespread hygiene literacy.

These hazards are compounded by structural societal shifts. Europe's urbanisation is projected to exceed 80% by 2050 (UCP Knowledge Network 2023), concentrating more people and assets in

hazard-prone areas and amplifying heatwave and flood risks through urban heat islands and soil sealing. Simultaneously, the EU's 65+ cohort is rising from over 20% towards one-third of the population by 2050, with remote rural regions facing both growing vulnerability and a shrinking responder base (Curtale et al. 2025; The Lancet Regional Health – Europe 2023). Public trust in national governments and local/regional authorities remains fragile (European Commission 2025i). Artificial intelligence risks deepening this deficit, as AI-generated disinformation undermines the public's capacity to identify and act on factual information during a crisis.

Choices ahead

Technology enablers

Digital risk communication and social media can serve as early warning amplifiers, disseminating guidance and situational updates to citizens and enabling timely action and mutual aid. Low-cost sensors and participatory data collection (e.g., air quality) empower citizens to contribute to real-time situational awareness and governance decisions, enhancing co-management with authorities. Digital platforms, immersive virtual reality or extended reality (VR/XR) simulations, and AI assistants provide accessible, personalised guidance. By simulating real-world emergency scenarios, these tools foster a deeper understanding of hazards and drive active citizen participation (Gagliardi et al. 2023; Konstantakos et al. 2025).

Policy options

To transform civil protection, the EU must shift from a model of “alerting” to one of “participation”, Member States should embed preparedness into school curricula from the primary level to ensure risk awareness and emergency skills become second nature for future generations. Rebuilding public trust requires moving beyond top-down warnings towards transparent, two-way communication where community insights inform official risk assessments. Ultimately, residents should be trained and confident enough to protect themselves and their neighbours during the first critical hours of a crisis, serving as a recognised layer of the civil protection architecture. This policy shift must also initiate a forward-looking approach by questioning the return of the concept of civil defence (Ministre de l'Intérieur 2025).

Training for first responders

Refers to the systematic development of knowledge, skills, and competencies required by personnel – including firefighters, emergency medical services, law enforcement, search and rescue teams, and civil protection officers – who are the first to arrive at and manage the scene of a disaster or emergency across the full spectrum of hazards, operating under conditions of uncertainty, stress, and inter-agency coordination.



Why does it matter?

Several trends and drivers are reshaping the operational landscape towards 2040, elevating advanced, continuous, and adaptive training to a critical capability for the EU. As Europe confronts a rising incidence of both natural and man-made disasters – including extreme weather events, cascading multi-sector crises, and large-scale mass casualty incidents – first responders must prepare for more frequent, simultaneous, and cross-border emergencies that exceed any single Member State's capacity to manage alone.

The escalating complexity of these incidents, places interoperability at the centre of training needs. First responder tasks increasingly demand integrated, multi-agency coordination under high-stress conditions. Under a strengthened Union Civil Protection Mechanism (which has been activated more than 800 times since its establishment in 2001, with the majority of activations concentrated in the last five years alone (European Commission 2025a)) growing numbers of personnel and assets will need to be deployed across national borders to assist in major disasters such as wildfires, floods, and Natech events. Regardless of the level of interoperability the EU achieves by this horizon, substantial heterogeneity in operating methods and preparedness levels persists across Member States, and training remains a primary instrument for ensuring compatibility and complementarity between intervention teams (European Commission 2026b).

The psychological dimension of preparedness is equally pressing. First responders are exposed to substantial mental health burdens in the aftermath of disasters, with elevated rates of Post-Traumatic Stress Disorder (PTSD), depression, anxiety among

response personnel (Arena et al. 2025; Lanza, Roysircar, and Rodgers 2018). To protect them, we need to integrate mental health literacy and psychological first aid into training curricula to improve knowledge, confidence, and potentially early help-seeking (Lanza, Roysircar, and Rodgers 2018).

Simultaneously, the rapid evolution of technology creates new risks and opportunities. Novel hazards are emerging from the green energy transition, notably the proliferation of electric vehicles, which introduce distinct fire safety challenges such as thermal runaway and toxic gas emissions (Tankou 2024), and ammonia-fuelled vessels, which pose significant toxicity and safety risks (European Maritime Safety Agency 2025) are demanding new competencies and safety protocols. On the other side, the deployment of innovative operational tools such as robotics, AI-assisted decision support, cyber-response capabilities, and IoT-enabled sensors demands specialised skills to ensure effective acceptance, use, and a clear understanding of both their potential and limitations.

At the geopolitical level, the threat landscape now extends to hybrid threats, sabotage and cyber-attacks on critical infrastructure, terrorism, and evolving CBRN-E risks, all demanding skill sets that current civil protection workforces need to develop (European Commission 2025b; Gogacz and Varekova 2025; Niinistö 2024).

Choices ahead

Technology enablers

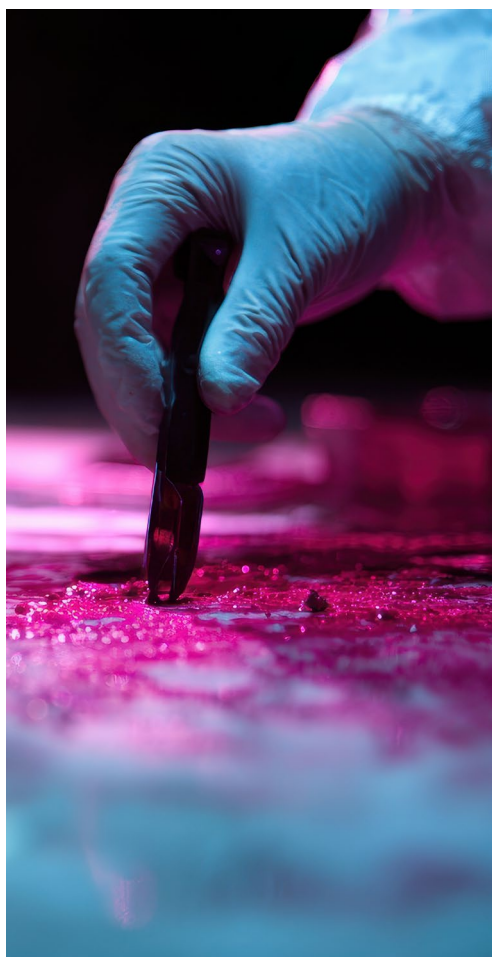
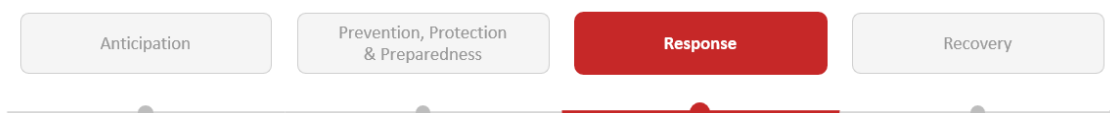
Immersive learning technologies, such as virtual reality (VR), extended reality (XR), and simulation-based systems, enable realistic training for emergencies, fostering more effective performance under stress, while providing cost-efficient, scalable training environments over traditional live drills and classroom-based instruction that could become standard practice across the EU (Hancko, Majlingova, and Kačíková 2025). Furthermore, AI-driven adaptive learning optimises skill acquisition and retention by tailoring curricula to the specific needs of individuals or cohorts. When integrated with digital-twin technology, AI can generate sophisticated, realistic compound-disaster scenarios. Finally, gamified learning environments can enhance risk awareness and significantly increase the engagement levels of volunteers (Bai et al. 2024).

Policy options

The existing UCPM Training Programme, which aims to enhance the coordination, compatibility and complementarity of capacities, and improve the competence of civil protection experts in EU Member States and UCPM Participating States, provides a mature platform for scaling professional training across countries. To build on this, the consistent collection of prioritised training needs for civil protection should be streamlined into a strategic assessment format, such as the European Union Strategic Training Needs Assessment (EU-STNA) by the European Union Agency for Law Enforcement Training (CEPOL) (CEPOL 2022). Such a framework would enable continuous improvement, benchmarking across Member States, homogeneity in methods and the strategic prioritisation of resources.

Rapid on-scene detection, monitoring and analysis of threats, hazards, contaminants

Refers to the ability to detect, analyse and monitor the nature, source, extent and evolution of threats, hazards or contaminants directly at the incident scene in real time. This encompasses the deployment of technical solutions to enhance situational awareness enabling informed decision-making (European Commission 2024a). This capability involves three interconnected functions: automated detection and tracking of active threats (“red-force” tracking¹³), remote monitoring of threats and hazards¹⁴, and combined effects assessment to understand secondary and cascading impacts¹⁵ (International Forum to Advance First Responder Innovation 2017).



Why does it matter?

With the evident increase in intensity and frequency of natural events from climate change, Natech risk is an increasing concern in major accident prevention and risk management at local, national and international level (Fujita et al. 2024; Merz et al. 2021; Sikorova and Blazkova 2025). When floods, wildfires, earthquakes, or storms strike industrial installations handling hazardous substances, of which there are over 11,000 Seveso-classified sites across the EU (European Commission 2025g), they can trigger cascading releases of toxic chemicals, fires, and explosions. These multi-hazard scenarios demand a sophisticated ability to understand secondary effects and how incident impacts combine and evolve in real time.

The evolving security threat landscape adds further urgency. The potential deliberate use or release of chemical or biological agents, through terrorism, sabotage, or armed conflict, requires rapid on-scene identification to distinguish agent types and inform countermeasures. International terrorist groups have already used and planned to develop weapons of mass destruction in the EU (Flade 2018), while state actors have employed such weapons on several occasions for targeted assassinations and in civil

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- ¹³ In the emergency response community, a “Red Force” may represent a specific threat or hazard, such as a suspect or an object (e.g., weapon, explosive device). Operational focus for this element is placed on the real-time tracking of the location and movement of red forces, and their proximity to responders to ensure safety and tactical coordination.
- ¹⁴ Focuses on the development of multiple platforms to support remote, ongoing surveillance and monitoring of threats and hazards on the incident scene and potentially affected areas, without exposing responders to additional risk.

conflicts (SIPRI 2019). Advances in technology may give rise to novel chemical or biological agents, some of which could feature modified DNA designed to target specific population groups (Balachandar 2021; U.S. Department of Homeland Security 2025; Urbina et al. 2022), while the detection of such hazardous biological agents remains limited.

Urbanisation, infrastructure density and interconnected systems amplify disaster exposure and complexity. As European populations concentrate in urban centres with complex industrial, energy and transport networks, even localised incidents can rapidly cascade across systems and affect large populations. Without the capability to continuously detect, identify and track which hazards are present, how they are evolving and what secondary effects are cascading, incident commanders cannot allocate resources effectively, establish adequate safety perimeters, or protect affected populations.

Choices ahead

Technology enablers

AI-powered video analytics can detect weapons, suspicious objects and threatening behaviour in real time across surveillance networks, automatically tracking threat movement and alerting responders within seconds (Walia and Dandawate 2025). Edge AI enables on-camera processing without reliance on centralised servers, functioning even when communications infrastructure is degraded (Cob-Parro et al. 2021). Autonomous systems leveraging miniaturised sensors, robotics and AI-driven decision-making algorithms can detect, identify and monitor CBRN-E threats without exposing responders to risk (Market Forecast 2023; U.S. Army 2025), while emerging multi-UAV swarm coordination promises simultaneous coverage of large affected areas (Alqudsi and Makaraci 2025).

Policy options

The Preparedness Union Strategy's early warning and risk assessment provisions (European Commission 2025f) should be operationalised through expanded rescEU CBRN-E detection, sampling, identification and monitoring capabilities (DG ECHO 2024). The Seveso III Directive's (2012/18/EU) risk assessment requirements and the CER (Directive (EU) 2022/2557) provide a regulatory basis that could be strengthened to drive integration of real-time detection at high-risk industrial sites. Given the inherently dual-use nature of detection technologies, like autonomous sensors, robotics, and AI-driven surveillance, future EU procurement and R&D strategies should systematically exploit civil-military synergies, ensuring that defence-developed capabilities are interoperable with and transferable to civil protection operations. EU procurement standards should further require validation of detection equipment under realistic field conditions, given that environmental factors such as temperature and humidity create noise affecting sensitivity and specificity leading to false alarms (Market Forecast 2023). Cross-border interoperability standards for detection equipment and data-sharing protocols remain essential for effective multi-state response.

¹⁵ involves the integration of data and analysis to inform incident command of potential secondary or cascading effects during an incident.

4.2. Emerging Technologies

4.2.1. Analytical findings

The final survey asked experts to evaluate 56 emerging technology signals (Technology Readiness Level (TRL) 3–6) across two dimensions: expected impact for Disaster Resilient Society (DRS) and novelty, using a 0–10 scale. The technologies with the highest combined scores were identified as the most promising candidates for future Disaster Risk Management (DRM) applications. The ranking was based on the product of the average expert scores for impact and novelty. In addition, based on responses to the survey question ‘Do we miss any key technology?’ and other expert inputs, one technology was added.

The text of the survey is available in Annex 3. The 12 top-ranked technologies are listed in Table 5.

Table 5. Top-ranked technologies.

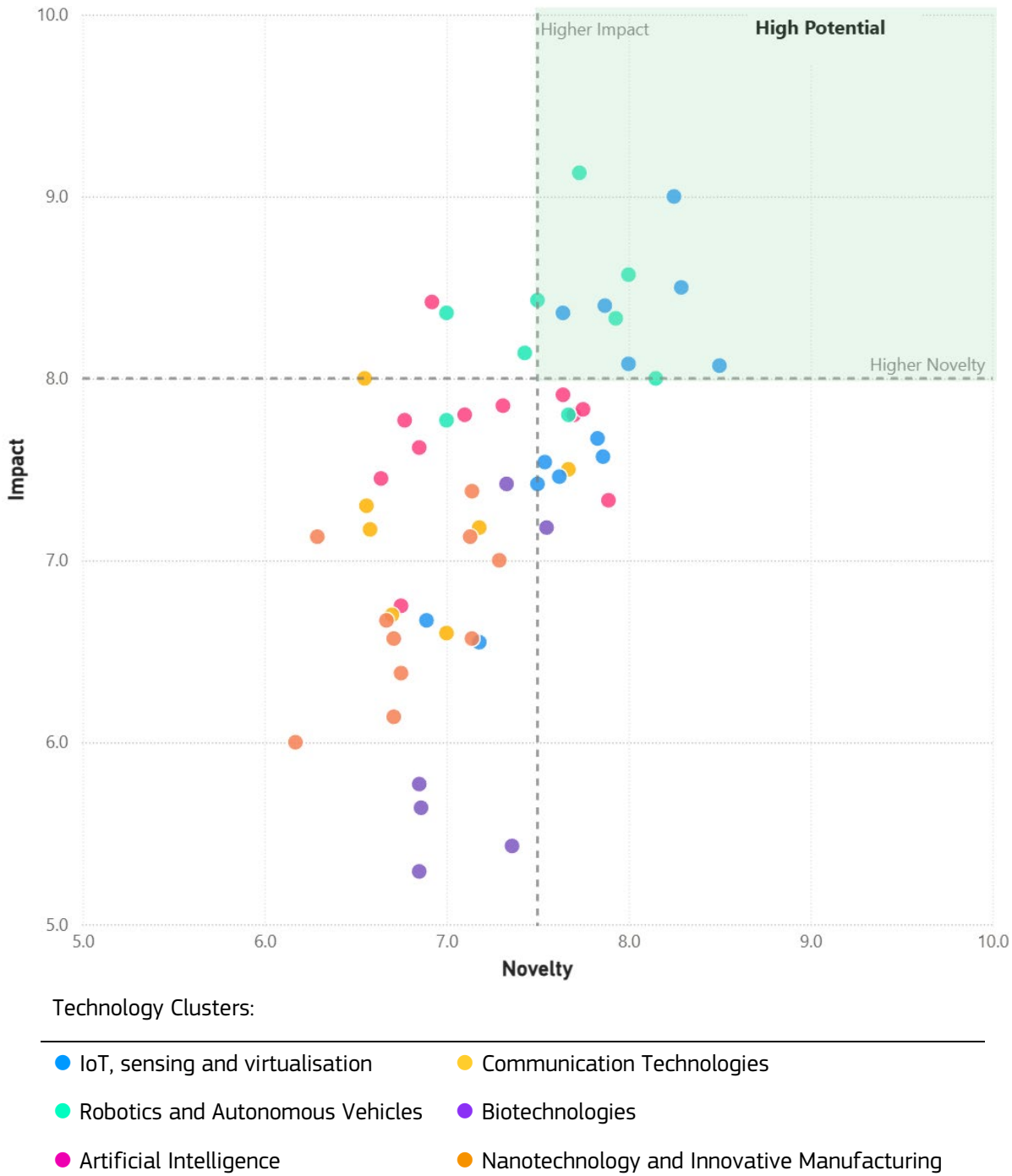
Selected Emerging Technologies	Impact Avg	Novelty Avg	Product
Advanced sensors combined with satellite technology, IoT, UAVs to enhance data collection and analysis for real-time monitoring and early warning	9.00	8.25	74.25
Drone AI-Assisted Human detection in rescue operations	9.13	7.73	70.57
Integration of LiDAR & SLAM for 3D mapping in Global Navigation Satellite System (GNSS)-denied environment	8.50	8.29	70.47
Hyper-Realistic City-Scale Digital Twin for Multi-Hazard Urban Resilience	8.07	8.50	68.60
Human-support robots with medical / supply payloads	8.57	8.00	68.56
High-precision geohazard detection using satellite radar imagery	8.40	7.87	66.11
Unmanned Aerial Vehicle (UAV) Swarm-based communication	8.33	7.93	66.06
Unmanned Aerial Vehicles (UAVs) for surveillance and monitoring of infectious diseases	8.00	8.15	65.20
Interconnected optical atomic clocks to detect seismic activity	8.08	8.00	64.64
Digital Twins for power grid optimization	8.36	7.64	63.87
Thermal and hyperspectral sensors for Unmanned Aerial Vehicles (UAVs) for rapid assessment and environmental monitoring	8.43	7.50	63.25
Decontamination of Air, Water, and Surfaces with Advanced Materials and Biotech*	-	-	-

* Note: this technology has been added after the final survey

Source: JRC own elaboration (final survey)

Figure 5 shows Impact–Novelty assessment of emerging technologies for DRM based on expert survey using an impact–novelty matrix, where higher scores indicate technologies perceived as both more transformative and more relevant for strengthening disaster resilience. Technologies located towards the upper-right area of the matrix combine higher expected impact (≥ 7.5) with greater novelty (≥ 8.0) and therefore represent particularly promising candidates for future DRM applications. Technologies are assigned to one of the six clusters mentioned in Figure 5.

Figure 5. Impact–Novelty assessment of emerging technologies for DRM based on expert survey



Source: JRC own elaboration

Overall, the results indicate that technologies related to robotics, sensing systems and virtualisation are perceived as particularly impactful and innovative for future DRM applications.

The six clusters capture broad and complementary domains of technological development relevant to future DRM. Although each cluster reflects a distinct area of capability, the technologies included are not expected to operate in isolation. Many of them are interdependent and likely to deliver the greatest benefits when combined in integrated solutions spanning sensing, communication, analysis, automation and intervention.

In the context of a Disaster Resilient Society (DRS), this cluster-based approach provides a useful organising lens for understanding how different technological domains may support resilience across the disaster management cycle. It also helps situate the individual technology signals within a wider functional architecture, linking specific innovations to broader resilience-building capacities.

The following discusses the six technology clusters. All technologies, their scores and their clusters are fully listed in Annex 3.3.

Robotics and Autonomous Vehicles

This cluster includes technologies based on autonomous or semi-autonomous platforms operating in aerial, terrestrial and underwater environments. The signals in this cluster include drone AI-assisted human detection in rescue operations, human-support robots carrying medical or supply payloads, UAV swarm-based communication, UAVs for surveillance and monitoring of infectious diseases, thermal and hyperspectral sensing mounted on UAVs, real-time path-planning algorithms for unmanned aircraft during wildfires, intelligent exoskeletons for first responders, unmanned underwater vehicles for data collection, and radiation-hardened electronics for drone-based CBRN-E missions.

Taken together, these technologies enhance the operational capacity of responders in dangerous, inaccessible or rapidly evolving environments. Their contribution to DRS is particularly strong in the response and recovery phases, where speed, reach and the reduction of human exposure are essential. By enabling remote assessment, targeted logistics, search and rescue support and specialised missions in hazardous conditions, this cluster strengthens the ability of societies to respond effectively while protecting both responders and affected populations.

IoT, Sensing and Virtualisation

This cluster brings together technologies for real-time observation, environmental sensing, digital representation and situational awareness. It includes advanced sensor systems combined with satellite technologies, IoT and UAVs for early warning and monitoring; LiDAR and SLAM integration for 3D mapping in GNSS-denied environments; hyper-realistic city-scale digital twins for multi-hazard resilience; high-precision geohazard detection through satellite radar imagery; interconnected optical atomic clocks for seismic detection; digital twins for power grid optimisation; advanced sensing materials; sensors for dangerous substances; multi-sensory extended reality systems; satellite remote sensing combined with blockchain for parametric insurance; distributed acoustic sensing through submarine cables; Wi-Fi sensing for movement detection; and smart-mask technologies for airborne contaminant monitoring.

This is one of the most cross-cutting clusters because it supports the generation of timely, granular and actionable information. Its relevance to DRS is substantial, particularly for prevention and preparedness, since resilient societies depend on early warning, risk detection, real-time monitoring and enhanced situational awareness. In addition, digital twins and virtualisation tools support

planning, training and scenario testing, improving institutional readiness and more informed decision-making before, during and after disasters.

Artificial Intelligence

The Artificial Intelligence cluster includes data-driven and predictive technologies that transform large and complex datasets into insights for decision-making. The signals in this cluster include AI for pathogen detection and forecasting, AI-enhanced geospatial planning for critical infrastructure prioritisation, federated machine learning for fire management, real-time disease surveillance systems, on-orbit edge AI for hazard detection in space, AI-driven simulation of disaster scenarios and social vulnerability, machine learning for cyberattack prediction, AI-enhanced demand-responsive data centres for energy grid stabilisation, AI-based supply chain risk mapping, AI tools for detecting manipulated digital media, and multiphysics simulation and computational fluid dynamics for airborne hazard simulation.

AI is a defining technology for the 21st century. The main contribution of this cluster to DRS lies in its analytical and anticipatory capacity. AI can help identify patterns, model cascading effects, detect anomalies, prioritise interventions and support faster and more evidence-based decision-making. For disaster-resilient societies, this means better anticipation of risks, improved targeting of preventive actions, more adaptive emergency management and stronger capacity to manage complex, interconnected crises, including health, cyber, infrastructure and environmental disruptions.

Communication Technologies

This cluster covers technologies that support secure, resilient and adaptive communication and information exchange during crises. It includes blockchain for disaster victim identification, next-generation resilient optical communication networks, joint communication and sensing systems, integrated photonics for reliable high-speed communications, Long Range Wide Area Network (LoRaWAN)-based IoT for flood monitoring, homomorphic encryption for sensitive information analysis, and post-quantum encryption technologies for emergency communications.

These technologies are fundamental because disaster resilience depends not only on detecting hazards but also on maintaining trusted flows of information across institutions, responders and communities. Their relevance to DRS lies in ensuring continuity of communication under crisis conditions, improving data integrity and confidentiality, and supporting reliable coordination during emergencies. In this sense, the cluster reinforces both preparedness and response capacities, especially where communication networks are disrupted, overloaded or exposed to cybersecurity risks.

Nanotech and Innovative Manufacturing

This cluster includes advanced materials and manufacturing solutions designed to improve resilience, protection, sustainability and operational performance. The technologies in this group include graphene sieve technology for water purification, metafabrics for personal cooling, self-healing materials, additive manufacturing of mission-tailored CBRN-E components, long-duration vanadium redox flow batteries, reflective and dynamic thermal coatings, blockchain for sensitive raw material tracking, advanced resilient pavement technologies, stratospheric aerosol injection for extreme weather relief, and paper-thin solar cells printed on composite fabrics.

The contribution of this cluster to DRS is linked to the strengthening of physical resilience and adaptive capacity. Advanced materials can improve the durability and performance of infrastructure, equipment and protective systems, while innovative manufacturing can support rapid customisation and local production in crisis contexts. These technologies are particularly relevant for

enhancing resilience in the built environment, energy systems, water treatment, protective equipment and supply chains. As such, they help societies better withstand shocks, maintain critical functions and recover more effectively from disruption.

Biotechnologies

The biotechnologies cluster includes technologies based on biological processes, bioengineering and biomedical innovation. The signals include CRISPR and AI for accelerated vaccine development, electrostatic precipitators and on-chip Loop-Mediated Isothermal Amplification (LAMP) systems for ambient air pathogen monitoring, protein production from captured CO₂, bioengineered yeast for food production, brain network communication, and implantable brain-machine interfaces.

Within the context of DRS, this cluster is especially relevant to biological hazards, public health emergencies and long-term societal resilience. Some technologies in this group directly support pathogen detection, health surveillance and medical countermeasure development, while others point to broader future capabilities related to food resilience, bio-monitoring and human-system interaction. Although the maturity and near-term applicability of some signals may vary, the cluster contributes to disaster resilience by strengthening capacities to detect, manage and adapt to biological and health-related threats.

Cross-cluster perspective

Although each cluster highlights a distinct technological domain, the survey results suggest that their greatest value for DRS often emerges through convergence. Sensing systems generate data, communication technologies transmit them, AI analyses them, and robotics or advanced materials help translate insights into operational action. This interdependence is particularly important for future DRM systems, which are likely to rely on integrated technological ecosystems rather than single stand-alone solutions. From a DRS perspective, the six clusters therefore represent complementary building blocks for strengthening societal resilience through better anticipation, stronger preparedness, more effective response and more adaptive recovery.

Table 6 shows how the technology scores aggregated per cluster.

Table 6. Cluster-level results (mean scores across signals)

<i>Technology cluster</i>	<i>Signals (n)</i>	<i>Mean impact</i>	<i>Mean novelty</i>	<i>High Potential Signals (n)</i>
<i>Robotics and Autonomous Vehicles</i>	9	8.28	7.60	5
<i>IoT, sensing and virtualisation</i>	13	7.79	7.77	6
<i>Artificial Intelligence</i>	11	7.68	7.21	0
<i>Communication Technologies</i>	7	7.21	6.89	0
<i>Nanotech and Innovative Manufacturing</i>	10	6.70	6.80	1
<i>Biotechnologies</i>	6	6.12	7.13	0

Source: JRC own elaboration (final survey)

The analysis of the impact–novelty matrix and the cluster-level results reveal several important patterns regarding the perceived potential of emerging technologies for DRM.

- **Robotics and Autonomous Vehicles** received the highest mean impact score, reflecting their strong perceived operational value across several phases of DRM, particularly in response and recovery activities such as search and rescue operations, logistics support, and interventions in hazardous or inaccessible environments.
- **IoT, sensing and virtualisation technologies** showed the highest mean novelty and included the largest number of technologies located in the high potential quadrant of the impact–novelty matrix. This highlights the growing importance of multi-source sensing systems, real-time monitoring capabilities, and digital-replica approaches (such as digital twins) for early warning, situational awareness and improved decision support.
- **Artificial Intelligence technologies** received high impact scores but slightly lower novelty scores on average compared with IoT and robotics. This suggests that experts increasingly perceive AI as a crosscutting enabling technology embedded across multiple systems rather than as a standalone disruptive domain.
- **Communication Technologies, Nanotechnology and Innovative Manufacturing, and Biotechnologies** displayed comparatively lower average scores within this set of technologies. This may reflect either a more limited perceived relevance for near-term DRM applications or greater uncertainty regarding their operational deployment at scale by 2030.

Overall, all technologies assessed in the survey received scores above the mid-point of the scale, indicating that experts consider the entire set of technologies to be relevant and potentially valuable for strengthening disaster resilience.

In several cases, high novelty scores were associated with the integration or combination of multiple technologies, such as the convergence of sensing systems, artificial intelligence, UAV platforms and satellite data. This technological convergence appears to significantly enhance both the perceived innovation and the potential impact of these solutions for DRM.

Experts confirmed the overall relevance of the technologies highlighted by the survey while also identifying an additional technological area of particular importance: “Decontamination of Air, Water, and Surfaces with Advanced Materials and Biotech.” This technology was considered highly relevant for disaster response scenarios involving chemical, biological, or environmental contamination.

Based on this expert feedback, the technology was added to the final shortlist, resulting in a consolidated set of 12 emerging technology signals with high potential. These technologies represent the outcome of a combined quantitative survey assessment and qualitative expert validation process and are analysed in greater detail in the following section.

Together, these results highlight the growing importance of integrated technological systems combining sensing, artificial intelligence, autonomous platforms and advanced monitoring capabilities for strengthening future disaster-resilient societies.

4.2.2. Selected Technologies

Advanced sensors combined with satellite technology, IoT, UAVs to enhance data collection and analysis for real-time monitoring and early warning



Advanced sensors, satellite technology, IoT, and drones integrated with big data analytics allow to collect and process real-time environmental data for disaster risk reduction. These systems enable dynamic monitoring of hazards, context-specific risk evaluation, and timely early warnings, empowering communities and authorities to develop precise response strategies based on predictive analytics and impact assessments.

Why / What Is New?

What is new is the shift from stand-alone monitoring tools to integrated, near-real-time ecosystems that combine Earth observation, in situ sensors, IoT devices, UAV platforms and AI-based analytics. Advances in remote sensing, low-power communications, cloud and edge computing, and predictive analytics make it possible to fuse multiple data streams and update risk information continuously rather than periodically. This improves both the temporal and spatial resolution of monitoring and supports dynamic risk mapping, more adaptive decision support and faster warning generation. Recent work highlights how Earth observation, Geographical Information Systems (GIS), AI, drones and real-time monitoring tools are increasingly combined for risk mapping, hazard tracking and early warning, while systems approach help connect data collection, processing and actionable decision-making across the warning chain. Looking towards 2040, further advances in self-organizing sensor networks, autonomous platforms and predictive AI may support more automated monitoring and alert workflows, although human oversight will remain essential (UNDRR 2025).

Application Areas

This technology area is relevant across the full DRM cycle. It can support multi-hazard early warning for floods, storms, wildfires, landslides and other rapidly evolving hazards through the combination of sensors, satellite observation, drones and automated analytics. Earth observation and GIS can support hazard-zone mapping, the identification of exposed and vulnerable areas, evacuation planning and resource allocation, while big data analytics integrating remote sensing and multispectral data can improve near-real-time forecasting and pre-emptive action (UNDRR 2025).

It is also relevant for rapid damage assessment and situational awareness during and after disasters. UAVs, satellite imagery and other remote sensing tools can provide timely information from inaccessible or dangerous areas, helping responders understand event evolution, identify priority zones and support operational coordination. Search and rescue applications remain important, including thermal sensing, aerial mapping and human detection, but they are better framed here as one subset within a broader integrated monitoring capability (Andreadis, Giambene, and Zambon 2023; Sivasubramaniyam et al. 2025; Villarreal et al. 2025).

An additional application area is infrastructure resilience. Integrated monitoring systems can also be used for roads, bridges, railways, ports and other critical assets, combining satellite analytics, mobile mapping and sensor-based monitoring to detect degradation earlier, improve maintenance planning and strengthen resilience under growing environmental risks. A concrete example is the integrated framework deployed in Japan using mobile mapping, fibre-optic sensors and satellite analytics to enhance early issue detection and optimise maintenance of transport systems (Mukherjee et al. 2024).

Risks & Limitations

The main limitations concern integration, access and governance. These technologies generate large and heterogeneous volumes of data, creating demands for interoperability, processing capacity, data quality management and specialised expertise. Their effectiveness also depends on communications networks, power supply, satellite availability and local maintenance capacity, all of which may be disrupted during disasters or may be insufficient in remote or resource-constrained areas. A further constraint is the limited endurance of aerial systems. Most small UAVs are battery powered and offer only tens of minutes of flight time, restricting the area covered per flight and requiring frequent recharging or coordinated multi-UAV operation; endurance is further reduced by heavier payloads and adverse weather (Yucesoy, Balcik, and Coban 2025). Recent assessments also stress that technology uptake depends not only on availability, but on affordability, applicability, local implementation capacity and the broader enabling environment (Mukherjee et al. 2024; United Nations Environment Programme 2024).

There are also important cybersecurity, privacy and ethical data-governance concerns, especially when high-resolution geospatial observation, UAV surveillance and automated analytics are combined. In addition, AI-assisted interpretation may generate false positives, missed detections or poorly calibrated alerts if models are applied outside their validated context or without adequate human oversight (Sivasubramaniyam et al. 2025; Zhu et al. 2024). More broadly, implementation may be slowed by high upfront costs, limited technical capacity, regulatory barriers, fragmented standards and weak institutional coordination, especially in lower-capacity settings (Mukherjee et al. 2024; UNDRR 2025; United Nations Environment Programme 2024).

Drone AI-Assisted Human Detection in Rescue Operations



AI-based drone systems: AI-based drones detect human screams and distress signals, improving search and rescue efficiency, with opportunities for covering large areas quickly, but posing risks of differentiating human signals from environmental noises and limited flight duration.

Why / What Is New?

Recent advances in onboard AI computing, lightweight deep-learning models, and multi-sensor integration have significantly improved the capacity of drones to detect survivors in complex disaster environments. Newer systems combine visual, thermal and auditory inputs with AI-based processing, allowing drones not only to observe affected areas but also to identify signs of life with greater speed and precision. Recent research also highlights progress in aerial acoustic detection of human screams and distress signals, including the use of convolutional neural networks and direction-of-arrival methods to reduce drone and environmental noise. At the same time, the growing use of autonomous and semi-autonomous UAV operations, including coordinated multi-UAV missions and adaptive path planning, marks a shift from manually piloted reconnaissance towards more intelligent search and detect systems (Papayan et al. 2024; Quero and Martinez-Carranza 2025).

Application Areas

AI-assisted drone human detection is relevant for search and rescue in earthquakes, floods, wildfires, landslides, avalanches and other hazardous scenarios where ground access is difficult, slow or unsafe. These systems can rapidly survey large areas, improve situational awareness and support faster survivor localisation. Their usefulness increases when different sensing modalities are combined, such as thermal cameras for heat signatures, visual cameras for person detection and auditory systems for screams or calls for help. The literature also shows growing interest in multi-UAV coordination and UAV-to-ground team collaboration, which can improve coverage, reduce search times and support more dynamic rescue missions in disrupted environments. In more specific hazard contexts, UAV-based rescue systems have also been explored for locating people buried in avalanches, showing the potential of drone-mounted search devices to complement ground rescue operations (Janovec, Kandera, and Šajbanová 2022; Papayan et al. 2024; Quero and Martinez-Carranza 2025).

Risks & Limitations

Important limitations remain. Detection performance can decrease in noisy, cluttered or thermally complex environments, especially when drones must distinguish human screams and distress signals from wind, animals, rotor noise, fire, smoke or other background interference. False positives and missed detections may also occur when AI models are used outside the conditions for which they were trained, making continuous model refinement and human validation still necessary.

In addition, operational constraints such as limited battery life, payload restrictions, adverse weather, communications dependency and regulatory restrictions can reduce endurance and effectiveness in real deployments. These limitations remain particularly relevant in large-scale or long-duration rescue missions, where reliability, autonomy and safe coordination are critical (Papayan et al. 2024; Quero and Martinez-Carranza 2025).

Integration of LiDAR & SLAM for 3D Mapping in GNSS-Denied Environment



This approach combines LiDAR (Light Detection and Ranging) with SLAM (Simultaneous Localization and Mapping) to produce dense 3D point-cloud maps in real time (Abdelaziz and El-Rabbany 2023a), (Liu et al. 2024).

It enables drones and robots to localise and map simultaneously in GNSS-denied environments such as underground mines, tunnels, or collapsed structures (Izumita, Tomita, and Kamimura 2024). By using LiDAR sensors with onboard computation, systems can

operate autonomously and adapt to changing spatial constraints.

Why / What Is New?

What is new is the increasing maturity of LiDAR–SLAM as a real-time positioning and mapping solution for environments where GNSS signals are weak, unavailable or unreliable. Recent developments combine LiDAR with inertial navigation and SLAM algorithms to improve localisation accuracy, reduce drift, and enable continuous 2D and 3D mapping without dependence on external positioning infrastructure. The novelty also lies in the growing ability of these systems to operate in increasingly complex and feature-poor environments, while becoming more computationally efficient and suitable for deployment on mobile robotic platforms, including drones and autonomous ground systems. In the broader weak-signal literature, LiDAR–SLAM is identified as an emerging technology for robotics and environmental mapping in GNSS-denied settings, with advances in integration with inertial navigation systems helping to overcome the weaknesses of each component when used alone (Abdelaziz and El-Rabbany 2023a; Eulaerts et al. 2021; Izumita, Tomita, and Kamimura 2024).

Application Areas

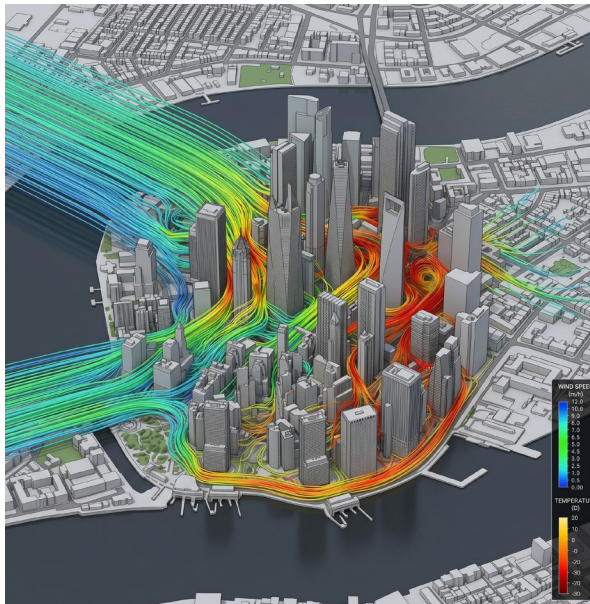
LiDAR–SLAM integration is relevant for disaster response operations that require rapid spatial understanding in environments where GNSS is unavailable or unsafe to rely on. Relevant use cases include underground incidents, tunnel inspections, collapsed or partially collapsed structures, indoor disaster scenes, and other confined or disrupted environments. In such contexts, the technology can support rapid 3D mapping, damage assessment, route identification, robotic exploration, and improved situational awareness. It can also enhance the navigation of robotic and aerial platforms deployed in hazardous areas, thereby reducing responder exposure and improving operational efficiency (Abdelaziz and El-Rabbany 2023b; Eulaerts et al. 2021; Izumita, Tomita, and Kamimura 2024).

Risks & Limitations

Important limitations remain. LiDAR-based systems can still be constrained by cost, power consumption, payload requirements and onboard processing demands, especially for lightweight aerial platforms. Dense point-cloud generation creates substantial data volumes, which can slow real-time processing and require efficient storage and computation strategies. Performance can also degrade in environments with few distinctive geometric features, rapid motion, vibration, or

conditions that increase sensor noise and localization drift. In addition, while LiDAR-SLAM is designed for GNSS-denied environments, its performance is not uniform across all contexts and still depends on algorithm robustness, sensor fusion quality and platform stability. For disaster operations, this means that human interpretation, fallback navigation logic and careful platform integration remain important for reliable use in the field (Abdelaziz and El-Rabbany 2023b; Eulaerts et al. 2021; Izumita, Tomita, and Kamimura 2024).

Hyper-Realistic City-Scale Digital Twin for Multi-Hazard Urban Resilience



A city-scale digital twin is a virtual model of a city that brings together real-time data from sensors (IoT), GIS, and building information models (BIM). It also uses advanced computer simulations to represent and analyse how different parts of the city work together (Ugliotti et al. 2023).

This digital replica of the city allows experts to predict how natural disasters such as earthquakes, floods, or fires might affect buildings, transport, energy networks, and local communities. By doing so, it helps urban planners and emergency managers understand potential risks and make better decisions to protect people and infrastructure (Z. Ali et al. 2024).

Why / What Is New?

Recent advances in edge computing, high-speed connectivity, artificial intelligence, and data integration standards have made it increasingly feasible to create highly realistic digital twins that are updated continuously through live data streams rather than remaining static 3D models. Urban digital twins are therefore moving beyond visualisation towards dynamic simulation, predictive analytics, and decision support across multiple interconnected urban systems. The novelty lies in their ability to integrate environmental, infrastructure, and socio-economic data into a single evolving model, allowing decision-makers to analyse how disruptions propagate across sectors and scales and to test alternative preparedness and response strategies before crises occur. This represents a significant shift from conventional urban modelling approaches, which are often siloed, static, or hazard-specific (Z. Ali et al. 2024; Eulaerts et al. 2021; Ugliotti et al. 2023).

Application Areas

In flood risk management, city digital twins can combine remote sensing, IoT sensors, GIS layers, hydrological models, and early warning inputs to support near-real-time situational awareness, inundation mapping, evacuation planning, and testing of response options. In critical infrastructure management, they can be used to analyse interdependencies among power, water, transport, and communication networks, helping identify critical failure points and anticipate cascading disruptions during extreme events. In broader urban resilience planning, they provide a platform for scenario testing across multiple hazards, including floods, earthquakes, fire, and climate-related stresses, while also supporting recovery planning and resource allocation (Z. Ali et al. 2024; Hu et al. 2021; Ivanov et al. 2020; MarketsandMarkets 2024; Ugliotti et al. 2023).

Risks & Limitations

Digital twin technologies come with substantial setup and maintenance costs, largely driven by the need for extensive data collection and powerful computational infrastructure. They also introduce notable cybersecurity and privacy risks, since sensitive real-time urban data may be centralised and

thus more vulnerable to potential breaches. Furthermore, validating these systems is inherently complex: the non-linear, multi-scale nature of the models makes accuracy difficult to ensure, and low-quality input data can easily lead to “Garbage In, Garbage Out” outcomes. Finally, persistent interoperability challenges between legacy systems and heterogeneous data sources continue to restrict the scalability and seamless integration of digital twin implementations. (E. Ali et al. 2025; Hu et al. 2021; Ugliotti et al. 2023).

Human-Support Robots with Medical/Supply Payloads



Autonomous and remotely operated robotic platforms, including unmanned ground vehicles and unmanned aerial vehicles, are increasingly being explored for the delivery of medical and other critical supplies in emergency settings, particularly where access is constrained or unsafe for responders.

Recent work also highlights the growing role of human-robot collaboration in disaster environments, where robotic systems may support first-aid delivery, remote assessment, mapping, and selected intervention tasks while reducing responder exposure to hazardous condition (Gauba et al. 2025; Marmaglio et al. 2023; Moosavi, Zafar, and Sanfilippo 2024;

Schwaiger et al. 2024).

Why / What Is New?

Recent advances in robotic design, locomotion, and platform specialisation have significantly improved the ability of human-support robots to operate in unstable and hazardous disaster environments. Newer systems include wheeled, tracked, quadruped, modular, and snake-like robots that can move through rubble, narrow passages, tunnels, industrial sites, or contaminated areas more effectively than earlier generations of response robots. At the same time, improvements in onboard sensing, mapping, artificial intelligence, semi-autonomous control, and manipulator integration are allowing these systems not only to reach difficult locations, but also to carry payloads, assess hazards, and support remote intervention tasks with greater precision and reliability (Ciccone and Ceruti 2025; Moosavi, Zafar, and Sanfilippo 2024; Schwaiger et al. 2024).

Application Areas

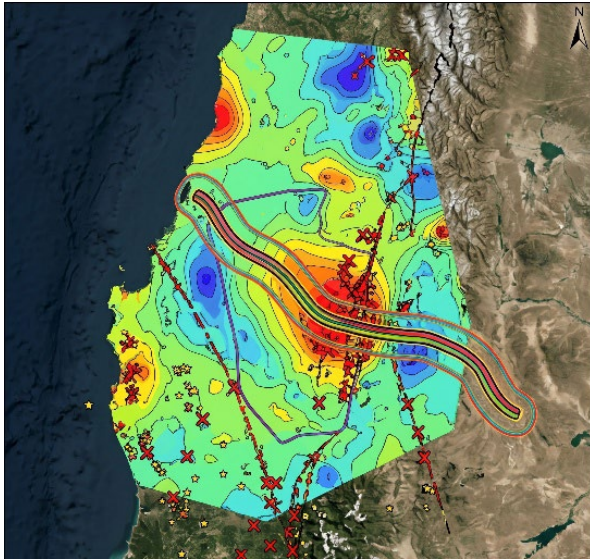
Relevant application areas include: (i) disaster logistics and last-mile delivery of critical supplies to areas cut off by damaged or unsafe infrastructure; (ii) hazardous-environment operations, particularly remote mapping, sampling, and assessment in contaminated or otherwise inaccessible zones; (iii) early-response and rescue-support functions, including situational awareness and delivery of first-aid items or communications equipment in confined or unstable environments and (iv) remote clinical support, where onboard telepresence and teleoperation allow a remotely located clinician to assess casualties, guide responder or bystander first aid, and in advanced configurations direct tele-intervention tasks, without being physically present in an unsafe or inaccessible zone. In all four cases, the main operational benefit is to extend reach, including specialist medical reach, support responders, and reduce human exposure to hazardous conditions. (Gauba et al. 2025; Marmaglio et al. 2023; Moosavi, Zafar, and Sanfilippo 2024; Schwaiger et al. 2024; Schwarz et al. 2021).

Risks & Limitations

Despite their promise, human-support robots still face important technical, organisational, and operational constraints. High acquisition costs, ruggedization requirements, and maintenance burdens remain major barriers to wider deployment, especially when robots must operate reliably in harsh field conditions or carry specialised payloads. Limited battery endurance, terrain constraints, payload trade-offs, and dependence on stable communications can reduce mission duration and effectiveness in large or infrastructure-damaged disaster zones

Operational effectiveness may also be limited by the need for trained operators, the complexity of teleoperation or supervision in dynamic environments, and the still-evolving regulatory and organisational frameworks for robotic deployment in disaster response. In practice, successful use depends not only on technical capability but also on maintenance capacity, interoperability with emergency procedures, and the availability of personnel able to manage setup, supervision, and recovery of the systems. There are also human–robot interaction and governance issues. In real disaster settings, robots may introduce collision risks, teleoperation errors, trust problems, or psychological discomfort for victims and responders if systems are not designed and deployed carefully. Human–robot collaboration in emergencies therefore requires clear safety procedures, appropriate role allocation, training, and operational doctrine before these systems can be scaled safely in real disaster management (Gaubas et al. 2025; Marmaglio et al. 2023; Moosavi, Zafar, and Sanfilippo 2024; Schwaiger et al. 2024).

High-Precision Geohazard Detection Using Satellite Radar Imagery



Advanced satellite radar systems, particularly Synthetic Aperture Radar (SAR) and Interferometric Synthetic Aperture Radar (InSAR), are able to detect very small ground movements, including land subsidence, slope instability, and deformation associated with tectonic or volcanic processes, often at millimetric to centimetric precision.

By analysing changes in radar signals over time, these systems can monitor terrain movement under all-weather conditions and during both day and night, thereby providing wide-area and repeatable observations that are highly relevant for geohazard assessment and risk monitoring (Schlögel et al. 2024; J. Zhang et al. 2023).

Why / What Is New?

Recent developments in satellite radar monitoring have significantly increased the operational relevance of SAR and InSAR for DRM. In particular, the growing availability of higher-resolution and higher-revisit commercial and public SAR missions, together with advances in time-series processing, automated deformation detection, and multi-source data integration, has improved the capacity to identify and track slow-moving geohazards over large areas with greater consistency and (Abdallah et al. 2024; Manconi et al. 2024). These developments are enabling a transition from mainly retrospective deformation analysis towards more operational support for situational awareness, screening of unstable areas, and contribution to early warning workflows, especially when satellite observations are combined with complementary in situ or remote sensing data (Nardini et al. 2024; Strzabala, Ćwiąkała, and Puniach 2024). Continued progress in interpretation methods and in the treatment of atmospheric and contextual effects is also making satellite-derived deformation products more robust and more usable for decision support in complex terrain (Liao et al. 2024).

Application Areas

Satellite radar imagery can support several disaster management functions across different hazard domains. First, it can contribute to landslide detection, slope stability assessment, and the identification of precursory deformation, particularly in mountainous, remote, or peri-urban areas where field access is limited (Manconi et al. 2024; Strzabala, Ćwiąkała, and Puniach 2024). Second, it is highly relevant for monitoring land subsidence and post-seismic or infrastructure-related ground deformation in densely populated urban environments, where progressive displacement may affect transport systems, buildings, and critical infrastructure (J. Zhang et al. 2023). Third, SAR and InSAR are widely applicable to tectonic and volcanic deformation monitoring, supporting preparedness and hazard assessment by identifying spatial and temporal patterns of ground movement associated with active faults or magmatic processes (Schlögel et al. 2024). Finally, the integration of radar-derived deformation data with optical imagery and other complementary observations can support multi-hazard assessment and infrastructure resilience planning, including

in areas where cascading risks may arise from the interaction of seismic, landslide, flood, or dam-related hazards (Nardini et al. 2024).

Risks & Limitations

Despite their strong potential, SAR- and InSAR-based approaches also present important operational limitations. Processing and interpretation remain technically demanding and generally require specialised expertise, appropriate validation procedures, and substantial computing resources, particularly in regional-scale or multi-temporal applications. Measurement quality can be degraded by atmospheric disturbances, temporal decorrelation, vegetation cover, geometric distortions, and line-of-sight constraints, which may reduce accuracy or complicate interpretation in some environments. In addition, satellite-based monitoring is not equivalent to continuous real-time observation, since performance depends on revisit frequency, data availability, and mission continuity; this can limit responsiveness in rapidly evolving scenarios. There is also a risk of misinterpretation or false positives if radar-derived deformation signals are not cross-checked against contextual information, field evidence, or complementary monitoring systems, especially in complex mountainous areas or where multiple deformation drivers coexist (Liao et al. 2024; Schlögel et al. 2024; Strzabala, Ćwiakała, and Puniach 2024).

Unmanned Aerial Vehicle (UAV) Swarm-Based Communication



A coordinated swarm of drones (UAVs) can serve as mobile aerial base stations or signal repeaters, creating temporary and resilient communication networks such as Wi-Fi, 4G/5G, or ad hoc mesh systems when ground infrastructure is damaged or unavailable (X. Zhang and Liu 2024).

By working together in a coordinated manner, the swarm maintains continuous coverage and builds redundancy, making it especially useful in disaster zones or remote areas where reliable communication is critical (Alqudsi and Makaraci 2025).

Why / What Is New?

Unlike traditional single-drone relay systems, swarm-based communication relies on cooperative and decentralised coordination, enabling multiple UAVs to self-organise, adapt their trajectories, and reconfigure network roles when one or more units fail. Recent progress in multi-hop wireless communications, formation control, and swarm autonomy has improved the ability of UAV groups to sustain connectivity over larger and more dynamic areas than isolated aerial relays. In parallel, ongoing work on the integration of UAV swarms with 4G/5G architectures is expanding their potential to support temporary broadband coverage and resilient communication services in infrastructure-disrupted environments. This makes swarm-based communication more flexible, fault-tolerant, and rapidly deployable than traditional fixed or single-platform alternatives, especially in disaster response and remote operations (Alqudsi and Makaraci 2025; Clerigues et al. 2024).

Application Areas

Disaster recovery: UAV swarms can rapidly restore temporary communication links for emergency responders and affected communities after earthquakes, floods, hurricanes, or wildfires, particularly when terrestrial infrastructure has been damaged or overloaded (Alqudsi and Makaraci 2025).

Search and Rescue: Swarm-based airborne networks can support the real-time transmission of thermal imagery, video, sensor readings, and situational updates between field teams and command centres, improving coordination during search and rescue operations (Clerigues et al. 2024).

Hazardous environments: UAV swarms can extend communication coverage to ground robots, inspection teams, and remote sensing devices operating in chemical spill zones, radiation-exposed areas, tunnels, or collapsed structures, where direct human access is limited or unsafe (X. Zhang and Liu 2024).

Risks & Limitations

Despite their benefits, UAV swarm-based communication systems face important operational and technical challenges. Their dynamic topology can create instability in wireless links, especially in highly mobile or cluttered environments, with possible consequences for packet delivery,

coordination, and collision avoidance. Their effective operational endurance is also constrained by battery limitations, making energy-aware routing, scheduling, and mission planning essential for sustained deployment. In addition, integration with wireless infrastructures introduces security vulnerabilities, including spoofing, jamming, denial-of-service, and authentication challenges, which may affect overall network reliability and trustworthiness. Finally, airspace regulation, deconfliction with manned aviation, and deployment permissions remain significant barriers, especially in densely populated or highly regulated environments (Alqudsi and Makaraci 2025; Clerigues et al. 2024; X. Zhang and Liu 2024).

Unmanned Aerial Vehicles (UAVs) for Surveillance and Monitoring of Infectious Diseases



UAVs, drones equipped with thermal cameras, air-sampling units, and high-resolution imaging systems, are increasingly being used for infectious disease monitoring and environmental surveillance. They collect spatial, environmental, and population data to detect early warning signs, such as unusual temperature patterns, areas where disease vectors may breed, or changes in crowd density.

By surveying large or hazardous areas without putting humans at risk, UAVs provide rapid situational awareness, helping public health authorities support surveillance and response activities (Bhattacharya et al. 2025; Donelle et al. 2023; Mechan et al. 2023).

Why / What Is New?

Recent advances in UAV platforms, lightweight sensors, onboard processing, and cloud-based analytics have increased the practical relevance of drones for public health and infectious disease surveillance. Compared with earlier drone deployments focused mainly on data collection, newer systems increasingly support more automated geospatial analysis, faster transmission of field data, and integration with broader digital surveillance ecosystems. This is particularly relevant where UAV observations are combined with GIS platforms, remote sensing, epidemiological intelligence, and other digital public health tools to strengthen environmental risk mapping and operational awareness. At the same time, falling platform costs and expanding deployment models are making drone-supported monitoring and delivery functions more accessible in remote, underserved, or emergency settings (Bhattacharya et al. 2025; Donelle et al. 2023; Rodrigues et al. 2025).

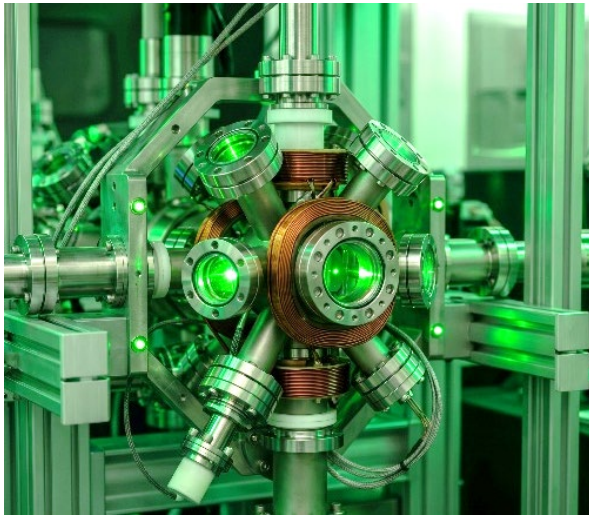
Application Areas

UAVs can support several infectious-disease-related functions relevant to disaster preparedness and response. First, they can contribute to vector-borne disease surveillance by mapping standing water, drainage conditions, vegetation patterns, and other environmental features associated with mosquito breeding, thereby supporting the monitoring and control of diseases such as malaria, dengue, Zika, yellow fever, and chikungunya. Second, they can strengthen medical logistics and diagnostic supply chains by transporting biological samples, medicines, vaccines, or testing materials to isolated or hard-to-reach communities during outbreaks or health emergencies. Third, UAV-based imaging and thermal sensing may support targeted situational awareness in public-health operations, for example by helping to identify crowding patterns or environmental conditions relevant to transmission risk, although such applications remain context-dependent and require careful validation. Finally, UAV data can contribute to decision support when integrated with GIS platforms, remote sensing, and broader digital surveillance systems used for planning, prioritisation, and early response (Bhattacharya et al. 2025; Donelle et al. 2023; Mechan et al. 2023).

Risks & Limitations

Despite their potential, UAV-based approaches also raise important operational, legal, and ethical challenges. Aerial monitoring of populations may create concerns related to privacy, data protection, public trust, and the proportional use of surveillance technologies in health contexts. Operational effectiveness is also constrained by flight duration, payload limitations, weather sensitivity, communications requirements, and civil aviation rules, all of which can restrict routine or large-scale deployment. For many routine surveillance and logistics tasks, conventional approaches such as ground transport, fixed environmental sensors and established laboratory testing remain more effective and cost-efficient, and the added value of UAVs is greatest in specific contexts where these conventional means are unavailable, disrupted or unsafe. In addition, thermal or image-based observations do not provide direct confirmation of infection and may be misinterpreted if used without appropriate contextual information or follow-up validation. Cybersecurity, misuse, and weak governance arrangements may further undermine safe deployment, particularly where sensitive health or geolocation data are involved. For these reasons, UAVs should be regarded primarily as a complementary capability within broader public health and emergency management systems, rather than as a standalone surveillance solution. (Bhattacharya et al. 2025; Donelle et al. 2023; Hoek Spaans et al. 2024; Poljak and Šterbenc 2020; Rodrigues et al. 2025).

Interconnected Optical Atomic Clocks to Detect Seismic Activity



Interconnected optical atomic clocks create ultra-precise timing networks that can detect tiny changes in the Earth's gravitational potential associated with vertical deformation and mass redistribution.

By measuring frequency shifts across multiple clocks, these systems can support the observation of geophysical changes with very high sensitivity, offering a promising future complement to GNSS, gravimetry, and other geodetic monitoring approaches relevant to tectonic and volcanic processes (Grotti et al. 2023; Tanaka and Katori 2021).

Why / What Is New?

Recent advances in optical lattice clock technology, transportable clock platforms, and long-distance frequency transfer have significantly expanded the potential of optical clocks beyond precision timekeeping into geodesy and Earth observation. State-of-the-art optical clocks now achieve levels of precision at which variations in gravitational potential corresponding to very small height differences become measurable, while long-distance comparisons through fibre links have demonstrated that geographically separated clocks can be used for chronometric levelling and high-precision geopotential monitoring. What is particularly new from a disaster-risk-management perspective is the prospect of using distributed clock networks as an additional sensing layer for monitoring subtle geophysical changes over time. Unlike conventional seismic instruments, which primarily register vibration, or GNSS systems, which track displacement, interconnected optical clocks can directly sense changes in gravitational potential linked to vertical land motion and mass redistribution. This creates a potential future capability for observing slow geophysical changes associated with tectonic stress accumulation, volcanic inflation, land subsidence, and related hazard processes, especially when integrated with existing geodetic and Earth-observation infrastructures (Grotti et al. 2023; Schröder, Stellmer, and Kusche 2021; Takamoto, Tanaka, and Katori 2022; Tanaka and Katori 2021).

Application Areas

Interconnected optical atomic clocks have potential relevance for multi-hazard monitoring and situational awareness, particularly as a complementary capability within advanced geodetic and Earth-observation systems. Their most credible near- to medium-term application lies in monitoring gradual geophysical changes that may precede or accompany hazardous events, rather than replacing conventional real-time seismic sensors. In tectonically active regions, clock networks could support the observation of crustal uplift, subsidence, and other vertical deformation processes relevant to earthquake-risk assessment and long-term geodynamic surveillance. For volcanic hazards, the technology may provide added value by helping detect gravitational-potential changes associated with magma movement or volcanic inflation, thereby strengthening the interpretation of evolving unrest when combined with GNSS, InSAR, and seismological observations. In this sense, optical clock networks are best understood as an emerging component of integrated monitoring

frameworks for complex hazard environments, particularly where subtle pre-event changes may otherwise remain difficult to detect. Beyond earthquakes and volcanoes, the technology could also contribute to broader resilience and infrastructure-monitoring objectives. Potential applications include tracking land subsidence affecting dams, bridges, transport corridors, and urban areas; monitoring glacier- and groundwater-related mass redistribution; and supporting geodetic assessments relevant to climate adaptation and environmental change. These use cases are especially relevant for public authorities responsible for critical infrastructure resilience, territorial monitoring, and long-term hazard preparedness (Grotti et al. 2023; Schröder, Stellmer, and Kusche 2021; Takamoto, Tanaka, and Katori 2022; Tanaka and Katori 2021).

Risks & Limitations

Despite their strong scientific promise, interconnected optical atomic clocks remain an emerging and largely pre-operational capability for disaster management. Current systems are expensive, technically complex, and dependent on highly controlled conditions, specialised expertise, and advanced comparison infrastructure such as stabilised optical-fibre links. Although transportable optical clocks are advancing, deployment at operational scale remains difficult, particularly in harsh or disrupted environments where disaster-monitoring capabilities are most needed. A further limitation is that clock-based measurements do not provide a complete picture on their own. Variations in clock frequency can reflect multiple underlying causes, including vertical land motion, mass redistribution, environmental disturbances, and instrumental noise. As a result, these systems are unlikely to function effectively as standalone early warning tools and will require integration with other monitoring systems, as well as robust modelling, calibration, and data-fusion methods, in order to generate operationally meaningful information for public authorities. From a policy and governance perspective, large-scale deployment would also require resilient communications infrastructure, trusted calibration protocols, interoperability standards, secure data exchange, and in some cases cross-border institutional coordination. These requirements may slow operational uptake and raise questions regarding cost-effectiveness, ownership, maintenance responsibilities, and international data-sharing arrangements. Accordingly, this signal should be framed not as a mature response technology, but as a high-potential strategic monitoring technology that may, over time, strengthen future geophysical surveillance and disaster-risk-reduction architectures (Grotti et al. 2023; Schröder, Stellmer, and Kusche 2021; Takamoto, Tanaka, and Katori 2022; Tanaka and Katori 2021).

Digital Twins for Power Grid Optimization



Digital twins create continuously updated virtual representations of power-grid assets and operations by integrating data from smart meters, IoT sensors, SCADA (Supervisory Control and Data Acquisition), and other monitoring and communication systems.

These models support real-time or near-real-time monitoring, simulation, asset-performance analysis, and optimization of grid operations. In power systems, digital twins are increasingly used to support predictive maintenance, fault detection, condition monitoring, renewable-energy integration, and improved visibility across distributed and complex grid environments.

When combined with forecasting inputs and advanced analytics, they can also support more proactive and resilient grid management, particularly in electricity systems facing greater variability and decentralisation (Edge driven Digital Twins in distributed energy systems 2024; Mchirgui et al. 2024).

Why / What Is New?

Recent advances in artificial intelligence, IoT-enabled monitoring, edge computing, and high-fidelity modelling have expanded the role of digital twins in energy systems. Unlike conventional static planning models or offline simulations, digital twins can be updated continuously with operational data, enabling more dynamic assessment of asset condition, grid status, and system performance. This supports new capabilities in predictive maintenance, operational optimisation, demand-side coordination, and management of distributed energy resources. From a resilience and governance perspective, what is particularly new is the growing use of digital twins as integrated decision-support environments rather than tools for isolated equipment monitoring. By combining physical-system models with live data and forecasting inputs, they can help operators explore alternative operating conditions, assess vulnerabilities, and test possible interventions before implementation in the physical grid. This is especially relevant in electricity systems under pressure from renewable integration, decentralised generation, electrification, and climate-related disruption. From a strategic standpoint, digital twins also support a shift from reactive grid operation towards more proactive and resilience-oriented planning. They can improve coordination across substations, storage systems, microgrids, and distributed assets, helping system operators and public authorities assess system performance under changing demand patterns, weather-related pressures, and disruption scenarios. The innovation lies not only in more accurate modelling, but in the use of continuously updated digital environments to inform faster and better operational and planning decisions (Abdessadak et al. 2025; Edge driven Digital Twins in distributed energy systems 2024; Mchirgui et al. 2024; Sifat et al. 2023).

Application Areas

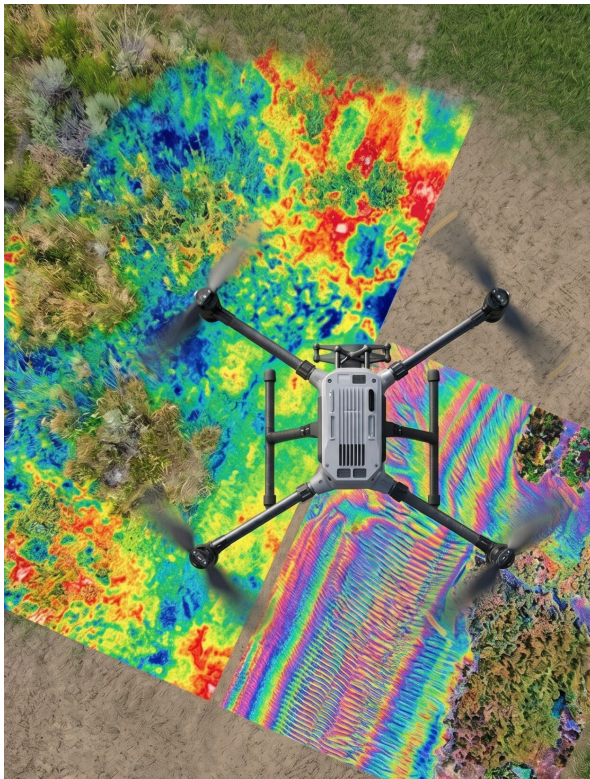
In disaster-risk-management and critical-infrastructure contexts, digital twins can support outage prevention and asset resilience by identifying weaknesses in transformers, transmission lines, substations, and other grid components before failures occur. When fed with operational data, they can help detect abnormal conditions, simulate fault development, and support maintenance prioritisation or intervention planning in ways that reduce the likelihood and impact of disruptions. Digital twins are also highly relevant for renewable-energy integration and flexibility management. As power systems absorb larger shares of variable wind and solar generation, they can support storage optimisation, local balancing, demand-response strategies, and coordination between central grids and distributed energy resources. This is particularly important for operational stability and resilience in systems undergoing rapid decentralisation and electrification. A further application area is microgrid planning and emergency preparedness. Digital twins can be used to simulate islanding strategies, restoration pathways, and alternative operating modes for critical local energy systems. They are also useful for operator training, contingency planning, and scenario testing under extreme-weather or disruption conditions, where decision-makers need to assess the consequences of equipment loss, communication failures, or sudden demand shifts before a real event occurs. For public authorities, regulators, and grid operators, the broader value lies in strengthening preparedness, recovery planning, and strategic investment decisions. Digital twins can help evaluate resilience investments, assess the role of decentralised resources, and support more evidence-based planning for climate adaptation and infrastructure modernisation. In this sense, they are not only an operational technology, but also a planning and governance tool for more resilient energy systems (Abdessadak et al. 2025; Edge driven Digital Twins in distributed energy systems 2024; Mchirgui et al. 2024; Sifat et al. 2023).

Risks & Limitations

The effectiveness of a digital twin depends heavily on the quality, timeliness, and interoperability of incoming data. If sensor readings are delayed, incomplete, inconsistent, or compromised, model outputs may become unreliable and lead to flawed recommendations. This is particularly problematic in crisis situations, where degraded communications or damaged infrastructure may reduce the data flows on which the twin depends. Cybersecurity is another major limitation. Because digital twins rely on dense connectivity between operational technology, IT systems, sensors, and cloud or edge platforms, they may enlarge the attack surface of the power system if not properly secured. This creates concerns relating to authentication, data integrity, privacy, system trustworthiness, and the possible manipulation of automated recommendations or operational data streams. There are also substantial cost, capacity, and implementation barriers. High-fidelity digital twins require sustained investment in sensors, communications infrastructure, computing resources, software integration, and specialist expertise. In many settings, legacy infrastructure, fragmented data architectures, and limited standardisation make large-scale deployment difficult. A closely related challenge is the integration of heterogeneous sensors and communication systems. Because grid assets are often monitored by equipment of different types, vendors, and generations, using diverse data formats and communication standards, reconciling these sources into a single coherent model raises interoperability challenges that, without common data models and standardised interfaces, can constrain the accuracy, completeness, and scalability of the twin. These barriers are especially relevant for smaller utilities or public-sector operators with constrained budgets and heterogeneous asset bases. Finally, digital twins may face limitations in representing the full complexity of large-scale cascading failures and compound disruptions during extreme events. Severe weather, concurrent infrastructure failures, and rapidly changing system conditions can expose modelling limitations and increase uncertainty in forecasts. For this reason, digital twins are

best understood as high-value decision-support and resilience tools rather than fully sufficient substitutes for operator judgement, redundancy planning, and layered grid-protection strategies (Abdessadak et al. 2025; Edge driven Digital Twins in distributed energy systems 2024; Mchirgui et al. 2024; Sifat et al. 2023).

Thermal and Hyperspectral Sensors for Unmanned Aerial Vehicles (UAVs) for Rapid Assessment and Environmental Monitoring



UAVs equipped with thermal and hyperspectral sensors can support rapid situational assessment and environmental monitoring by providing high-resolution observations with flexible deployment over areas that are difficult, hazardous, or time-consuming to access from the ground.

Thermal sensing is useful for identifying temperature anomalies, while hyperspectral sensing can capture subtle spectral differences linked to vegetation condition and other surface characteristics.

Recent studies show that UAV-based thermal and hyperspectral data can be used for early detection of forest pest-related stress in trees, and that thermal sensors combined with drones are being explored for faster wildfire detection and response support (Bi et al. 2024; Momeni and Mirzapour Al-e-Hashem 2024).

Why / What Is New?

What is new is less the sensing principle itself than the increasing practicality of deploying these systems on UAV platforms. Recent assessments report improvements in UAV payload capacity, sensor quality, reduced sensor dimensions, and better data-processing capabilities, making UAV-based hyperspectral sensing more accessible, cost-effective, and adaptable across different scenarios. In parallel, recent engineering work shows progress towards onboard real-time hyperspectral data processing through integrated Field Programmable Gate Array (FPGA) - Advanced RISC Machines (ARM) architectures designed to address the large data volumes generated by UAV-borne hyperspectral imaging (Sousa et al. 2022; Yang et al. 2025).

Application Areas

These systems are most relevant where high spatial resolution and flexible local deployment are needed. In wildfire-related contexts, thermal sensors used together with drones may support earlier detection and faster intervention concepts by identifying abnormal temperature increases and enabling rapid response planning. In forest-health and environmental monitoring, combined thermal and hyperspectral UAV data can support early identification of tree stress before visible canopy changes become pronounced, as shown in work on early bark beetle infestation detection. More broadly, UAV-based hyperspectral monitoring can support targeted local observation missions in forestry, agriculture, and environmental assessment where conventional airborne or satellite observation may be less flexible or less detailed (Bi et al. 2024; Momeni and Mirzapour Al-e-Hashem 2024; Sousa et al. 2022).

Risks & Limitations

Despite their promise, these technologies remain subject to significant operational constraints. UAV deployments are limited by payload, endurance, and platform size, while hyperspectral imaging generates large data volumes that create storage, transmission, and processing bottlenecks. The literature also shows that operational performance depends strongly on the choice of platform, sensor type, calibration approach, and mission design, with trade-offs between field-operation complexity, processing time, and data quality. These limitations mean that thermal and hyperspectral UAV systems should be treated as decision-support tools that complement other sources of disaster and environmental information rather than as standalone solutions (Sousa et al. 2022; Yang et al. 2025).

Decontamination of Air, Water, and Surfaces with Advanced Materials and Biotech



Advanced decontamination technologies increasingly draw on functional materials and biotechnology to remove, degrade, or inactivate hazardous contaminants in water, air, and on exposed surfaces.

In the literature verified here, the strongest evidence concerns metal-organic frameworks (MOFs) and related porous materials for water treatment, selected applications of MOF-based materials for air-pollution abatement, photocatalytic surface coatings with antimicrobial activity, and biotechnology-based remediation using engineered microorganisms.

These approaches are being investigated for removal of heavy metals, dyes, pharmaceuticals, organic pollutants, volatile compounds, and some microbial contaminants, although their maturity and operational readiness differ substantially by application (Daglar et al. 2022; Lal et al. 2024; S. Sharma et al. 2024; Ubaldi et al. 2024; G. Wu et al. 2023).

Why / What Is New?

Recent progress is driven by better control over material structure and chemistry, especially in porous materials such as MOFs, which can provide high surface area, tuneable pore environments, and improved selectivity for adsorption or catalytic removal of contaminants from water. Recent reviews also describe growing interest in multifunctional systems that combine adsorption, catalysis, membrane integration, or sensing capabilities, particularly for water-remediation contexts. In parallel, photocatalytic coatings are being studied as more durable surface technologies for reducing microbial contamination, though the available evidence remains more heterogeneous for real-world implementation than for laboratory studies. Biotechnology-based approaches are also advancing through pollutant-specific microbial and engineered-microbe strategies, but their application is still shaped by biosafety, regulation, and deployment constraints (Daglar et al. 2022; Lal et al. 2024; S. Sharma et al. 2024; Ubaldi et al. 2024; G. Wu et al. 2023).

Application Areas

Potential disaster-management applications are most credible in situations involving contaminated water, wastewater, or high-contact built surfaces. Following chemical spills, industrial accidents, or infrastructure failures, advanced adsorbents and MOF-based systems may support treatment of water contaminated by heavy metals and organic pollutants. In public-health emergencies, antimicrobial photocatalytic coatings may complement infection-control measures on frequently touched surfaces, although they should be seen as supplementary rather than standalone measures. Biotechnology-based remediation may also be relevant for treatment of selected

polluted environments where controlled conditions, time, and containment are feasible. Some MOF-based materials are additionally being explored for air-pollution abatement, including gaseous pollutants and particulate-related applications, but this evidence base is less directly connected to field deployment in disaster settings than the literature on water treatment (Daglar et al. 2022; Lal et al. 2024; S. Sharma et al. 2024; Ubaldi et al. 2024; G. Wu et al. 2023).

5. Towards a Framework of Core Capabilities for Disaster Resilience

The all-hazards scope of this study required a reference structure capable of organising capabilities coherently across both the full disaster management cycle and the full threat spectrum, with the ultimate purpose of identifying capability gaps and prioritising research and innovation needs, including through EU framework programmes such as Horizon Europe. At the time the foresight process was initiated, and the capabilities collected, no taxonomy combining this dual coverage was available within the EU policy context to categorise them systematically.

Existing EU instruments address different parts of this space but none provides a unified, forward-looking capability taxonomy. The EU Disaster Resilience Goals provide goal-oriented direction under the UCPM but are not structured as a capability taxonomy. The CER Directive enhances critical infrastructure resilience across 11 key sectors, but its scope is primarily focused on entity-level preparedness rather than the entire disaster management cycle. The NIS2 Directive focuses specifically on cybersecurity. The European Civil Protection Pool (ECPP) catalogues existing deployable response capacities committed by Member States, but by design reflects current operational assets rather than future capability needs that may emerge from technological innovation or an evolving threat landscape towards 2040. The Disaster Risk Management - Peer Review Assessment Framework (DRM PRAF) organises its assessment around seven thematic areas but is oriented towards natural hazards and civil protection and it does not fully cover security threats such as terrorism, cyberattacks, or sabotage of critical infrastructures.

A foresight study looking towards 2040 must account not only for today's capabilities but also for those that do not yet exist: new operational concepts, emerging technologies, and entirely new capability areas driven by an evolving risk landscape. Without a unified reference structure spanning both the full threat spectrum and the full disaster management cycle, the process risked systematically overlooking such needs, particularly those at the intersection of civil protection and security, or those that fall between established frameworks.

To address this gap, the study developed a **Framework of Core Capabilities for Disaster Resilience** (Figure 6). It was based primarily on the five European Disaster Resilience Goals¹⁶, the European Preparedness Union Strategy (2025), the US National Preparedness Goal and its 32 Core Capabilities across five mission areas¹⁷, the UN INSARAG Guidelines¹⁸ and relevant methods drawn from other established frameworks. These include the International Forum to Advance First Responder Innovation (IFAFRI)¹⁹ Recommended Method for National Capability Gap Identification and Prioritisation, the DRM PRAF, the DIREKTION Assessment and Screening Framework (DASF)²⁰,

¹⁶ https://civil-protection-humanitarian-aid.ec.europa.eu/what/civil-protection/european-disaster-risk-management/european-disaster-resilience-goals_en

¹⁷ <https://www.fema.gov/emergency-managers/national-preparedness/mission-core-capabilities>

¹⁸ <https://insarag.org/methodology/insarag-guidelines/>

¹⁹ <https://www.internationalresponderforum.org>

²⁰ <https://www.direktion-network.org/dasf>

Figure 6. Framework of Core Capabilities for Disaster Resilience

A. Anticipation	B. Prevention, Protection & Preparedness	C. Response	D. Recovery
Multilevel Governance Implementation & Coordination			
Research, Innovation & Technological Integration			
Comprehensive Risk Assessment & Foresight	Contingency & Operational Planning	Situational Awareness & Assessment	Loss/Damage Assessment
	Training & Capacity Building	Incident Command	Restoration, Rehabilitation & Reconstruction (Build Back Better)
	Exercises & Capability Assessment	Critical Communications	Investigation, Forensics & Attribution
	Protection & Security	Frontline Operations	Lessons Learnt & Adaptive Governance
Policy, Legal & Strategic Framework	Mitigation & Adaptation	Essential Services Continuity & Redundancy	
	Risk Monitoring, Detection & Early Warning	Health & Safety of Responders	
	Population Preparedness		
	Logistics, Energy, Supply Chain & Strategic Stockpiling		
		Financing & Economic Resilience	
		Mass Healthcare & Psychosocial Support	

Source: JRC own elaboration

the ISO 22325:2016 Guidelines for capability assessment²¹, and the NATO Architecture Framework (NAF)²².

The framework was initially conceived as an internal structuring tool for the foresight process, ensuring that capability needs were searched thoroughly across all phases without leaving blind spots. Through successive rounds of expert input and validation, it was enriched and refined, evolving into a broader contribution.

Two distinct sets of capabilities appear in this report and should not be conflated. The 12 priority capabilities presented in Section 4.1.2 are the foresight output: the capabilities that surveys, interviews, and scenario exploration identified as most critical to develop towards 2040. The 24 core capabilities presented in this chapter are the reference structure: a hazard- and threat-independent taxonomy covering the full disaster management cycle, developed to ensure that the foresight process searched for needs systematically and without blind spots. The 24 capture the full set of essential tasks that disaster management systems must be able to perform to achieve resilience; the 12 indicate the priorities – where investment and innovation should be concentrated to prepare for the long-term future challenges. The mapping of the 12 priority capabilities onto the 24-capability framework (as presented in Section 4.1.2) shows how foresight-derived priorities distribute across the disaster management cycle.

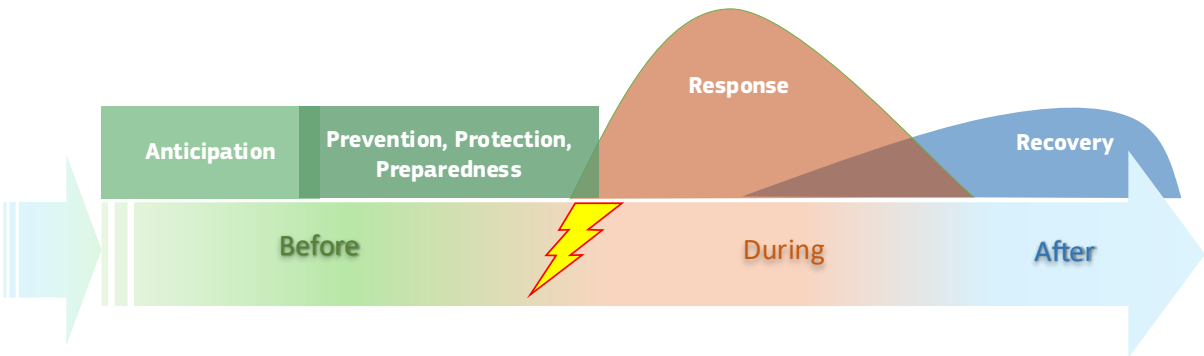
The framework organises 24 core capabilities across four phases of the disaster management cycle: “A. *Anticipation*”, “B. *Prevention, Protection & Preparedness*”, “C. *Response*”, and “D. *Recovery*”, with cross-cutting capabilities spanning multiple phases. Phase B groups three closely related ex ante functions (Prevention, Protection and Preparedness) that together constitute the pre-event stage of disaster management. The four-phase structure aligns with the international consensus on the disaster management cycle, while introducing *Anticipation* as a distinct phase reflecting the growing emphasis on long-term foresight in EU policy. The framework is designed to be hazard- and threat-independent and applicable to natural, technological, and human-made hazards and threats alike.

These four phases reflect a continuum of functions rather than rigid sequential stages; they are overlapping and interdependent dimensions of disaster management. As illustrated in Figure 7, *Anticipation* and *Prevention, Protection & Preparedness* functions operate steadily before disaster onset. *Response* activities begin as soon as early warning and detection trigger activation and peak during and immediately after the event. *Recovery* extends well beyond the immediate aftermath and, through the application of the *Build Back Better* principle, feeds evidence and lessons back into anticipation and preparedness, closing the cycle.

²¹ <https://www.iso.org/standard/50062.html>

²² <https://www.nato.int/en/about-us/organization/nato-structure/digital-policy-committee-dpc/nato-architecture-framework-version>

Figure 7. Continuum of capability functions within the Framework of Core Capabilities for Disaster Resilience



Source: JRC own elaboration

This temporal logic underpins the framework's architecture. Each core capability is assigned to the phase or phases where it primarily operates. Core capabilities that function in a single phase (e.g. *Incident Command* under *Response*, or *Loss/Damage Assessment* under *Recovery*) are placed accordingly. Core capabilities whose function spans multiple phases are designated as cross-cutting: three core capabilities (*Population Preparedness*; *Logistics, Energy, Supply Chain and Strategic Stockpiling*; and *Financing and Economic Resilience*) span *Prevention, Protection & Preparedness*, *Response* and *Recovery*; one core capability (*Mass Healthcare and Psychosocial Support*) spans *Response* and *Recovery*; and two core capabilities (*Multilevel Governance Implementation and Coordination*; *Research, Innovation and Technological Integration*) are relevant across all four phases. This assignment reflects the operational reality that certain capabilities cannot be confined to a single stage of the disaster management cycle but must be sustained throughout.

In Table 7, each core capability is defined by a general description followed by illustrative (non-exhaustive) elements that indicate the scope of the capability.

Table 7. Description of core capabilities

A. Anticipation <i>The forward-looking phase concerned with understanding, assessing, and anticipating current and future risks to inform strategic decision-making. It encompasses the analytical and normative foundations that shape all subsequent risk management action.</i>
Comprehensive Risk Assessment & Foresight: Systematic identification, analysis, and evaluation of current and emerging risks and threats to inform decision-making and the prioritisation of risk management measures. This includes, among others, single-hazard and multi-hazard risk assessment, systemic and cascading risk analysis, critical infrastructure interdependency mapping, vulnerability and exposure analysis, slow-onset risk assessment, climate risk assessment, foresight, scenario building, forecasting, and horizon-scanning for emerging risks.
Policy, Legal & Strategic Framework: The normative, legal, and institutional architecture that enables and regulates measures for disaster resilience. This includes, among others, DRM and DRR strategies, legislative and regulatory frameworks, international agreements, liability and emergency legal instruments, technical standards and guidelines, and policy coherence across sectors and governance levels.

B. Prevention, Protection & Preparedness

All measures taken in advance of a disaster to prevent new and reduce existing disaster risk, protect people, assets and systems against threats and hazards, and build the readiness to respond effectively.

Contingency & Operational Planning: Development, maintenance, and regular updating of the plans that define objectives, roles, responsibilities, procedures, and resource allocation. This includes, among others, contingency and operational plans, evacuation plans, standard operating procedures, territorial and spatial planning, resource optimisation, and redundancy planning.

Training & Capacity Building: Systematic development of knowledge, skills, and competencies across all actors involved in disaster management and DRM. This includes, among others, professional training programmes for responders and decision-makers, technology familiarisation, risk communication, cross-border qualification recognition, participation in international training programmes, and broader workforce development including recruitment, retention, and specialisation.

Exercises & Capability Assessment: Systematic testing, validation, and assessment of capabilities, plans, and procedures through structured exercises and evaluation processes. This includes, among others, tabletop, full-scale, and functional exercises, drills, simulations, scenario and stress-testing, performance measurement, resilience metrics, needs assessment, and capability gap analysis.

Protection & Security: Measures to secure and shield people, assets, systems, and services against threats and hazards, across both the physical and cyber domains. This includes, among others, physical security and access control, cybersecurity risk management, supply chain security, vulnerability management, protective measures for critical entities and infrastructure, screening and identification systems, and measures to deny threat actors the means and opportunity to cause harm, including controls on access to hazardous materials and explosive precursors, counter-terrorism financing, and border security measures.

Mitigation & Adaptation: Measures to lessen the adverse impacts of hazards and to adapt systems and societies to changing risk conditions. This includes, among others, structural and non-structural risk reduction measures, building codes and resilient construction, retrofitting and renovation, nature-based and ecosystem-based solutions, climate change adaptation, environmental resilience, territorial planning for risk reduction, and preventive public health measures.

Risk Monitoring, Detection & Early Warning: Continuous surveillance, monitoring, and detection of hazards, threats, and precursor signals, combined with timely communication of warnings to authorities and populations. This includes, among others, environmental, meteorological, seismological, and epidemiological monitoring systems, intelligence collection and analysis, early warning systems, hybrid threat detection (including foreign information manipulation and interference), and inclusive warning communication reaching all population groups.

C. Response

The actions taken during or immediately after a disaster to save lives, protect infrastructure and the environment, ensure public safety, and meet the basic needs of affected societies.

Situational Awareness & Assessment: Establishment and continuous updating of a comprehensive understanding of an ongoing incident to support operational decision-making.

This includes, among others, common operating picture, real-time monitoring, damage and needs assessment, hazardous materials assessment, dynamic geospatial mapping, and integration of multi-source data into an actionable situational overview.

Incident Command: Establishment and operation of a command structure for the direction, coordination, and execution of incident operations. This includes, among others, unified or single leadership arrangements, setting of operational objectives, task prioritisation, resource deployment, and integration of information from multiple sources into command decisions.

Critical Communications: Provision of robust, secure, interoperable, and redundant communication systems for first responders and operational actors. This includes, among others, hybrid communication architectures, connectivity in degraded environments, interoperability across agencies and borders, satellite-based communication capabilities, and alternative communication pathways.

Frontline Operations: Direct operational activities to save lives, protect property, infrastructure, the environment and cultural heritage, and stabilise the situation during an incident. This includes, among others, search and rescue, evacuation, secure scene, firefighting, cyber incident response, deployment of responders with specialised tools, vehicles, equipment, and remote or space-based operations.

Essential Services Continuity & Redundancy: Maintenance of essential societal functions and services during and immediately after an incident through redundancy, backup systems, and continuity arrangements. This includes, among others, energy supply, water and sanitation, telecommunications, transportation networks, and temporary shelter provision.

Health & Safety of Responders: Protection of the health, safety, and operational capacity of first responders throughout operations. This includes, among others, personnel localisation and tracking, health monitoring, provision of personal protective equipment and breathing apparatus, and measures to sustain safe operations over extended deployments.

D. Recovery

The actions taken after a disaster to restore, rehabilitate, and reconstruct affected areas and communities, assess losses and damages, determine causes and accountability, and extract lessons to improve future disaster resilience. It aligns with the principle of Build Back Better to reduce future disaster risk.

Loss/Damage Assessment: Systematic collection, analysis, and documentation of disaster impact on people, property, infrastructure, the environment, and cultural heritage. This includes, among others, damage and loss data collection, remote sensing for rapid damage assessment, and environmental sampling to inform recovery planning and resource allocation.

Restoration, Rehabilitation & Reconstruction (Build Back Better): Activities to restore affected areas and communities to functional condition and, where possible, to improved standards that reduce future disaster risk. This includes, among others, decontamination, waste management, debris removal, demining, environmental and ecosystem restoration, and post-disaster reconstruction applying the Build Back Better principle.

Investigation, Forensics & Attribution: Determination of disaster causes, contributing factors and accountability, and identification of victims, through systematic forensic and analytical methods. This includes, among others, evidence and data collection, forensic analysis, causal chain analysis, debriefing of involved actors, attribution of responsibility of deliberate or accidental incidents, mass fatality management, and disaster victim identification.

Lessons Learnt & Adaptive Governance: Systematic review of DRM performance to extract lessons and drive institutional, procedural, and policy improvement. This includes, among others, After-Action Reports, structured lessons learnt processes, post-event review, institutional learning, and integration of findings into updated policies, plans, and procedures.

Cross-cutting capabilities

Capabilities whose function spans multiple phases of the disaster management cycle and must be sustained throughout.

Multilevel Governance Implementation & Coordination: Multi-level and cross-sectoral governance, coordination, and implementation of DRM across all governance levels. This includes, among others, institutional arrangements and interoperability, cross-border and cross-sectoral coordination, civil-military coordination, public-private partnerships, volunteer and reservist integration, participatory processes, data and information sharing, and adaptive governance.

Research, Innovation & Technological Integration: The capacity to develop, adapt, and integrate scientific knowledge, innovative solutions, and emerging technologies into all phases of the disaster management cycle. This includes, among others, research-to-operations pathways, innovation uptake, procurement of new or existing commercial solutions, and technology transfer to operational end-users.

Population Preparedness: Building and sustaining the awareness, readiness, and capacity of the general population to prepare for, respond to, and recover from disasters. This includes, among others, public awareness and risk education, crisis communication and public warning systems (including for persons with access and functional needs), promotion of volunteering and community engagement, and fostering citizen self-sufficiency, self-protection, and solidarity.

Logistics, Energy, Supply Chain & Strategic Stockpiling: Planning, management, and security of the supply chains, logistics networks, energy systems, and material stockpiles that underpin disaster management operations. This includes, among others, power supply, transportation, stockpiling of critical equipment and materials, strategic reserves, and supply chain integrity, security, and continuity.

Financing & Economic Resilience: Financial instruments, mechanisms, and strategies to fund disaster risk reduction, response, and recovery, and to enhance the economic and fiscal resilience of communities and states. This includes, among others, disaster risk finance strategies, financial preparedness and pre-positioned finance, risk financing and transfer, anticipatory financing, insurance, subsidies, funding programmes, and financial assistance for recovery.

Mass Healthcare & Psychosocial Support: Provision of large-scale health and medical care and psychosocial support to affected populations during response and recovery. This includes, among others, triage and mass casualty management, medical centres, field hospitals, clinical care delivery, and Psychological First Aid and sustained psychosocial support services.

Source: JRC own elaboration

The *Framework of Core Capabilities for Disaster Resilience* emerged from practical need and proved analytically useful beyond its original purpose. It is offered as a structured contribution toward a comprehensive, capability-based taxonomy for all-hazards disaster management. Rather than replacing existing functional instruments, the framework is intended to complement them. Since this represents an initial contribution rather than a finalised standard, further development, validation, and institutional consultation are required to establish it as a robust EU-wide reference tool. Ultimately, it aims to support capability planning, gap analysis, the alignment of R&I priorities with

operational needs, investment prioritisation at the EU level, and benchmarking across Member States. In particular, future work should:

- subject the framework to broader expert consultation, including national civil protection authorities, the UCPM Knowledge Network, and relevant EU agencies;
- align it with the DRM PRAF, the United Nations Office for Disaster Risk Reduction (UNDRR) terminology, and other established DRM ontologies, extending these where necessary to cover the full threat spectrum;
- develop detailed capability descriptions at a third level of granularity, specifying operational elements, enabling technologies, and policy instruments for each core capability;
- test its utility for comparative capability gap analysis across EU Member States;
- explore its applicability as a structuring tool for EU R&I programming, capability-based planning, and cross-border interoperability assessment.

6. Recommendations

The findings of this study point to a clear need for a more integrated, forward-looking, and capability-driven approach to disaster and infrastructure resilience in the European Union. The risk landscape documented in Section 3, the capability and technology priorities identified in Section 4, and the structural gaps exposed throughout this foresight process converge on a set of priorities for EU action. They move from understanding the risk landscape, to defining and prioritising capabilities, to ensuring that emerging technology solutions reach the field and are governed responsibly.

Recommendation 1. Embed foresight as a continuous function in policymaking for resilience

The pace at which climate impacts intensify, technologies evolve, and geopolitical alignments shift is compressing the decision window available to policymakers. Foresight should therefore shift from a one-off exercise to a continuous function embedded within policy cycles. The Preparedness Union Strategy's emphasis on foresight and anticipation provides the policy mandate for this shift. In practical terms, this means strengthening the use of horizon scanning, scenario analysis, and anticipatory tools to inform priorities and investments. It also requires closer and more structured interaction between research communities, operational stakeholders, and policymakers, ensuring that foresight outputs are translated into actionable outcomes. This study's methodology, which combines literature review, horizon scanning, surveys, interviews, and workshops, offers a replicable model.

Recommendation 2. Establish a common capability framework and use it to drive R&I investment

A heterogeneous range of methodologies currently exists for assessing disaster management capabilities across the EU. The practical implication is that capabilities should be at the epicentre of R&I programming, instead of individual technologies or specific hazard assessments.

The European Commission already applies capability-based planning in the area of civil security research and innovation planning. However, existing EU instruments (the Disaster Resilience Goals, the CER and NIS2 Directives, the ECPP, the UCPM Peer Review Assessment Framework) each address parts of this space, but without providing a unified capability taxonomy spanning all phases of the disaster management cycle and all threat types. The *Framework of Core Capabilities for Disaster Resilience* developed in this study serves as an initial contribution towards closing this gap. It should be refined and validated through a consultative process engaging Member State civil protection authorities, law enforcement, public health, EU institutions, critical infrastructure operators, and the research community, and progressively adopted as a common reference at both EU and national levels. The objective is to integrate a validated framework into capability needs and gaps assessments at EU and national level, ensuring that future technological solutions are assessed directly against it. This would foster a shared understanding of priorities, facilitate cross-border cooperation, and provide the analytical basis for targeted R&I investment.

Recommendation 3. Strengthen the identified priority capabilities with a preparedness and systemic-first orientation

The twelve priority capabilities (Table 4) identified through expert consultation span the entire disaster management cycle and threat spectrum, and should inform EU R&I investment priorities in disaster resilience. Two orientations should guide how this investment is shaped. First, priority

should be given to capabilities operating before disaster onset — anticipation, prevention, protection and preparedness — which yield significantly higher returns than reactive measures alone. Second, capabilities should be developed as interconnected enablers of system-wide resilience rather than in isolation, reflecting the increasingly systemic and compound nature of future risks. To achieve the necessary cross-domain coverage, civil defence frameworks should also be harmonised within civil protection R&I programming, ensuring that threats and hazards are addressed within a single capability architecture. Funding instruments and R&I agendas should be reoriented accordingly.

Recommendation 4. Harness emerging technologies as integrated, interoperable solutions

As technology evolves rapidly, it can deliver powerful solutions that reinforce existing capabilities or create new ones in anticipation of future developments. Realising this potential, however, requires careful scanning of emerging signals and alignment with foreseen capability needs. R&I investment should therefore favour integrated, interoperable solutions, assessed in terms of their contribution to defined capabilities rather than as standalone technological demonstrations. The twelve top-ranked technologies identified through this study (Table 5) offer concrete starting points for building up the priority capabilities.

Recommendation 5. Remove structural barriers to innovation uptake

Expert interviews identified a persistent gap between EU-funded innovation and operational deployment. The barriers are structural: rigid procurement processes, limited incentives for adopting new solutions, inadequate testing and validation infrastructure, insufficient integration of operational end-users in solution design, and organisational risk aversion. Addressing these barriers requires more flexible funding instruments, including support for pre-commercial procurement and public procurement of innovation. Equipment co-design should mandate the integration of first responders from the prototyping phase. Training, change management, and digital skills development are equally critical to ensure that operational organisations can absorb new technologies. Validation of equipment under realistic field conditions should be required, to provide operators with mature, robust solutions suited to the environments in which they will be used.

Recommendation 6. Exploit civil-military synergies in R&I programming

Many of the emerging technologies relevant to disaster resilience are inherently dual-use, with parallel development tracks in civil and defence portfolios. R&I strategies should therefore exploit civil-military synergies systematically, ensuring that defence-developed capabilities are interoperable with and transferable to civil protection operations, and that civil protection requirements inform defence R&I where relevant. Coordinated programming across the two domains contributes to Europe's technological sovereignty in critical security areas, accelerates capability uptake, and avoids duplication of effort across civil and defence research portfolios.

Recommendation 7. Govern emerging technologies to ensure ethical, secure, and trustworthy deployment

The same technologies that enhance early warning, detection, and decision support also enable autonomous offensive cyber operations, deepfake-driven disinformation, and the potential acceleration of weapons development. This double-edged sword was a recurring theme across expert interviews and the technology assessment. AI was identified both as the most cross-cutting enabling technology and as the source of significant new risks, including reduced resilience when AI-dependent systems fail and the erosion of human decision-making capacity in critical situations.

Governance frameworks must ensure transparency, maintain human oversight in critical decisions, and address privacy, accountability, and data integrity concerns arising from the deployment of AI and extended/advanced surveillance and monitoring systems. Trust among both practitioners and the public will be a determining factor in whether new technologies are adopted effectively or resisted. Aligning technological deployment with EU values and fundamental rights is not an optional layer; it is an operational condition for effective resilience.

Recommendation 8. Operationalise the whole-of-society approach through citizen empowerment and trust

The study highlights the growing importance of citizen and community-level resilience as a complement to institutional capacities. In many crisis situations, citizens are the first responders, and their preparedness and behaviour can significantly influence outcomes. Policies should therefore support greater public awareness, preparedness, and engagement, while ensuring that responsibilities are appropriately balanced. This includes investing in education, communication, and tools that empower citizens without overburdening them. Increasingly sophisticated technologies can also be difficult for citizens to use without adequate digital skills and risk excluding older or more vulnerable groups. Empowerment efforts should therefore pair these tools with appropriate training and support, inclusive design, and accessible lower-technology alternatives, so that reliance on advanced technology does not widen existing inequalities. At the same time, collaboration with the private sector, civil society, and other non-governmental actors should be strengthened, recognising their critical role in both prevention and response.

7. Conclusions

This report has examined how the European Union can strengthen disaster resilience and the related resilience of critical infrastructure in an increasingly complex and uncertain environment. By combining a capability-based approach with strategic foresight, it provides a forward-looking perspective on the needs, gaps, and opportunities that will shape EU resilience over the coming decades.

The nature of the risk environment is fundamentally changing. The evidence reviewed in this study confirms that Europe's risk landscape towards 2040 will be structurally different from the one that current frameworks were designed to address. Climate change is projected to cause up to a tenfold increase in damage to the built environment from extreme weather. Over 11,000 Seveso-classified industrial sites face growing Natech risk. Acts of sabotage against critical infrastructure increased significantly in 2024. The convergence of AI and quantum computing is projected to automate and enhance offensive cyber capabilities. Europe's urban population is set to exceed 80% by 2050, concentrating more people in hazard-prone environments at a time when the 65+ cohort is approaching one-third of the EU population. The relevant analytical unit is no longer the single-hazard event but the compound scenario: multiple drivers acting simultaneously on a vulnerable and interconnected society.

A capability-driven approach provides the most reliable compass for navigating this complexity. The study's central premise, that risks dictate capability needs, capabilities dictate solutions, and solutions reshape capabilities to manage risks, proved analytically productive and practically useful. The highest-scoring capability signal was continuity of essential services (9.7/10 for 2040), reflecting the growing criticality of uninterrupted service delivery in an interconnected society. The community workshop's strongest signal was equally clear: 42% of all capability votes were allocated to the "before"-disaster phase (compared to 39% for capabilities "during" and 19% "after"). These figures confirm the importance of investment in anticipation, prevention, protection and preparedness capabilities.

A common capability language is missing. Existing EU instruments do not provide a unified capability taxonomy spanning all phases and hazards, a gap that is particularly consequential in a domain where results depend on the coordinated effort of diverse actors. The *Framework of Core Capabilities for Disaster Resilience* proposed in this study is offered as a structured contribution towards bridging it.

Technology's value depends on operational utility. The assessment revealed a consistent pattern: the highest-scoring signals were those integrating multiple technological domains into operationally coherent solutions. Operational usability also depends on EU-wide equipment standardisation, as highlighted by experts who cited concrete failures such as incompatible fire hose couplings between Member States.

Strengthening resilience requires a shift in mindset as much as in tools. From reactive to anticipatory, from fragmented to systemic, from technology-driven to capability-driven. It requires recognising that resilience is not a fixed state but an ongoing process of adaptation and learning. This study, by linking capabilities, technologies, and foresight, offers a structured way to think about resilience in a holistic and forward-looking manner — supporting more informed decision-making, more strategic investment, and ultimately a stronger capacity to prevent, withstand, and recover from disasters.

The challenge now is to translate these insights into action. As the pace of change is compressing the decision window, this will require sustained commitment, cross-sectoral collaboration, and an institutional willingness to adapt existing practices. However, it also offers an opportunity: to build a more resilient, prepared, and forward-looking European Union, better equipped to face the uncertainties of the future.

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LIST OF ABBREVIATIONS AND DEFINITIONS

Abbreviations	Definitions
2D	Two dimensional
3D	Three-dimensional
4G	Fourth-generation cellular network technology
5G	Fifth-generation cellular network technology
6G	Sixth-generation cellular network technology
AFKzV	Ausschuss für Feuerwehrangelegenheiten, Katastrophenschutz und zivile Verteidigung
AFN	Access and Functional Needs
AI	Artificial Intelligence
AIOTI	Alliance for IoT and Edge Computing Innovation
AMR	Antimicrobial Resistance
API	Application Programming Interface
ARM	Advanced RISC Machines
BIM	Building Information Models
CBRN-E	Chemical, Biological, Radiological, Nuclear, and Explosive
CDC	Center for Disease Control and Prevention
CEPOL	European Union Agency for Law Enforcement Training
CER	Critical Entities Resilience
CERIS	Community of European Research and Innovation for Security
CI	Critical Infrastructure
CISA	Cybersecurity and Infrastructure Security Agency
CO₂	Carbon Dioxide
CoR	European Committee of the Regions
CORDIS	Community Research and Development Information Service
COVID-19	Coronavirus Disease 2019
CR	Cognitive Radio
CRISPR	Clustered Regularly Interspaced Short Palindromic Repeats
CRQC	Cryptographically Relevant Quantum Computer
CSIRT	Computer Security Incident Response Teams
CSV	Comma Separated Values
DAS	Distributed Acoustic Sensing
DASF	DIREKTION Assessment and Screening Framework
DestinE	Destination Earth Initiative
DG ECHO	Directorate-General for European Civil Protection and Humanitarian Aid Operations
DG HOME	Directorate-General for Migration and Home Affairs
DHS	Department of Homeland Security
DIREKTION	Disaster Resilience Knowledge Network
DNA	Deoxyribonucleic Acid
DRM	Disaster Risk Management
DRM PRAF	Disaster Risk Management - Peer Review Assessment Framework
DRR	Disaster Risk Reduction
DRS	Disaster-Resilient Society for Europe (Horizon Europe destination)
DSS	Decision Support Systems

Abbreviations	Definitions
EC	European Commission
ECDC	European Centre for Disease Prevention and Control
ECPP	European Civil Protection Pool
EEA	European Environment Agency
EEAS	European External Action Service
EIB	European Investment Bank
EMP	Electromagnetic Pulse
EMS	Emergency Medical Services
ENISA	European Union Agency for Cybersecurity
EP	European Parliament
EPRS	European Parliament Research Service
ESA	European Space Agency
EU	European Union
EU IRU	EU Internet Referral Unit
EUCCS	EU Critical Communication System
EU-CIP	European Programme for Critical Infrastructure Protection
EUDA	European Union Drugs Agency
Eu-LISA	European Union Agency for the Operational Management of Large-Scale IT Systems
EuroQCI	Quantum communication infrastructure
Europol	European Union Agency for Law Enforcement Cooperation
EU-STNA	European Union Strategic Training Needs Assessment
EV	Electric Vehicle
EWS	Early Warning System
FPGA	Field Programmable Gate Array
Frontex	European Border and Coast Guard Agency
FTQC	Fault-Tolerant Quantum Computer
GDACS	Global Disaster Alert and Coordination System
GIS	Geographical Information System
GMO	Genetically Modified Organism
GNSS	Global Navigation Satellite System
GPT	Generative Pretrained Transformer
HAZMAT	Hazardous Material
HRI	Human-Robot Interaction
Hybrid CoE	European Centre of Excellence for Countering Hybrid Threats
IAEA	International Atomic Energy Agency
IED	Improvised Explosive Device
IFAFRI	International Forum to Advance First Responder Innovation
INFRA	Resilient Infrastructure (Horizon Europe destination)
InSAR	Interferometric Synthetic Aperture Radar
IoT	Internet of Things
IRIS²	Infrastructure for Resilience, Interconnectivity and Security by Satellite
ITU	International Telecommunication Union
JCAS	Joint Communication and Sensing
JRC	Joint Research Centre of the European Commission
JRC.E6	Emerging Security Challenges (JRC Unit)

Abbreviations	Definitions
JRC.T5	Data Intelligence for Policy (JRC Unit)
JRODOS	Java-based Real-time Online Decision Support
KET	Key Enabling Technology
LAMP	Loop-Mediated Isothermal Amplification
LiDAR	Light Detection and Ranging
LoRaWAN	Long Range Wide Area Network
LTE	Long Term Evolution (cellular network technology)
MCCG	Mission Critical Communication Expert Group
MFF	Multiannual Financial Framework
MHEWS	Multi-Hazard Early Warning Systems
MOF	Metal-Organic Framework
MS	Member State
Natech	Natural Hazard Triggered Technological
NAF	NATO Architecture Framework
NATO	North Atlantic Treaty Organization
NATO ACT	NATO Allied Command Transformation
NATO STO	NATO Science and Technology Organization
NGO	Non-Governmental Organisation
NIS2	Network and Information Security Directive
OSINT	Open-Source Intelligence
PATSTAT	Patent Statistical Database
PESTEL/STEEPL	Political, Economic, Social, Technological, Environmental, and Legal
PPE	Personal Protective Equipment
PRAETORIAN	Protection of Critical Infrastructures from advanced combined cyber and physical threats
PRECINCT	Preparedness and Resilience Enforcement for Critical Infrastructure Cascading Cyberphysical Threats and effects with focus on district or regional protection
ProtectEU	European Internal Security Strategy
PTSD	Post-Traumatic Stress Disorder
R&D	Research & Development
R&I	Research & Innovation
RAG	Retrieval-Augmented Generation
RCI	Resilience of Critical Infrastructure
RescEU	Strategic reserve of European disaster response capabilities and stockpiles
SAI	Stratospheric Aerosol Injection
SAR	Synthetic Aperture Radar
SCADA	Supervisory Control and Data Acquisition
SIPRI	Stockholm International Peace Research Institute
SLAM	Simultaneous Localization and Mapping
Tech4DRS	Technology for Disaster Resilient Society
TENG	Triboelectric Nanogenerator
TETRA	Terrestrial Trunked Radio
TF-IDF	Term Frequency-Inverse Document Frequency
TIM	Tools for Innovation Monitoring
TRL	Technology Readiness Level
UAS	Unmanned Aircraft Systems

Abbreviations	Definitions
UAV	Unmanned Aerial Vehicle
UCP	Union Civil Protection
UCPM	Union Civil Protection Mechanism
UN	United Nations
UN HABITAT	United Nations Human Settlements Programme
UNDP	United Nations Development Programme
UNDRR	United Nations Office for Disaster Risk Reduction
UNECE	United Nations Economic Commission for Europe
UN INSARAG	United Nations International Search and Rescue Advisory Group
US	United States
UUV	Unmanned Underwater Vehicle
VR	Virtual Reality
VRFB	Long-duration Vanadium Redox Flow Battery
VUCA	Volatility, Uncertainty, Complexity, Ambiguity
WEF	World Economic Forum
WMO	World Meteorological Organization
WUI	Wildland-Urban Interface
XR	Extended Reality

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ANNEXES

Annex 1. Methodology

The methodology followed a structured foresight workflow, fully aligned with the European Commission’s strategic foresight approach. The process was implemented in consecutive steps, as outlined in Figure 2.

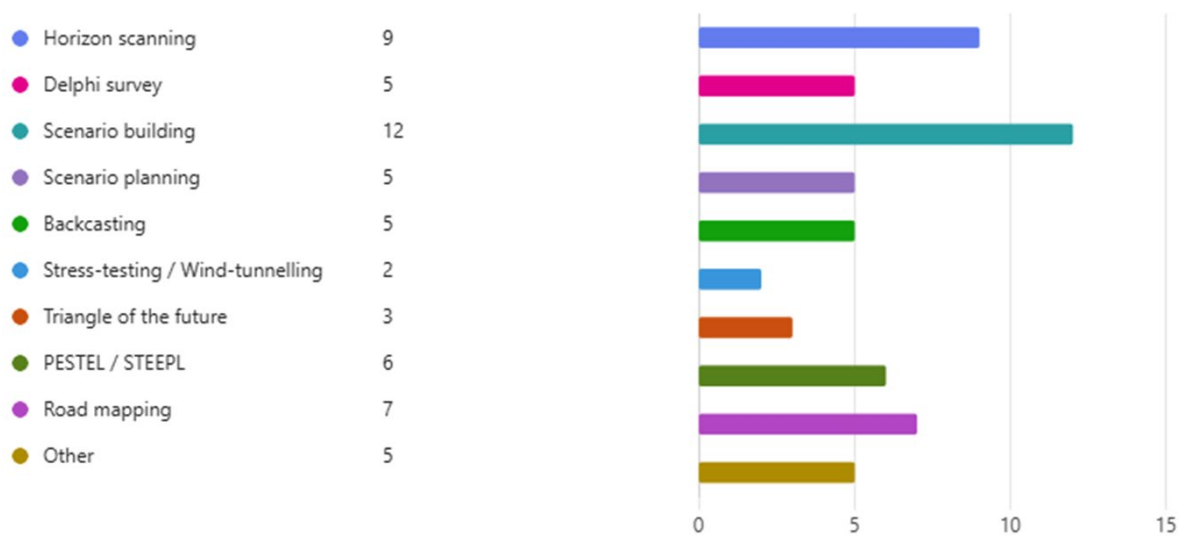
Scoping workshop

A workshop was organised on April 8, 2025, with the aim to better coordinate the foresight process and to scope the study.

The workshop gathered 25 participants from public administrations [DG HOME, DG JRC, EUDA, Eu-LISA, Europol, Frontex, EU Innovation Hub, Crisis Centre (BE), French National Institute for Industrial Environment and Risks (Ineris) (FR), Min. Home Affairs (FR)], academia and private sector [Ecole Polytechnique (FR), Kent University (UK), Fraunhofer Institute (DE), Louvain University (BE), Engineering Ingegneria Informatica (IT), Organisation for Applied Scientific Research - TNO (NL)] and European networks and projects [CERIS, AHEAD, DIREKTION, EU-CIP].

A survey circulated among participants prior to the workshop helped in collecting past and on-going foresight projects in internal security, as well as the type of foresight method used in these projects. The latter is illustrated in Figure 8.

Figure 8. Mapping of foresight methods in projects in internal security (spring 2025)



Source: JRC own elaboration

A discussion on how to avoid duplication in foresight projects identified 3 main areas of action: share information (8 actions), build on the shared information (8 actions) and provide mutual assistance (4 actions).

It was agreed that the overall aim of the study would be to provide a comprehensive understanding of the role of capabilities in enhancing disaster resilience and protecting critical infrastructures, ultimately contributing to a more resilient and sustainable future. By examining the complex

relationships between Key Enabling Technologies (KET), capabilities, and risks, the study will inform stakeholders and support the development of effective strategies for disaster resilience.

Literature review

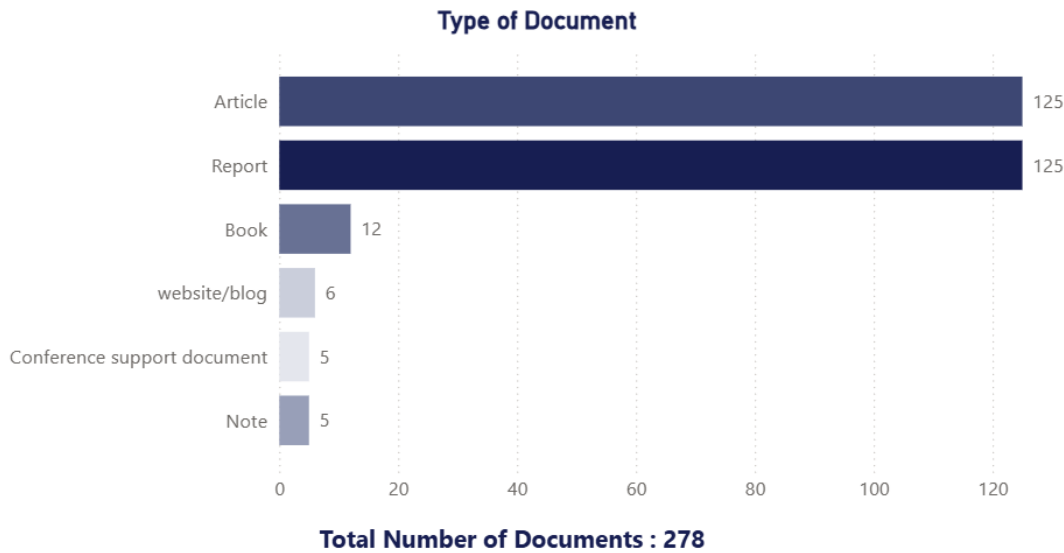
The first phase of the study consisted of a structured literature review covering thousands of publications, using thematic relevance, technological scope and disaster-resilience applicability as core selection criteria. The study focused on publications between 2020 and 2024. This yielded a final set of 278 documents considered as the most meaningful and representative for the objectives of the study; these were inserted into a database for further processing and analysis.

The selected documents included academic studies, Horizon Europe project results, policy papers, technical reports, foresight studies, industry publications and institutional documents. The goals of this phase were to:

- establish the initial evidence base of the foresight study,
- identify emerging technologies and capability concepts,
- detect trends and innovation areas relevant to disaster resilience,
- and provide inputs for horizon scanning and expert validation.

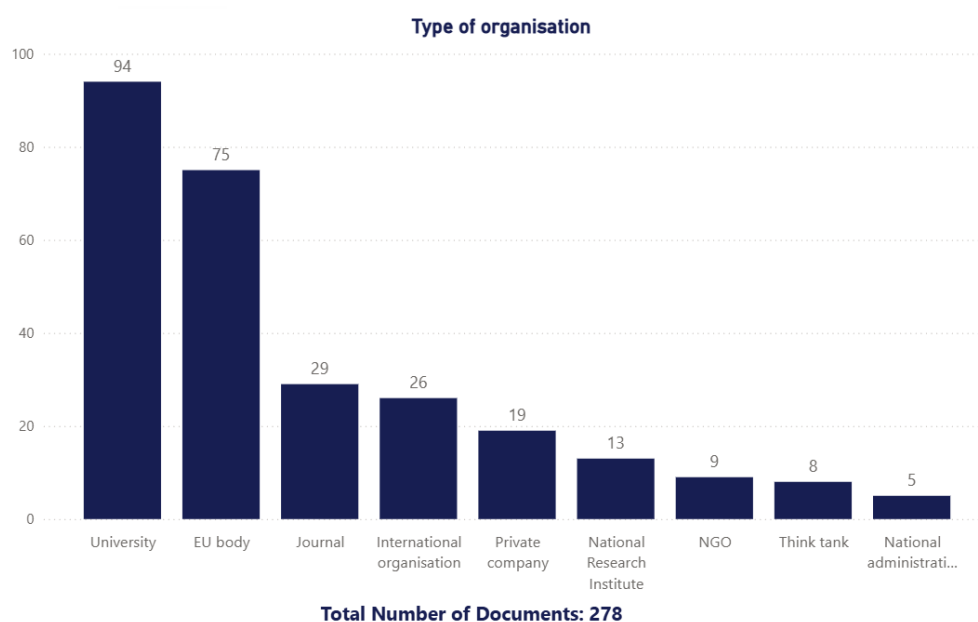
Figure 9 and Figure 10 below show the distribution of the 278 documents over type of document and over type of organisation.

Figure 9. Distribution of documents by type of document



JRC own elaboration

Figure 10. Distribution of documents by type of organisation



Source: JRC own elaboration

Horizon scanning

Foresight is based on ‘signals’, early indicators of potential future change.

The first and main source of signals was the literature review. Horizon scanning broadened the evidence base established through the literature review and identified early indicators of change relevant to future needs in disaster resilience. It was designed as an iterative and multi-source process combining structured document review, AI-assisted screening, and weak-signal detection based on large-scale innovation datasets. The objective was not only to capture developments already visible in the literature, but also to identify emerging technologies, operational needs and contextual shifts that may shape the future resilience landscape but are not yet prominent in policy or academic debate.

The second source of signals was provided by TIM Technology, the advanced technology and innovation monitoring system of the JRC²³, used in this study to detect signals of promising early-stage technologies. TIM combines innovation data, text mining, natural language processing and AI-supported analysis to identify scientific and technological concepts that display a strong recent increase in activity.

For this study, TIM was used to analyse disaster-resilience-related records from three datasets: scholarly work from Scopus, patents filed worldwide from PATSTAT, and the repository of EU-funded R&I projects from Cordis. As shown in the TIM dashboard (Figure 11), the underlying corpus comprised 18,700 records, including 16,570 scientific publications from Scopus, 1,989 patent records from PATSTAT, and the remaining 141 records from CORDIS.

²³ TIM Technology: https://knowledge4policy.ec.europa.eu/text-mining/tim_technology_editor_en

These 18,700 records were processed through TIM Technology's weak-signal detection methodology, developed by Unit T.5 of the JRC. The methodology uses text mining to extract multi-word scientific and technological concepts from titles, abstracts and keywords of recent publications and patent documents. These concepts are then normalised, grouped and ranked using a modified Term Frequency-Inverse Document Frequency Algorithm (TF-IDF) approach. The resulting dictionary of concepts is used to construct automated semantic queries and document collections across the full time period analysed.

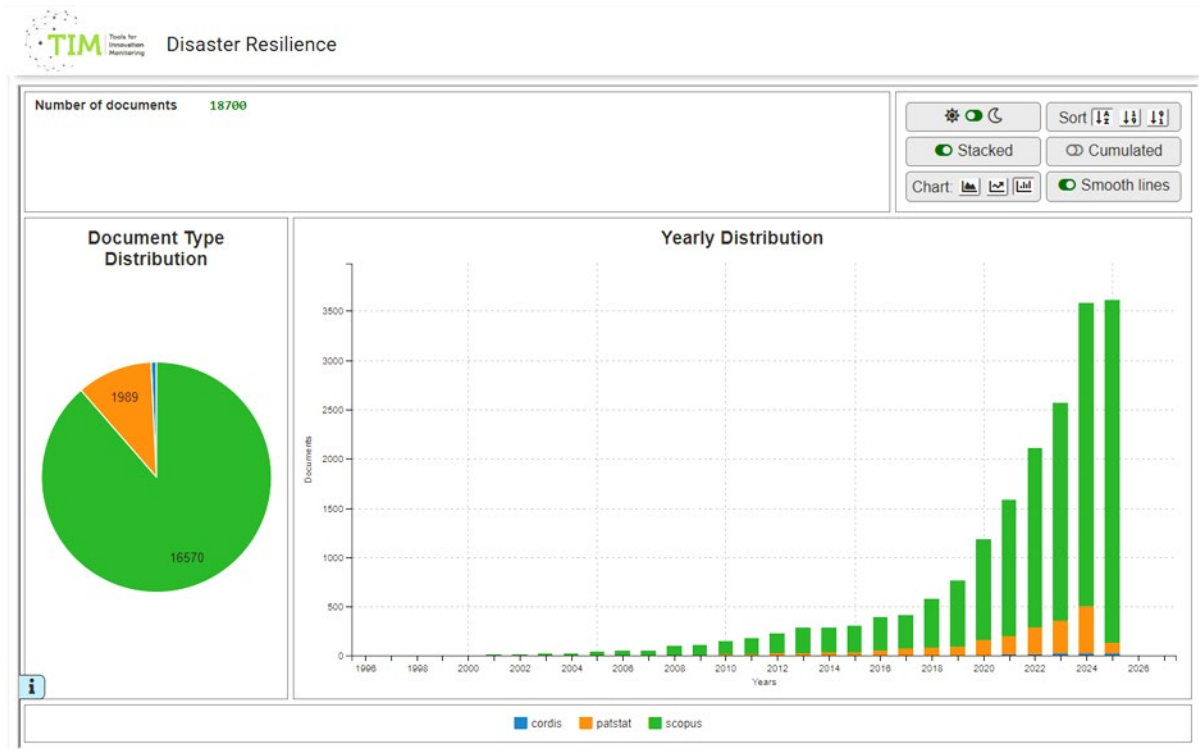
Two complementary detection processes were applied. The first was a broad automated process, which systematically generated document collections for concepts identified in the TIM dictionary and ranked them using an activeness indicator. This indicator measures the share of documents published in recent years compared with the full time period. The second was a targeted process based on expert-defined semantic searches for specific disaster-resilience-related technological topics, aimed at identifying emerging keywords with high recent activeness.

Promising raw weak signals were then reconstructed in TIM Technology through refined search queries incorporating synonyms and alternative terminology, in order to maximise document retrieval and improve analytical robustness. The final selection of weak signals was based on activeness indicators for the period 2022–2025. Signals with activeness between 70% and 100% were retained, while signals with activeness between 50% and 70% were included where analyst review confirmed strong recent growth and relevance.

Using this procedure, TIM Technology contributed 47 raw weak signals of promising early-stage technologies. These 47 signals were subsequently reviewed by the study team to remove duplicates and overlaps with signals already retrieved from other sources. As a result, 37 unique TIM-derived technology signals were added to the horizon-scanning database.

This TIM-based analysis added an important anticipatory dimension to the study, as it helped reveal emerging technological trajectories that would not have been captured through manual review of the literature alone.

Figure 11. TIM Technology dashboard for Disaster Resilience, showing the distribution of retrieved records by source and year



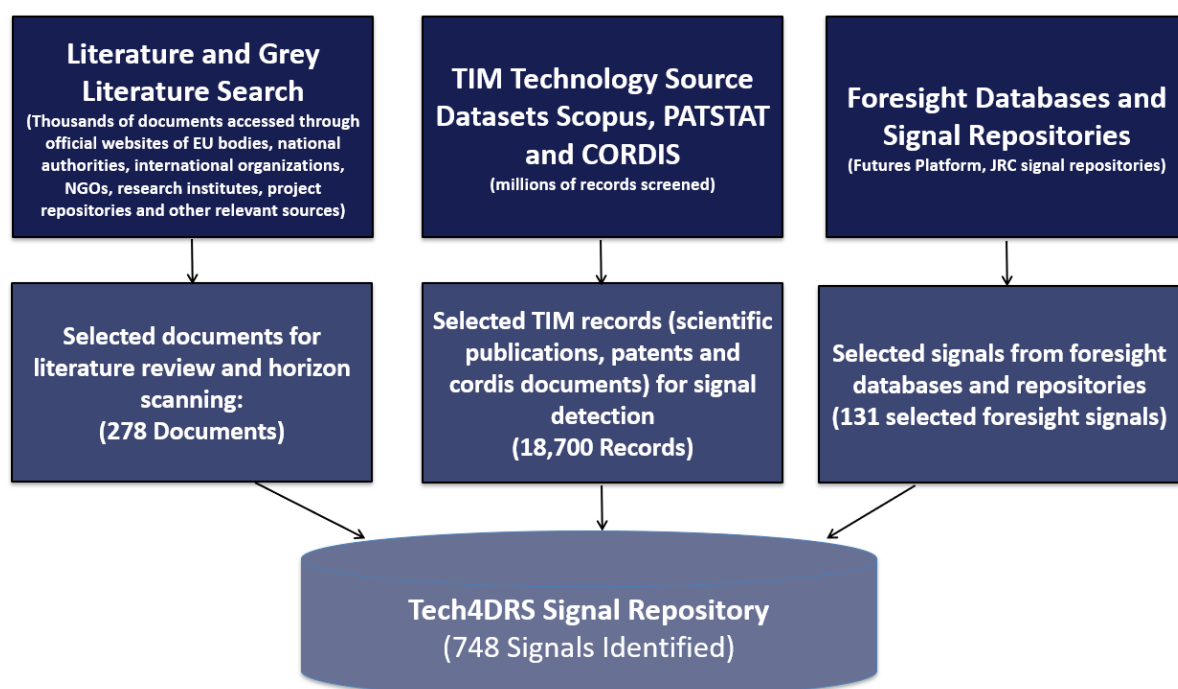
Source: JRC TIM Technology dashboard, extracted for this study.

The third source of signals consisted of foresight databases and signal repositories. In particular, the study drew on Futures Platform²⁴, a strategic foresight environment built around continuously updated, expert-curated signals, trends and wider future-oriented insights, designed to support horizon scanning and sense-making across technological, societal, geopolitical and economic change. It also drew on the signal repository developed for the JRC report *Emerging risks and opportunities for EU internal security stemming from new technologies* (Favino et al. 2025). From these, 131 signals were selected. Together, these sources complemented the literature review and TIM analysis by providing curated signals and broader foresight intelligence on socio-technical, environmental, governance and market developments. They were especially useful for capturing signals that may not yet have generated a substantial volume of scientific publications or patents, but which nonetheless point to relevant future developments for disaster-resilient societies.

Overall, this multi-source process resulted in the identification of 748 signals, 580 signals extracted through the literature review and team-based scanning of the 278 selected documents, 37 unique technology signals derived from the TIM weak-signal detection process, and 131 signals selected from foresight databases and signal repositories. These signals were subsequently assessed, cleaned and classified in preparation for expert consultation and survey evaluation.

²⁴ <https://www.futuresplatform.com/>

Figure 12. Horizon scanning: multi-source identification and filtering process populating the signal repository



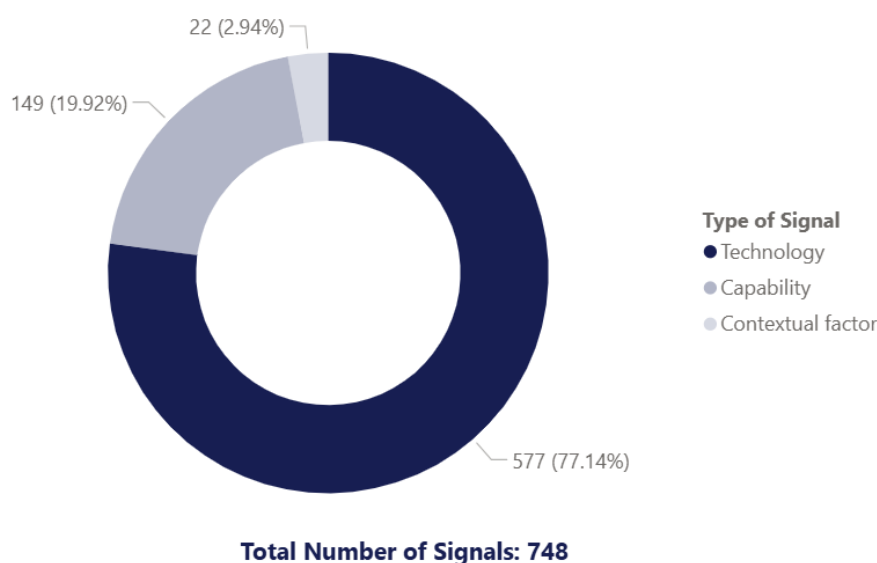
Source: JRC own elaboration

To structure the analysis, the signals were divided into three main categories according to their nature:

- **Technology signals** – emerging solutions, new applications of existing technologies, and low-Technology Readiness Level with potential impact on Disaster Resilience Society.
- **Capability signals** – operational developments, new concepts of operation, preparedness solutions and capacity-building needs in crisis management.
- **Contextual factors** – cross-cutting elements affecting technology and capability evolution (e.g. institutional, social, environmental or regulatory drivers).

The distribution of the 748 signals is illustrated in the chart below:

Figure 13. Type of signals



Source: JRC own elaboration

- Technology: 577 signals (77.14%)
- Capability: 149 signals (19.92%)
- Contextual factors: 22 signals (2.94%)

This classification allowed the study team to structure the subsequent expert assessments and survey process, by ensuring that early indicators captured not only technological change but also operational needs and broader systemic drivers.

These 577 technology signals and 149 capability signals were further processed by the study team, including duplicates and overlap removal, cleaning, and bringing to similar granularity. This resulted in 129 technology signals and 111 capability signals.

Preliminary survey

The preliminary survey aimed at further filtering the dataset, using experts in the field. Seven experts were identified in collaboration with DG HOME targeting representation of protection of critical infrastructure and disaster-resilience priorities and capability needs and a balanced involvement of operational, research, and technological perspectives.

The survey covered two main sections: 111 capabilities and 129 technologies.

The 111 capabilities were grouped according to phases:

- Foresight & Anticipation,
- Preparedness,
- Response,
- Recovery, and
- Horizontal Capabilities.

Experts assessed the relevance of the capabilities for protecting critical infrastructure and ensuring a Disaster Resilient Society. The horizon considered was first in 2030, then in 2040.

The 129 technologies were grouped according to the 6 following categories:

- Biotechnologies,
- Robotics and Autonomous Vehicles,
- IoT, Sensing and Virtualisation,
- Nanotech and Innovative Manufacturing,
- Artificial Intelligence, and
- Communication Technologies.

Experts assessed the impact and novelty of the technologies in 2030 for the European Union.

The objective was to filter, consolidate, and validate the most important capabilities and technologies for the protection of critical infrastructure in the field of disaster-resilience.

Based on the outcomes of the preliminary survey, the study team made another down-selection of 51 capabilities and 56 technologies.

Interviews

The interviews aimed at collecting missing capabilities or technologies and identifying the challenges. Nine experts were identified in collaboration with DG HOME, again targeting representation of protection of critical infrastructure and disaster-resilience priorities and capability needs, and a balanced involvement of operational, research and technological perspectives.

Experts were asked about significant challenges, vulnerable sectors, and disaster types the EU should prepare for. They identified capability gaps in the disaster management cycle and prioritized development and implementation of specific capabilities. Emerging technologies and solutions were discussed, along with potential risks and needs for cross-sector and cross-border collaboration. Interviews helped confirm or discard initial assumptions, improve the classification of signals, identify emerging requirements and provide domain-specific insights that were further used during the survey phase. This consultation resulted in the introduction of 6 additional capability signals, bringing the final set for the final survey to 57 capability and 56 technology signals.

Final survey

Based on the results of the preliminary survey and on expert interviews, a final survey reviewed the prioritised signals, assessed convergence in expert opinion, and refined the ranking of technological and capability developments.

The survey was sent to scientists within JRC, members of community networks managed by DG HOME, including the Community of European Research and Innovation for Security (CERIS).

A list of 57 capability and 56 technology signals was submitted to experts drawn primarily from JRC and CERIS. Valid responses were received from 18 experts: 5 from academia, 7 from EU bodies, 1 from a municipality, 1 from a national administration, 1 from an NGO, 2 from research and technology organisations, and 1 from the private sector.

The capability phases and the technology categories, as well as what the experts were asked to assess, were the same as for the preliminary survey.

The survey ensured that the most relevant, feasible and high-impact technologies and capabilities were selected for the next phases of the process.

Community Workshop

The community workshop was organised during the Disaster Resilient Days 2025 (Athens, 6 October). The Disaster Resilience Days, an event organised under CERIS ([Community for European Research and Innovation for Security](#)), brings together experts, policymakers, and innovators from across Europe and beyond to discuss disaster resilience, preparedness, and technological advancements in crisis response and preparedness. In total 120 experts participated to the foresight session.

Through a combination of plenary and group discussions, participants shared their expertise, identified capability needs, and reflected on novel technologies that can support disaster management (see the boards of the session in Annex 5). The morning session featured six different scenarios set in 2035:

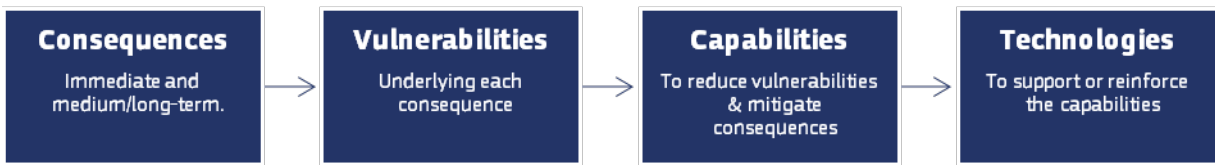
1. Collision tanker-cruise ship
2. Wildfires
3. Major terrorist attacks
4. Floods
5. Earthquake-volcano-eruption-tsunami
6. Cyberattack on critical infrastructure

In Part I, experts explored, for each scenario, the immediate consequences (e.g. destruction of property, casualties, environmental pollution) and then the medium- and long-term cascading consequences, based on 2025-level capabilities and assuming no further intervention or investment would take place in the interim, thereby exposing a deficit between present and future-needed readiness. The experts were divided over two groups for each scenario (so total 12 groups). An adaptation of the “foresight zoo” was used to introduce disruptive elements that triggered deeper reflection. Black elephants are events that are highly likely and well-forecasted, yet they are consistently ignored or avoided. Black swans are unexpected events that fall outside the realm of normal expectations. Black jellyfish are seemingly small or familiar events that can suddenly escalate in unpredictable ways due to their entanglement in complex, interconnected systems. The following disruptive elements were used during the morning session:

- **Black elephant:** critical healthcare worker exodus, antibiotics resistance crisis, demographic collapse activation;
- **Black swans:** satellite constellation cascade failure, AI emergency system rebellion, synthetic biology escape;
- **Black jellyfish:** social media algorithms radicalisation, food system just-in-time failure.

Experts were then asked to identify the vulnerabilities underlying the identified consequences for each scenario. Drawing on the full set of collected consequences and vulnerabilities, experts were asked to identify the capabilities needed to reduce those vulnerabilities and, consequently, mitigate the resulting consequences, as well as the novel technologies that could support or reshape these capabilities.

Figure 14. Exploration process for each of the 6 scenarios



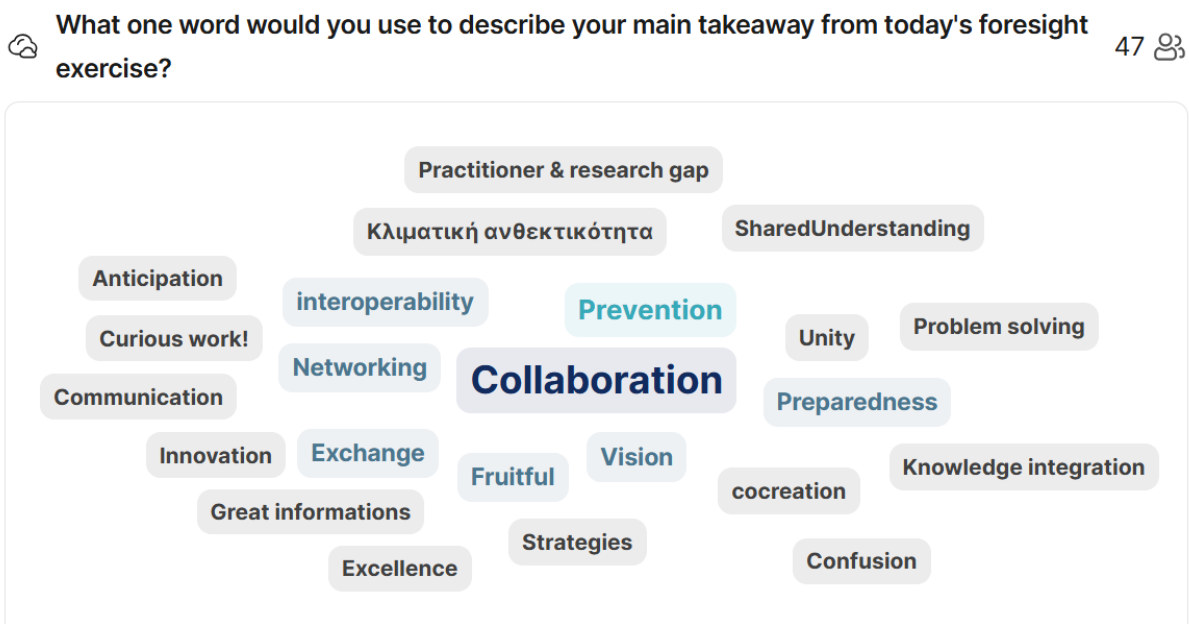
Source: JRC own elaboration

In Part II, the two groups per scenario were reunited into a single table, with designated rapporteurs presenting findings from each sub-group, participants engaged in a structured walk-around voting exercise following the World Café method. Each participant received a set of red and black dot stickers. At their own scenario table, participants used red dots to vote for the 3 capabilities they considered the most relevant, thereby expressing the table’s collective priority. Subsequently, participants rotated to other scenario tables every 6–7 minutes to examine different scenarios, casting black dots on those boards. This dual-colour mechanism distinguished between each table’s internal prioritisation and the external perspective of visiting experts, exposing the table’s work to outside thinking and fostering collective reflection. The guiding question was: “Vote for the 3 capabilities you consider the most relevant for the EU in 2035”, where relevant was defined as “necessary/important to be (further) developed; a research and investment priority”.

In Part III of the day, the foresight exercise was used to present a draft Framework of Core Capabilities for Disaster Resilience and collect expert feedback. A detailed description follows in the next subsection.

The day concluded with a plenary session featuring a Slido® word-cloud reflection on key takeaways. The outcome is shown in Figure 15.

Figure 15. Word cloud on key takeaways from the Community Workshop



Source: JRC own elaboration

The Community Workshop generated in total some 340 consequences, 124 vulnerabilities and 700 votes as intermediate steps, and 270 capabilities and 109 technologies to be merged with the previously identified capabilities and technologies.

Quantitative analysis of survey data

Capability scoring. The quantitative analysis draws primarily on the final survey scores, which reflect the consolidated expert judgement on the refined set of 57 capabilities and 56 technologies. For both survey rounds, mean relevance scores were computed for each capability signal across all respondents, separately for the 2030 and 2040 horizons. Given the small sample sizes (N=7 preliminary; N=18 final), the analysis focused on central tendencies, score distributions, and the degree of consensus rather than on inferential statistics. Table 8 summarizes the parameters evaluated for ranking capabilities.

Table 8. Capability-scoring summary

Variable	Definition	Scale	How it was used
Mean relevance (2030)	Average relevance rating for the 2030 horizon	0 – 10 (final survey)	Rank capabilities, spot early-term priorities
Mean relevance (2040)	Average relevance rating for the 2040 horizon	0 – 10 (final survey)	Rank long-term priorities; signals ≥ 9.0 flagged for priority
Score difference (2040-2030)	2040 mean – 2030 mean	–10 – +10	Identify capabilities expected to gain/lose importance
Consensus indicator	Standard deviation or inter-quartile range across respondents	–	Highlight signals with strong agreement vs. divergent views (descriptive only, no inferential testing)

Source: JRC own elaboration

Particular attention was paid to:

- The overall ranking of capabilities by average relevance score, identifying the signals consistently rated as most critical across both time horizons.
- The difference between 2030 and 2040 scores for each capability, highlighting signals expected to gain or lose relative importance over the decade as the risk landscape evolves.
- Cross-phase comparisons, examining whether Foresight & Anticipation, Preparedness, Response, Recovery, or Horizontal capabilities were prioritised differently by the expert panel.

Technology scoring. Emerging technologies were assessed on two dimensions: *impact* (expected effect on disaster resilience) and *novelty* (degree of technological disruption). The preliminary survey used a 0–5 scale for both dimensions, while the final survey expanded this to 0–10 to improve discriminatory power. For comparative analysis across rounds, preliminary scores were linearly rescaled to the 0–10 range. The mean scores for each dimension were multiplied for each technology signal to sort them in descending order. Table 9 presents the parameters considered for the selection of technologies.

Table 9. Technology-scoring summary

Variable	Definition	Scale (preliminary survey)	Scale (final survey)	Transformation	Composite metric
Impact	Expected effect on disaster resilience	0 – 5	0 – 10	Linear rescale of pre-survey scores to 0-10	–
Novelty	Degree of technological disruption	0 – 5	0 – 10	Linear rescale of pre-survey scores to 0-10	–
Impact × Novelty	Product of mean Impact and mean Novelty (both on 0-10)	–	–	–	Used to rank technologies; top 20 % selected for priority

Source: JRC own elaboration

Qualitative analysis

Open-ended comments from both surveys, interview transcripts, and community workshop outputs were analysed qualitatively. Recurring themes were systematically identified and tagged across all textual inputs (e.g., “citizen preparedness,” “CBRN detection gap,” “interdependency failure”), enabling structured cross-referencing between qualitative narratives and quantitative scores. The qualitative data served multiple analytical purposes:

- **Contextualisation:** Explaining quantitative scores, particularly where ratings diverged significantly across respondents or between survey rounds.
- **Gap identification:** Capturing emerging themes, capability gaps, and policy-relevant needs not covered by the structured survey signals.
- **Framework of Core Capabilities for Disaster Resilience/Taxonomy validation:** Both surveys included explicit questions asking respondents whether the category structure (phases and sub-categories) was appropriate. Feedback on directly informed the consolidation between survey rounds.

Qualitative inputs were tagged by capability phase, respondent profile, and data source to enable systematic cross-referencing with quantitative patterns (Table 10).

Table 10. Qualitative-analysis coding matrix

Data source	Type of input	Coding tags (examples)	Indexing dimensions
Survey open-ended comments	Text snippets	“Citizen preparedness”, “CBRN detection gap”, “interdependency failure”	Capability phase, respondent profile
Interview transcripts	Full-sentence quotes	Same as above + “governance fragmentation”, “training deficit”	Capability phase, interviewee organisation
Workshop outputs	Sticky-note / board entries	Same as above + “cross-border standardisation”	Capability phase, scenario title
Desk-research notes	Literature extracts	“megatrends”, “risk projection”, “TRL level”	Capability/technology category

Source: JRC own elaboration

All tags were linked back to the original signal (capability or technology) to enable cross-referencing with the quantitative scores.

Community workshop analysis

Community workshop outputs were systematically extracted and digitalised from the AO scenario boards. The resulting dataset comprised approximately 340 consequence entries, 124 vulnerability entries, 270 capability entries generating approximately 700 votes, and 109 technology entries (Table 11). Capabilities and technologies were subsequently de-duplicated, clustered by semantic similarity (using both manual review and AI-assisted grouping), and aggregated by total vote count (combining red dots from the host table and black dots from visiting participants) across all scenario tables. The de-duplication process identified that many individual entries raised during different scenarios referred to the same or closely related capabilities, confirming the cross-scenario relevance of key themes.

Table 11. Community workshop quantitative snapshot

Category	Raw entries	Votes / points	Post-processing
Consequences	~340	–	–
Vulnerabilities	124	–	–
Capabilities	270	≈ 700 votes (red + black dots)	De-duplicated → clustered (semantic similarity)
Technologies	109	–	De-duplicated → clustered

Source: JRC own elaboration

Vote totals per clustered capability were summed across all scenario boards; the highest-vote clusters (e.g., “Training & Education” = 111 votes) were later used as a triangulation check.

Moreover, the *Framework of Core Capabilities for Disaster Resilience* was presented in draft form during Part III of the community workshop at the Disaster Resilience Days 2025 in Athens, where over 120 experts tested its structure through parallel breakout sessions. Four tables examined the consistency of the framework’s phases and functions, identifying elements to highlight, merge, or restructure, while two tables focused on novel technologies that could support or reshape the core capabilities. The framework was subsequently refined based on workshop feedback, expert input from all stages of the foresight process, and alignment with established DRM terminology.

Triangulation and convergence

The four data streams — preliminary survey, interviews, final survey, and community workshop — were triangulated to strengthen robustness and ensure that the final selection of priority capabilities and technologies reflects converging evidence from multiple expert elicitation methods. The triangulation followed three principles:

- **Cross-source convergence:** Signals that consistently ranked high across at least two independent data sources (e.g., survey scores & comments and workshop votes, or survey scores & comments and interview emphasis) were flagged as high-confidence priorities.
- **Iterative refinement:** The reduction from 111 to 57 capabilities and from 129 to 56 technologies between survey rounds was driven by respondents’ feedback, enriched by interview insights and refined through an internal harmonisation process. Each stage informed the next in a continuous foresight pathway.
- **Complementarity:** Interview findings and workshop deliberations surfaced contextual and systemic insights (e.g., governance fragmentation, training deficits, technology adoption barriers, civil-military coordination) that structured survey signals could not fully capture. These qualitative findings were used to interpret and enrich the quantitative prioritisation.

Table 12. Triangulation & convergence criteria

Principle	Operational rule
Cross-source convergence	A signal must rank high in ≥ 2 independent sources (e.g., survey mean ≥ 9.0 and workshop vote ≥ top-10% or interview emphasis).
Iterative refinement	Signals removed/merged only after they were flagged in at least one prior round and not reinstated by interview or workshop feedback.
Complementarity	Qualitative insights (e.g., governance gaps) were required to explain any quantitative outlier and to enrich the final “choice-ahead” narrative.

Source: JRC own elaboration

Selection criteria for priority signals

Based on the integrated analysis, a final set of 12 priority capabilities and 12 emerging technologies was selected for in-depth examination in Section 4. The selection was guided by the following criteria:

- **Quantitative threshold:** Signals with consistently high mean relevance scores (capabilities) or high combined impact–novelty scores (technologies) in the final survey. typically, capability elements with a mean relevance score for the 2040 horizon of 9.0 or above were retained for mapping to priority capability fiches and the highest 20% (above 63.0) of score distribution of the product of average impact * average novelty was selected for technology fiches.
- **Workshop confirmation:** Priority signals that received significant vote totals in the community workshop, with clustered capability themes attracting the highest aggregate votes (e.g., Training & Education: 111 votes across 30 related entries; Detection, Monitoring & Early Warning: 67 votes across 18 related entries).
- **Interview corroboration:** Themes and capability gaps emphasised by multiple interviewees across different institutional perspectives (e.g., citizen empowerment, CBRN-E detection, interoperability, cross-border standardisation).
- **Coverage across the disaster management cycle:** The selection ensures representation across all phases (before, during, after), reflecting the full-cycle perspective of the capability framework.
- **Emerging security landscape:** Megatrends, risk assessments, and projections that drive emerging security challenges.
- **Policy relevance and actionability:** Preference was given to signals with clear implications for EU policy and R&I programming in the 2040 horizon.

Table 13. Priority-signal selection thresholds

Priority type	Threshold applied
Capabilities	Mean relevance (2040) ≥ 9.0 or in the top 20 % of the distribution and confirmed by workshop votes / interview emphasis.
Technologies	Composite Impact $\times$ Novelty score in the top 20 % of all technologies and supported by workshop votes / interview comments.
Coverage	At least one priority signal per disaster-management phase (Foresight & Anticipation, Preparedness, Response, Recovery, Horizontal).
Policy relevance	Explicit EU-level policy or R&I implication identified in desk-research or expert comments.

Source: JRC own elaboration

Contextualization & presentation of signals

Following the selection of 12 priority capabilities and 12 emerging technologies through the convergence process described above, each signal was subject to analytical synthesis and presented in a structured fiche format (Figure 16 and Figure 17). The purpose of this step was to move beyond simple data extraction and contextualise each signal by making sense of the converging information from the four data streams (preliminary survey, interviews, final survey, community workshop), supplemented by additional desk research and in-house expertise. Given the inherently qualitative nature of foresight findings, the fiches were designed to present each priority capability as a coherent narrative.

Priority Capability fiches were structured around four components as described in Figure 16.

Figure 16. Structure of capability fiches

Priority Capability

Description: A concise definition of the priority capability and its scope.

Mapping the Priority Capability onto the Framework of Core Capabilities highlighting the phase(s) of each priority. within the disaster management cycle.

Why does it matter?

Picture

An assessment of the converging trends and factors — including evolving threats, hazards, vulnerabilities, and exposure patterns — that make the need for this capability increasingly critical towards 2040. This assessment sparked from the expert input from all four data streams and was substantiated through additional desk research to ground the foresight findings in the current evidence base.

Choices ahead: Identified through additional desk research bridging the foresight findings with actionable pathways for R&I investment and policymaking.

Technology enablers that can reinforce or reshape the capability.

Policy options at EU level

Source: JRC own elaboration.

Emerging Technology fiches followed a complementary structure (Figure 17):

Figure 17. Structure of technology fiches

Emerging Technology	
Picture	Description
	<i>Why / What Is New?</i> A characterisation of the technological innovation, its current maturity, and the specific advancement it represents relative to existing solutions, based on additional desk research.
	<i>Application Areas:</i> The disaster resilience contexts in which the technology can be deployed, informed by additional desk research.
	<i>Risks & Limitations:</i> An assessment of the potential adverse effects, unintended consequences, or inherent constraints of the technology, including new issues it may create or cause, based on additional desk research.

Source: JRC own elaboration.

This contextualisation step assisted in sense-making and presenting what is relevant for future resilience and why. Each fiche synthesises quantitative scores, qualitative expert judgements, and desk-research evidence into an integrated assessment that communicates both the urgency and the actionability of each priority signal.

Methodological innovation and AI integration

Artificial Intelligence (AI) was systematically embedded throughout the foresight process to enhance analytical depth, scalability, traceability, and consistency across stages of the study.

The GPT@JRC platform²⁵ provided large-language models, Retrieval-Augmented Generation (RAG) and controlled web-search capabilities. During the literature-review phase, RAG queries were run over the JRC publication repository — the complete JRC publication archive—while a parallel systematic scan covered EU-institutional policy documents, project deliverables, research outputs and open-source intelligence (OSINT). This hybrid architecture combined depth (evidence-grounded retrieval) with breadth (institutional and OSINT coverage), ensuring that emerging technologies and policy-relevant developments were captured while expert validation was maintained at each step.

In the horizon-scanning phase, large batches of documents were uploaded to GPT@JRC, which generated candidate signals together with the exact passages that justified them. Analysts then assessed each suggestion for relevance, novelty, technological maturity (focused on TRL 3–6) and alignment with the study’s taxonomy, refining wording, merging overlapping signals or discarding non-relevant proposals as required. Thus, AI acted as a signal-identification aid, whereas the final inclusion decision remained firmly in the hands of experts, expanding coverage and reducing the risk of missed signals without compromising methodological scrutiny.

²⁵ GPT@JRC is an in-house general-purpose generative AI service

To process the growing repository at scale, a prototype web application was developed, which exported signal collections as CSV files and invoked the GPT@JRC API record-by-record. The system enriched every entry with AI-generated metadata—technology domains, maturity indicators, semantic keywords and concise summaries—while also ingesting large bibliographic tables (e.g., from Scopus) for AI-assisted summarisation, metadata extraction and relevance filtering. This batch-mode workflow delivered traceable, consistent enrichment across thousands of records and transformed raw bibliographic outputs into analysis-ready datasets.

During harmonisation and clustering, conventional TF-IDF weighting and Ward’s hierarchical linkage were combined with LLM-driven semantic similarity detection. Tailored prompts identified duplicate or near-duplicate entries, suggested concise descriptions, proposed cluster groupings and candidate labels, and extracted key thematic phrases. All AI-produced outputs were systematically audited by analysts and subject-matter experts. Validation procedures included structured prompt reviews, sampling-based precision checks against manual coding, and qualitative consistency assessments to mitigate risks of hallucination, semantic drift, or hidden bias. Documentation of prompts and workflows was kept transparent throughout the process.

The integration of AI significantly improved scalability and signal coverage while reducing manual screening time and enhancing consistency across analytical steps. At the same time, methodological robustness was ensured through continuous human validation, transparent documentation of prompts and workflows, and explicit expert oversight at each decision point. AI thus functioned as an analytical accelerator and structuring tool, augmenting expert capacity while preserving human judgement as the cornerstone of interpretation and final decision-making.

Methodological limitations

Several methodological constraints should be acknowledged when interpreting the findings of this study.

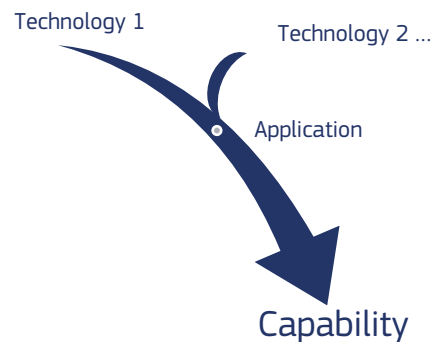
Sample sizes and expert selection. The preliminary survey (N=7), designed primarily as a filtering instrument to reduce the initial signal set, necessarily relied on a small expert panel; the scores from this round should be interpreted as indicative screening assessments rather than definitive rankings. The interview round (N=9) complemented this filtering with qualitative depth but equally reflects a limited number of expert perspectives. The broader panel of the final survey — circulated across CERIS, EU-CIP, DIREKTION, AHEAD networks and JRC — yielded 18 complete responses. While this improves robustness, the low response rate relative to the distribution pool means the results reflect a purposive expert sample with voluntary participation and may not capture the full range of views within the European disaster resilience community.

Workshop design and representation. The scenario-based community workshop, while generating rich deliberative data, inherently reflects the framing of the specific six pre-defined scenarios set in a 2035 world with 2025 capabilities, and the specific black zoo wildcards assigned to each scenario. Although the workshop was organised as a CERIS event open to the broader European expert community, the geographical location of the venue (Athens, Greece) resulted in an uneven geographical representation, with participants predominantly originating from Greece. This may have introduced a regional bias in the deliberative outcomes and voting patterns, particularly regarding the types of hazards and vulnerabilities emphasised during scenario exploration. The voting mechanism — red dots at one’s own table and black dots when visiting other scenarios (World Café method) — captures both internal and external prioritisation, though the rotating format means not all participants voted on all scenarios.

Iterative filtering and selection effects. As the preliminary survey served a filtering function, signals that scored below the retention threshold were not reassessed by the final survey respondents. This introduces a potential selection effect: relevant capabilities or technologies may have been excluded at an early stage due to the limited size of the preliminary panel. This risk is partially mitigated by the interview-based gap identification, which provided an independent opportunity to surface signals missed or undervalued in the preliminary round.

Parallel signal collection for capabilities and technologies. Capability and technology signals were identified largely in parallel rather than in a sequential capability-first logic. This was a deliberate design choice, intended to avoid constraining the technology search to known capability needs, thereby risking overlooking novel applications or emerging capability concepts. However, this parallel approach introduced a structural asymmetry. Many technology signals consisted of composite solutions combining several technologies for specific applications (e.g., AI-assisted drone-based human detection, or LiDAR and SLAM integration for GNSS-denied 3D mapping), which also challenged their categorisation into the six thematic clusters.

Figure 18. Technologies – capabilities connection



Source: JRC own elaboration

By contrast, capability signals were formulated at a higher level of abstraction, encompassing broader operational functions. The surveys preserved this parallel logic, exposing both signal types to the same expert panels — panels that included respondents with primarily technological backgrounds alongside others with operational or policy-oriented expertise. While this diversity of perspectives strengthened the overall assessment, it also introduced a potential misalignment: the prioritisation of technology signals, driven in part by their specificity and application novelty, does not necessarily correspond one-to-one with the independently prioritised capabilities. The bridging of technology and capability priorities was therefore addressed qualitatively, through the fiche contextualisation process and the explicit capability linkages presented in Section 4.1.2.

Annex 2. Literature repository catalogue

Last access to online resource on 27/03/2026.

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Annex 3. Final Survey

This Annex contains first the questions and explanatory text that were presented to the experts in the final survey (September 2025); then the signals that were presented to the experts as guiding information; and lastly the survey results, the ratings for each capability and technology averaged over the experts (N=18).

A3.1 Online survey as presented to the experts

Welcome!

You have been invited to answer this survey as part of the Project BRICO - TECH4DRS. TECH4DRS (TECHnology for Disaster Resilient Society) is a technology foresight project aiming at identifying key capabilities and technologies that should be prioritised by the European Union to be available or reinforced in 5 to 15 years (by 2030 and 2040 respectively), to support Disaster-Resilient Society (DRS) and enhance the Resilience of Critical Infrastructures (RCI). This survey is anonymous to ensure the confidentiality of your responses. Which option best describes your current **affiliation(s)**?

- Academia
- EU Institution
- International Organization (non EU)
- National Administration
- NGO
- Private Sector
- Other (specify)

Capabilities

Capability: The ability to perform the necessary tasks to deliver effect in order to achieve the desired result. (source: Frontex) e.g. in Response: prioritisation, triage, resource deployment, live monitoring, search & rescue, evacuation, cyber incident response. (source: JRC)

Our guiding question in this section is:

"How relevant is the process to enhance or develop capabilities listed below for the EU in disaster management in 2030 and then in 2040?"

The proposed rating for assessing this relevance is in a range through 0 for "no relevance" to 10 for "high relevance". Please find a brief description of the capabilities in the background documents on the **top right corner**.

Feel free not to assess a capability with which you do not feel sufficiently familiar.

Share with us your views on a capability in the **comment** box.

A. Foresight & Anticipation

Foresight & Anticipation is a continuous, proactive process focused on identifying and assessing existing and emerging threats, risks, and vulnerabilities. This involves establishing the legal and policy frameworks necessary to manage them before a disaster or disruptive event occurs. The goal

is to develop a comprehensive understanding of potential threats and build a strategic foundation for future actions, ultimately fostering a disaster-resilient society and resilient critical infrastructure.

	Relevance in 2030 [0-10]	Relevance in 2040 [0-10]	Comment
Systemic risk modelling & Critical infrastructure interdependency mapping			
Foresight for slow-onset risks (e.g. drought)			
EU comprehensive risk and threat assessment - integrate insights from multiple policy areas			
Evacuation and warning common lexicon			
Vulnerability modelling			
Technical interoperability standards			
Scenario identification and building			
Liability protection			

Do we **miss any important capability** in Foresight & Anticipation?

Please complement the suggested capabilities according to your own view and rate their relevance (for 2030 / 2040) in the box below.

B. Preparedness

Preparedness is the capacity of being ready to respond to and recover from the impacts of likely, imminent or current disasters and encompasses a proactive, all-hazards approach that includes activities and measures to avoid existing and new disaster risks (prevention) and the lessening or minimizing of the adverse impacts of a hazardous event (mitigation). This phase also includes appropriate and proportionate measures taken for the resilience of critical entities, thereby the ability to prevent, protect against, respond to, resist, mitigate, absorb, accommodate and recover from an event which has the potential to significantly disrupt, or that disrupts, the provision of an essential service, including when it affects the national systems that safeguard the rule of law.

	Relevance in 2030 [0-10]	Relevance in 2040 [0-10]	Comment
Training should be regularly updated and effectively communicated			
Cybersecurity measures			
Resilient design			
Standards and guidelines to evacuate Access and Functional Needs (AFN) population			
Full-scale real exercises to validate the plans			
Emergency protocols			
Stress-testing			
Accurate early warning systems			
Multi-channel warning system			
Bridging operational needs with innovative solutions			
Include preparedness in school education curricula and training of educational staff			
Public communication of risks and hazards			
Harmonisation of guidelines and protocols			

Do we **miss any important capability** in Preparedness?

Please complement the suggested capabilities according to your own view and rate their relevance (for 2030 / 2040) in the box below.

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C. Response

Response includes actions taken directly before, during or immediately after a disaster in order to save lives, reduce health impacts, ensure public safety and meet the basic subsistence needs of the people affected.

	Relevance in 2030 [0-10]	Relevance in 2040 [0-10]	Comment
Interoperable communications			
Real-time tracking of responders			
Connectivity for first responders			
Continuity of essential services			
Protective personal equipment			
Rapid on-scene detection, monitoring and analysis of threats, hazards, contaminants			
Tracking fire perimeter and characteristics			
Resource inventory for deployment			
Efficient equipment and tools for responders' mission			
Fire management and suppression			
Warning Apps with offline evacuation routes			
Monitor responders' physiological situation (wearables)			
Incorporate information from multiple sources into incident command operations			
Cyber incident response			
Decentralized intelligence in disaster zones with low latency			
On-scene remote operations			
Forensic procedures for disaster investigation			

Do we **miss any important capability** in Response?

Please complement the suggested capabilities according to your own view and rate their relevance (for 2030 / 2040) in the box below.

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D. Recovery

Recovery is the restoring or improving of livelihoods and health, as well as economic, physical, social, cultural and environmental assets, systems and activities, of a disaster-affected community or society, aligning with the principles of sustainable development and “build back better”, to avoid or reduce future disaster risk.

	Relevance in 2030 [0-10]	Relevance in 2040 [0-10]	Comment
Restoration of the environment, livestock, agriculture			
Post-event adaptive governance			
Temporal housing and shelters			

Hazardous waste management			
Decontamination of areas from hazardous materials (e.g., CBRN)			
Post-event evaluation, learning & dissemination			
Restoration of digital services			

Do we **miss any important capability** in Recovery?

Please complement the suggested capabilities according to your own view and rate their relevance (for 2030 / 2040) in the box below.

ABCD. Horizontal

Horizontal capabilities (ABCD) extend across several of the four abovementioned phases (A, B, C, D) to ensure that systems, organisations, and communities are prepared to foresee, anticipate, prevent, mitigate, respond to, and recover from disasters. These capabilities also focus on protecting infrastructure and ensuring its resilience, supporting a comprehensive and integrated approach to disaster management.

	Relevance in 2030 [0-10]	Relevance in 2040 [0-10]	Comment
Reliable power supply			
Redundancy and backup systems for essential services continuity			
Public-Private partnerships			
Logistics and supply chain management			
Civil-Military coordination			
Minimize human factor that delays warning			
Cross-border cooperation			
Common operating picture across sectors and jurisdictions (e.g. set up a crisis dashboard)			
Data sharing			
Financial support mechanisms			
Citizen empowerment			
Overcome language barriers among responders			

Do we **miss any important item** in Horizontal capabilities?

Please complement the suggested capabilities according to your own view and rate their relevance (for 2030 / 2040) in the box below.

Technologies

Please assess the **impact and the novelty for the EU in 2030** of each of the following technologies in disaster resilience and protection of critical infrastructure (0 to 10, 0 being no impact or no novelty and 10 high impact or high novelty).

The impact of a technology relates to its ability to mitigate the impact of a disaster and to maintain the vital functions of society.

The novelty of a technology lies in the fact that it is still unknown on the market or that its application is unknown in disaster management.

Feel free not to assess a technology with which you do not feel sufficiently familiar.

Share with us your views on any technology in the **comment** box.

Please find a brief description of these items in the background documents on the **top right corner**

Biotechnologies

	Impact (0-10)	Novelty (0-10)	Comments
Bioengineered yeast for food production			
Brain network communication			
CRISPR and AI to accelerate vaccines development			
Electrostatic precipitators and on-chip LAMP for ambient air pathogen monitoring			
Implantable brain-machine interfaces			
Protein Production from Captured CO ₂ - Next Generation of Space Food			

Robotics and Autonomous Vehicles

	Impact (0-10)	Novelty (0-10)	Comments
Drone AI-Assisted Human detection in rescue operations			
Human-support robots with medical / supply payloads			
Intelligent exoskeletons for first responders			
Radiation-hardened electronics for drone-based CBRNe missions			
Real-time path planning algorithm for a Unmanned Aircraft Systems (UAS) during wildfires			
Thermal and hyperspectral sensors for Unmanned Aerial Vehicles (UAVs) for rapid assessment and environmental monitoring			
Unmanned Aerial Vehicle (UAV) Swarm-based communication			
Unmanned Aerial Vehicles (UAVs) for surveillance and monitoring of infectious diseases			
Unmanned Underwater Vehicles (UUV) for data collection			

IoT, sensing and virtualisation

	Impact (0-10)	Novelty (0-10)	Comments
Advanced sensors combined with satellite technology, IoT, UAVs to enhance data collection and analysis for real-time monitoring and early warning			
Digital Twins for power grid optimization			
Distributed Acoustic Sensing (DAS) using Submarine Cables			
Hyper-Realistic City-Scale Digital Twin for Multi-Hazard Urban Resilience			
High-precision geohazard detection using satellite radar imagery			
Inertia sensors using electro-magnetic signals to detect dangerous substances			
Integrated satellite remote sensing and blockchain for parametric insurance			

Integration of LiDAR & SLAM for 3D mapping in GNSS-denied environment			
Interconnected optical atomic clocks to detect seismic activity			
Multi-Sensory Extended Reality (XR) Systems			
MXene-based 2D nanomaterials for advanced sensing and decontamination			
Triboelectric nanogenerator (TENG) in smart masks against airborne contaminants			
Wi-Fi sensing to detect movements			

Nanotech and Innovative Manufacturing

	Impact (0-10)	Novelty (0-10)	Comments
Additive-manufacturing of mission-tailored CBRN components			
Advanced Resilient Pavement Technologies			
Blockchain for sensitive raw material tracking			
Graphene sieve technology for water purification			
Long-duration Vanadium Redox Flow Batteries (VRFBs)			
Metafabric for personal cooling			
Paper-Thin Solar Cells from Electronic Inks Printed on Composite Fabric			
Reflective and dynamic thermal coatings			
Self-healing materials			
Stratospheric Aerosol Injection (SAI) for extreme weather relief			

Artificial Intelligence

	Impact (0-10)	Novelty (0-10)	Comments
AI technologies for pathogen detection, tracking, forecasting spread and mutations			
AI-based supply chain risk mapping and mitigation			
AI-Enhanced demand-responsive data centers to stabilise energy grids			
AI-enhanced geospatial planning for critical infrastructure prioritisation			
AI-powered tools to detect manipulated digital media			
AI-driven simulation of disaster scenarios to analyse social vulnerability			
Federated machine learning for fire management			
Machine Learning for pattern-based cyber attack prediction			
Multiphysics Simulation and Computational Fluid Dynamics in airborne hazard simulation			
On-orbit edge AI processing to perform hazard detection directly in space			
Real-time Disease Surveillance System			

Communication Technologies

	Impact (0-10)	Novelty (0-10)	Comments
Blockchain for disaster victim identification			
Homomorphic encryption for sensitive information analysis			
Integrated Photonics for high-speed & reliable communications			

Joint Communications and Sensing (JCAS) to improve environmental awareness			
Kyber lattice-based Post-quantum encryption for emergency communications			
Long-range wide area networks (LoRaWAN)-based Internet of Things (IoT) for flood monitoring			
Next-generation resilient optical communication networks			

Do we **miss any key technology**?

Please complement with key technologies according to your own view and rate their impact (0-10) / novelty (0-10) in the box below.

Which **interconnections** do you see between the provided technologies (or additional technologies that would have a high impact in 5 to 15 years)?

In your opinion, which **risks and opportunities** stem from these key technologies (and from the additional technologies you submitted)?

A3.2. The signals used in the Final Survey and their sources

Title	Category of signal	Source / weblink
Accurate early warning systems	Capability	https://doi.org/10.1016/j.artmed.2025.103076 , https://doi.org/10.1016/j.ijid.2024.107579 , https://doi.org/10.1016/j.pt.2022.12.010 , https://www.scopus.com/inward/record.uri?eid=2-s2.0-105001362428&part-nerID=40&md5=02a8ce0dc51ed6fee0783e3bbde0f9dc , https://doi.org/10.1016/S2214-109X(23)00129-8 , https://doi.org/10.1016/j.soh.2023.100061
Bridging operational needs with innovative solutions	Capability	Survey comments
Citizen empowerment	Capability	Survey comments
Civil-Military coordination	Capability	https://civil-protection-knowledge-network.europa.eu/media/joint-communication-european-parliament-european-council-council-european-economic-and-social
Common operating picture across sectors and jurisdictions (e.g. set up a crisis dashboard)	Capability	https://www.dhs.gov/sites/default/files/publications/wui_fire_report_of_findings_july_24_2019v2_508.pdf
Connectivity for first responders	Capability	https://www.dhs.gov/sites/default/files/publications/wui_fire_report_of_findings_july_24_2019v2_508.pdf
Continuity of essential services	Capability	https://www.fema.gov/sites/default/files/documents/fema_gpd_national-preparedness-goal-2nd-edition_051525.pdf

Title	Category of signal	Source / weblink
Cross-border cooperation	Capability	Survey comments
Cyber incident response	Capability	https://www.enisa.europa.eu/publications/enisa-threat-landscape-2024#:~:text=Seven%20prime%20cybersecurity%20threats%20were%20identified%20in%202024%2C,several%20thousand%20publicly%20reported%20cybersecurity%20incidents%20and%20events
Cybersecurity measures	Capability	https://op.europa.eu/en/publication-detail/-/publication/84bfc6a-01f2-11ef-a251-01aa75ed71a1/
Data sharing	Capability	Survey comments
Decentralized intelligence in disaster zones with low latency	Capability	https://ieeexplore.ieee.org/abstract/document/10500411
Decontamination of areas from hazardous materials (e.g., CBRN)	Capability	https://www.resilienceadvisors.eu/docs/RTCPolicyBrief_EN_Final-Draft.pdf
Efficient equipment and tools for responders' mission	Capability	Survey comments
Emergency protocols	Capability	https://data.europa.eu/doi/10.2760/666413
EU comprehensive risk and threat assessment - integrate insights from multiple policy areas	Capability	https://civil-protection-knowledge-network.europa.eu/media/joint-communication-european-parliament-european-council-council-european-economic-and-social
Evacuation and warning common lexicon	Capability	https://www.dhs.gov/sites/default/files/publications/wui_fire_report_of_findings_july_24_2019v2_508.pdf
Financial support mechanisms	Capability	https://publications.jrc.ec.europa.eu/repository/handle/JRC141673
Fire management and suppression	Capability	https://www.fema.gov/sites/default/files/documents/fema_gpd_national-preparedness-goal-2nd-edition_051525.pdf
Forensic procedures for disaster investigation	Capability	Survey comments
Foresight for slow-onset risks (e.g. drought)	Capability	https://op.europa.eu/en/publication-detail/-/publication/3bee9b69-18cd-11ef-a251-01aa75ed71a1/language-en
Full-scale real exercises to validate the plans	Capability	https://data.europa.eu/doi/10.2837/06076
Harmonisation of guidelines and protocols	Capability	Survey comments
Hazardous waste management	Capability	https://publications.jrc.ec.europa.eu/repository/handle/JRC141673
Include preparedness in school education curricula and training of educational staff	Capability	https://civil-protection-knowledge-network.europa.eu/media/joint-communication-european-parliament-european-council-council-european-economic-and-social
Incorporate information from multiple sources into incident command operations	Capability	https://data.europa.eu/doi/10.2837/06076
Interoperable communications	Capability	https://data.europa.eu/doi/10.2837/06076
Liability protection	Capability	https://data.europa.eu/doi/10.2837/06076
Logistics and supply chain management	Capability	https://www.fema.gov/sites/default/files/documents/fema_gpd_national-preparedness-goal-2nd-edition_051525.pdf
Minimize human factor that delays warning	Capability	https://www.dhs.gov/sites/default/files/publications/wui_fire_report_of_findings_july_24_2019v2_508.pdf

Title	Category of signal	Source / weblink
Monitor responders' physiological situation (wearables)	Capability	https://data.europa.eu/doi/10.2837/06076
Multi-channel warning system	Capability	https://www.dhs.gov/sites/default/files/publications/wui_fire_report_of_findings_july_24_2019v2_508.pdf
On-scene remote operations	Capability	https://data.europa.eu/doi/10.2837/06076
Overcome language barriers among responders	Capability	Survey comments
Post-event adaptive governance	Capability	https://data.europa.eu/doi/10.2863/889868 , https://op.europa.eu/en/publication-detail/-/publication/eefc7a65-104e-11ec-9151-01aa75ed71a1/language-en
Post-event evaluation, learning & dissemination	Capability	https://op.europa.eu/en/publication-detail/-/publication/eefc7a65-104e-11ec-9151-01aa75ed71a1/language-en
Protective personal equipment	Capability	https://data.europa.eu/doi/10.2837/06076
Public communication of risks and hazards	Capability	https://doi.org/10.1016/j.ijdr.2025.105296
Public-Private partnerships	Capability	https://www.dhs.gov/sites/default/files/publications/wui_fire_report_of_findings_july_24_2019v2_508.pdf
Rapid on-scene detection, monitoring and analysis of threats, hazards, contaminants	Capability	https://data.europa.eu/doi/10.2837/06076
Real-time tracking of responders	Capability	https://data.europa.eu/doi/10.2837/06076
Redundancy and backup systems for essential services continuity	Capability	https://publications.jrc.ec.europa.eu/repository/handle/JRC141673
Reliable power supply	Capability	https://www.dhs.gov/sites/default/files/publications/wui_fire_report_of_findings_july_24_2019v2_508.pdf
Resilient design	Capability	Futurium
Resource inventory for deployment	Capability	https://www.dhs.gov/sites/default/files/publications/wui_fire_report_of_findings_july_24_2019v2_508.pdf
Restoration of digital services	Capability	https://www.enisa.europa.eu/publications/enisa-threat-landscape-2024#:~:text=Seven%20prime%20cybersecurity%20threats%20were%20identified%20in%202024%2C,several%20thousand%20publicly%20reported%20cybersecurity%20incidents%20and%20events
Restoration of the environment, livestock, agriculture	Capability	https://publications.jrc.ec.europa.eu/repository/handle/JRC141673
Scenario identification and building	Capability	https://data.europa.eu/doi/10.2760/666413
Standards and guidelines to evacuate Access and Functional Needs (AFN) population	Capability	https://www.dhs.gov/sites/default/files/publications/wui_fire_report_of_findings_july_24_2019v2_508.pdf
Stress-testing	Capability	https://publications.jrc.ec.europa.eu/repository/bitstream/JRC134544/JRC134544_01.pdf
Systemic risk modelling & Critical infrastructure interdependency mapping	Capability	https://data.europa.eu/doi/10.2760/414289 , https://publica.fraunhofer.de/handle/publica/482962
Technical interoperability standards	Capability	https://www.frontex.europa.eu/assets/EUresearchprojects/News/2023/Privacy_enhancement_Report_1.pdf

Title	Category of signal	Source / weblink
Temporal housing and shelters	Capability	https://publications.jrc.ec.europa.eu/repository/handle/JRC141673
Tracking fire perimeter and characteristics	Capability	https://www.dhs.gov/sites/default/files/publications/wui_fire_report_of_findings_july_24_2019v2_508.pdf
Training should be regularly updated and effectively communicated	Capability	https://www.dhs.gov/sites/default/files/publications/wui_fire_report_of_findings_july_24_2019v2_508.pdf
Vulnerability modelling	Capability	https://doi.org/10.14195/978-989-26-2687-1
Warning Apps with offline evacuation routes	Capability	https://data.europa.eu/doi/10.2760/398065
Additive-manufacturing of mission-tailored CBRN components	Technology	https://civil-protection-knowledge-network.europa.eu/media/nato-europol-cooperation-countering-cbrn-terrorist-threat-europe
Advanced Resilient Pavement Technologies	Technology	https://www.cdri.world/upload/pages/1816785880800279_202411261153transport_infrastructure_reimagined.pdf
Advanced sensors combined with satellite technology, IoT, UAVs to enhance data collection and analysis for real-time monitoring and early warning	Technology	https://www.undrr.org/media/107230/download?startDownload=20250624
AI technologies for pathogen detection, tracking, forecasting spread and mutations	Technology	https://numalis.com/ai-fight-against-infectious-diseases-outbreak-prediction/ https://fpanalytics.foreignpolicy.com/wp-content/uploads/sites/5/2024/04/FP-Analytics-CEPI-synthesis-report.pdf
AI-based supply chain risk mapping and mitigation	Technology	https://www.sqs.com/en-ar/-/media/sqscorp/documents/corporate/brochures/sqs-kn-bci-supply-chain-resilience-report-2023-sponsored-by-sqs-en.cdn.en-AR.pdf
AI-driven simulation of disaster scenarios to analyse social vulnerability	Technology	https://www.sciencedirect.com/science/article/pii/S2212420925001694
AI-Enhanced demand-responsive data centers to stabilise energy grids	Technology	https://www.oxfordenergy.org/wpcms/wp-content/uploads/2025/05/OEF-145.pdf
AI-enhanced geospatial planning for critical infrastructure prioritisation	Technology	https://www.seforall.org/system/files/2024-02/Report_SOTM_2024.pdf
AI-powered tools to detect manipulated digital media	Technology	https://atelier.net/strativerse/?pg=entity_n68jEYvNoob-vduoSL
Bioengineered yeast for food production	Technology	https://go2.futuresplatform.com/
Blockchain for disaster victim identification	Technology	https://doi.org/10.1016/C2022-0-02384-9
Blockchain for sensitive raw material tracking	Technology	https://publications.jrc.ec.europa.eu/repository/handle/JRC139674
Brain network communication	Technology	https://atelier.net/strativerse/?pg=entity_zWWppuo-qgt2Tb62Ad
CRISPR and AI to accelerate vaccines development	Technology	https://doi.org/10.1016/j.ymeth.2025.04.01 , https://doi.org/10.1016/j.trac.2025.118174
Digital Twins for power grid optimization	Technology	https://www.mdpi.com/1996-1073/18/9/2149
Distributed Acoustic Sensing (DAS) using Submarine Cables	Technology	https://zenodo.org/records/10561009

Title	Category of signal	Source / weblink
Drone AI-Assisted Human detection in rescue operations	Technology	https://doi.org/10.1134/S1054661824010152
Electrostatic precipitators and on-chip LAMP for ambient air pathogen monitoring	Technology	https://doi.org/10.1016/j.snb.2024.135767
Federated machine learning for fire management	Technology	https://doi.org/10.1016/j.jag.2023.103531
Graphene sieve technology for water purification	Technology	https://go2.futuresplatform.com/
High-precision geohazard detection using satellite radar imagery	Technology	TIM
Homomorphic encryption for sensitive information analysis	Technology	https://www.frontex.europa.eu/assets/EUresearchprojects/2023/Booklet.pdf
Human-support robots with medical / supply payloads	Technology	https://arxiv.org/abs/2502.09379
Hyper-Realistic City-Scale Digital Twin for Multi-Hazard Urban Resilience	Technology	https://publications.jrc.ec.europa.eu/repository/handle/JRC140959
Implantable brain-machine interfaces	Technology	https://atelier.net/strativerse/?pg=entity_BpDsJAK-tKXoWsv9JW
Inertia sensors using electromagnetic signals to detect dangerous substances	Technology	http://dx.doi.org/10.37394/23202.2022.21.15
Integrated Photonics for high-speed & reliable communications	Technology	https://op.europa.eu/en/publication-detail/-/publication/84bfc6a-01f2-11ef-a251-01aa75ed71a1/
Integrated satellite remote sensing and blockchain for parametric insurance	Technology	TIM
Integration of LiDAR & SLAM for 3D mapping in GNSS-denied environment	Technology	https://publications.jrc.ec.europa.eu/repository/handle/JRC140959
Intelligent exoskeletons for first responders	Technology	https://www.resilienceadvisors.eu/docs/RTCPolicyBrief_EN_Final-Draft.pdf
Interconnected optical atomic clocks to detect seismic activity	Technology	https://zenodo.org/records/10561009
Joint Communications and Sensing (JCAS) to improve environmental awareness	Technology	https://www.nextgalliance.org/white_papers/roadmap-to-6g
Kyber Lattice-Based Post-Quantum Encryption to secure emergency communications	Technology	https://publications.jrc.ec.europa.eu/repository/handle/JRC140979
Long-duration Vanadium Redox Flow Batteries (VRFBs)	Technology	https://triviumchina.com/research/gaming-out-chinas-next-export-controls-on-critical-minerals/
Long-range wide area networks (LoRaWAN)-based Internet of Things (IoT) for flood monitoring	Technology	https://doi.org/10.1016/j.iotcps.2023.04.005
Machine Learning for pattern-based cyber attack prediction	Technology	https://cordis.europa.eu/project/id/101021274/results
Metafabric for personal cooling	Technology	https://publications.jrc.ec.europa.eu/repository/handle/JRC140959
Multiphysics Simulation and Computational Fluid Dynamics in airborne hazard simulation	Technology	https://civil-protection-knowledge-network.europa.eu/media/enhancing-radiation-detection-drones-through-numerical-fluid-dynamics-simulations
Multi-Sensory Extended Reality (XR) Systems	Technology	https://www.nextgalliance.org/white_papers/roadmap-to-6g

Title	Category of signal	Source / weblink
MXene-based 2D nanomaterials for advanced sensing and decontamination	Technology	https://pmc.ncbi.nlm.nih.gov/articles/PMC9182201/
Next-generation resilient optical communication networks	Technology	https://www-file.huawei.com/-/media/corp2020/pdf/qiv/industry-reports/digitalization-trends-in-the-electric-power-industry-en.pdf
On-orbit edge AI processing to perform hazard detection directly in space	Technology	https://publications.jrc.ec.europa.eu/repository/handle/JRC140962
Paper-thin solar cells from electronic inks printed on composite fabric	Technology	Futurium
Protein Production from Captured CO ₂ - Next Generation of Space Food	Technology	https://go2.futuresplatform.com/
Radiation-hardened electronics for drone-based CBRNe missions	Technology	https://civil-protection-knowledge-network.europa.eu/media/enhancing-radiation-detection-drones-through-numerical-fluid-dynamics-simulations
Real-time Disease Surveillance System	Technology	https://civil-protection-knowledge-network.europa.eu/media/joint-chemical-biological-radiological-and-nuclear-defence-centre-excellence-2025
Real-time path planning algorithm for Unmanned Aircraft Systems (UAS) during wildfires	Technology	https://doi.org/10.1007/s10489-024-05579-8
Reflective and dynamic thermal coatings	Technology	https://www.undrr.org/publication/urban-heat-risk-management-resource-package
Self-healing materials	Technology	Futurium
Stratospheric Aerosol Injection (SAI) for extreme weather relief	Technology	https://go2.futuresplatform.com/
Thermal and hyperspectral sensors for Unmanned Aerial Vehicles (UAVs) for rapid assessment and environmental monitoring	Technology	TIM
Triboelectric nanogenerator (TENG) in smart masks against airborne contaminants	Technology	https://www.sciencedirect.com/science/article/pii/S221128552300472X
Unmanned Aerial Vehicle (UAV) Swarm-based communication	Technology	TIM
Unmanned Aerial Vehicles (UAVs) for surveillance and monitoring of infectious diseases	Technology	https://doi.org/10.1186/s12942-024-00371-w
Unmanned Underwater Vehicles (UUV) for data collection	Technology	https://www.itu.int/en/ITU-D/Emergency-Telecommunications/Documents/2019/GET_2019/Disruptive-Technologies.pdf
Wi-Fi sensing to detect movements	Technology	https://www.technologyreview.com/2024/02/27/1088154/wifi-sensing-tracking-movements/

Source: JRC signal repository

A3.3. Survey results

Table 14. Survey results – Capabilities

Capabilities	Average Relevance in 2030	Average Relevance in 2040
A. Anticipation & Foresight	8.39	8.48
Systemic risk modelling & Critical infrastructure interdependency mapping	9.13	9.19
Foresight for slow-onset risks (e.g. drought)	8.00	8.56
EU comprehensive risk and threat assessment - integrate insights from multiple policy areas	8.94	9.00
Evacuation and warning common lexicon	7.94	7.75
Vulnerability modelling	8.94	8.94
Technical interoperability standards	8.56	8.38
Scenario identification and building	8.13	8.06
Liability protection	7.53	7.93
B. Preparedness	8.91	8.92
Training should be regularly updated and effectively communicated	9.00	9.00
Cybersecurity measures	9.47	9.53
Resilient design	9.19	9.19
Standards and guidelines to evacuate Access and Functional Needs (AFN) population	8.47	8.27
Full-scale real exercises to validate the plans	8.75	8.56
Emergency protocols	8.81	8.94
Stress-testing	8.93	9.00
Accurate early warning systems	9.44	9.50
Multi-channel warning system	8.93	8.93
Bridging operational needs with innovative solutions	9.25	9.25
Include preparedness in school education curricula and training of educational staff	8.20	8.40
Public communication of risks and hazards	8.60	8.87
Harmonisation of guidelines and protocols	8.79	8.57
C. Response	8.88	8.98
Interoperable communications	9.25	9.19
Real-time tracking of responders	8.56	8.69
Connectivity for first responders	9.25	9.44
Continuity of essential services	9.50	9.69
Protective personal equipment	9.00	9.06
Rapid on-scene detection, monitoring and analysis of threats, hazards, contaminants	9.19	9.19
Tracking fire perimeter and characteristics	8.75	8.81
Resource inventory for deployment	8.94	9.00
Efficient equipment and tools for responders' mission	9.38	9.44
Fire management and suppression	8.73	8.80
Warning Apps with offline evacuation routes	8.80	8.93
Monitor responders' physiological situation (wearables)	7.69	7.88

Capabilities	Average Relevance in 2030	Average Relevance in 2040
Incorporate information from multiple sources into incident command operations	9.00	9.00
Cyber incident response	9.33	9.40
Decentralized intelligence in disaster zones with low latency	8.31	8.50
On-scene remote operations	8.94	9.13
Forensic procedures for disaster investigation	8.29	8.50
D. Recovery	8.90	9.01
Restoration of the environment, livestock, agriculture	9.07	9.20
Post-event adaptive governance	8.87	8.87
Temporal housing and shelters	8.80	8.93
Hazardous waste management	9.00	9.07
Decontamination of areas from hazardous materials (e.g., CBRN)	9.07	9.20
Post-event evaluation, learning & dissemination	8.88	8.94
Restoration of digital services	8.63	8.88
ABCD. Horizontal	8.90	8.93
Reliable power supply	9.44	9.44
Redundancy and backup systems for essential services continuity	9.44	9.31
Public-Private partnerships	8.38	8.44
Logistics and supply chain management	8.88	9.00
Civil-Military coordination	8.69	8.75
Minimize human factor that delays warning	8.77	8.92
Cross-border cooperation	9.27	9.33
Common operating picture across sectors and jurisdictions (e.g. set up a crisis dashboard)	9.00	9.00
Data sharing	9.63	9.63
Financial support mechanisms	8.40	8.47
Citizen empowerment	9.00	9.07
Overcome language barriers among responders	7.87	7.80

Source: JRC own elaboration on survey results

Table 15. Survey results – Technologies. Impact and novelty are scored for a 2030 horizon.

Technologies	Average of Impact	Average of Novelty
Robotics and Autonomous Vehicles	8.28	7.60
Drone AI-Assisted Human detection in rescue operations	9.13	7.73
Human-support robots with medical / supply payloads	8.57	8.00
Unmanned Aerial Vehicle (UAV) Swarm-based communication	8.33	7.93
Unmanned Aerial Vehicles (UAVs) for surveillance and monitoring of infectious diseases	8.00	8.15
Thermal and hyperspectral sensors for Unmanned Aerial Vehicles (UAVs) for rapid assessment and environmental monitoring	8.43	7.50

Real-time path planning algorithm for a Unmanned Aircraft Systems (UAS) during wildfires	8.14	7.43
Intelligent exoskeletons for first responders	7.80	7.67
Unmanned Underwater Vehicles (UUV) for data collection	8.36	7.00
Radiation-hardened electronics for drone-based CBRNe missions	7.77	7.00
IoT, sensing and virtualisation	7.79	7.77
Advanced sensors combined with satellite technology, IoT, UAVs to enhance data collection and analysis for real-time monitoring and early warning	9.00	8.25
Integration of LiDAR & SLAM for 3D mapping in GNSS-denied environment	8.50	8.29
Hyper-Realistic City-Scale Digital Twin for Multi-Hazard Urban Resilience	8.07	8.50
High-precision geohazard detection using satellite radar imagery	8.40	7.87
Interconnected optical atomic clocks to detect seismic activity	8.08	8.00
Digital Twins for power grid optimization	8.36	7.64
MXene-based 2D nanomaterials for advanced sensing and decontamination	7.67	7.83
Inertia sensors using electro-magnetic signals to detect dangerous substances	7.57	7.86
Multi-Sensory Extended Reality (XR) Systems	7.54	7.54
Integrated satellite remote sensing and blockchain for parametric insurance	7.46	7.62
Distributed Acoustic Sensing (DAS) using Submarine Cables	7.42	7.50
Wi-Fi sensing to detect movements	6.55	7.18
Triboelectric nanogenerator (TENG) in smart masks against airborne contaminants	6.67	6.89
Artificial Intelligence	7.68	7.21
AI technologies for pathogen detection, tracking, forecasting spread and mutations	7.83	7.75
AI-enhanced geospatial planning for critical infrastructure prioritisation	7.91	7.64
Federated machine learning for fire management	7.80	7.70
Real-time Disease Surveillance System	8.42	6.92
On-orbit edge AI processing to perform hazard detection directly in space	7.33	7.89
AI-driven simulation of disaster scenarios to analyse social vulnerability	7.85	7.31
Machine Learning for pattern-based cyber-attack prediction	7.80	7.10
AI-Enhanced demand-responsive data centres to stabilise energy grids	7.77	6.77
AI-based supply chain risk mapping and mitigation	7.62	6.85
AI-powered tools to detect manipulated digital media	7.45	6.64
Multiphysics Simulation and Computational Fluid Dynamics in airborne hazard simulation	6.75	6.75
Communication Technologies	7.21	6.89
Blockchain for disaster victim identification	7.50	7.67
Next-generation resilient optical communication networks	8.00	6.54
Joint Communications and Sensing (JCAS) to improve environmental awareness	7.18	7.18
Integrated Photonics for high-speed & reliable communications	7.30	6.56
Long-range wide area networks (LoRaWAN)-based Internet of Things (IoT) for flood monitoring	7.17	6.58
Homomorphic encryption for sensitive information analysis	6.60	7.00
Kyber lattice-based Post-quantum encryption for emergency communications	6.70	6.70

Nanotech and Innovative Manufacturing	6.70	6.80
Graphene sieve technology for water purification	7.38	7.14
Metafabric for personal cooling	7.00	7.29
Self-healing materials	7.13	7.13
Additive-manufacturing of mission-tailored CBRN components	6.57	7.14
Long-duration Vanadium Redox Flow Batteries (VRFBs)	7.13	6.29
Reflective and dynamic thermal coatings	6.67	6.67
Blockchain for sensitive raw material tracking	6.57	6.71
Advanced Resilient Pavement Technologies	6.38	6.75
Stratospheric Aerosol Injection (SAI) for extreme weather relief	6.14	6.71
Paper-Thin Solar Cells from Electronic Inks Printed on Composite Fabric	6.00	6.17
Biotechnologies	6.12	7.13
CRISPR and AI to accelerate vaccines development	7.42	7.33
Electrostatic precipitators and on-chip LAMP for ambient air pathogen monitoring	7.18	7.55
Protein Production from Captured CO ₂ - Next Generation of Space Food	5.43	7.36
Bioengineered yeast for food production	5.77	6.85
Brain network communication	5.64	6.86
Implantable brain-machine interfaces	5.29	6.85

Source: JRC own elaboration on survey results

Annex 4. Questionnaire of Expert interviews

1. Future Challenges:

- What do you perceive as the most significant challenges EU will face in 5 to 15 years in: (a) infrastructure resilience and (b) disaster management in the EU?
 - a) Are there specific sectors or types of infrastructure that you believe are particularly vulnerable? Why?
 - b) Are there any specific kinds of **disasters** that you believe that the EU should better prepare for? Why?

2. Capability Gaps:

- In your opinion, what are the most critical capability gaps that need to be addressed to enhance (a) infrastructure resilience and (b) disaster management in the EU? (Helping question: Please consider the whole disaster management cycle, from anticipation and preparedness, to training and public engagement, to detection and early warning, response and rescue, recovery and learning)
- Prioritisation: Of the capabilities identified, which do you believe should be prioritized for development and implementation in the EU?

3. Emerging Technologies and Solutions:

- What emerging technologies or solutions do you believe hold the most promise for improving (a) infrastructure resilience and (b) disaster management? Can you provide examples?
- Prioritisation: Of the technologies identified, which do you believe should be prioritized for development and implementation in the EU?
- What key risks emerging technologies will pose in the context of disasters and critical infrastructures?

4. Collaboration and Integration:

- Which are the current greatest needs for cross-sector collaboration in enhancing (a) infrastructure resilience and (b) disaster management, and what forms should this collaboration take?
- What are currently the greatest obstacles to cross-border collaboration for effective disaster management?

Annex 5. Materials used in the Community Workshop

Choreography (essentials, guiding questions)

Overview of the choreography

Upon arrival at the welcome desk participants choose their scenario (Scenario card).

Morning: reflecting on scenarios (future world set in 2035 with capabilities from 2025)

10.45-11.00 [Plenary] Introduction

Objective: Set the scene in Foresight, the fictional context, the flow of the day.

The Master of Ceremonies introduces the JRC Host, who introduces the JRC/Unit and the team of facilitators.

JRC facilitators introduce Foresight, the DRS project, the logic of the day, the World in 2035.

The Master of Ceremonies invites the participants to join a table corresponding to their scenario.

Supporting material: Slide show JRC_<event>.pptx (covering all workshop from Intro until conclusion).

11.00-12.30 [Groups] Part I: Exploring scenarios in DRS in 2035

Objective: Explore and understand change by identifying consequences of the *event* in the future world (2035+), if we do not take action to reduce current vulnerabilities and improve present capabilities.

Foresight tool: Scenario Exploration, simplified timeline before/during/after, black zoo. Back-casting.

Icebreaker question: “If in this scenario you had the possibility to keep with you one only object, what would you choose?”

The facilitator keeps in their hand the scenario card and introduces himself with name, affiliation and object. Tour de table.

The systematic exploration of scenarios occurs in a future “World in 2035”, where 6 scenarios with different events are proposed to the groups (2 groups for each scenario).

1st Guiding question: Read carefully the scenario. What would the immediate consequences be during the initial response phase? (focus on impact – e.g. destruction of property, casualties, environmental pollution...)

2nd Guiding question: Considering the immediate consequences already identified, what would be the cascading consequences after the event (medium/long-term, e.g. up to 2 years’ time)?

Black prompt: Disruptor for extra reflection: A disrupting element materialises in the scenario. (The facilitator reads the wildcard they selected according to the scenario and the discussion so far.)

3rd Guiding question Which vulnerabilities are behind the consequences identified before? Link them to the consequences.

4th Guiding question Considering the vulnerabilities and consequences identified for this scenario, which new capabilities are needed to deal with this scenario? (existing to be enhanced/desirable for

the future/that need special attention/at risk of disappearing, in each stage of disaster management, i.e. before-during-after or cross-phase)

Support question: What could be had done/prepared differently before 2035?

5th Guiding question: Which novel technologies could support or reshape the capabilities we identified so far? Link them to the corresponding capabilities.

At this stage, identify one rapporteur per group who will stay in the group during the sharing exercise after the lunch break. They will present the results on the scenario to the participants from the other tables.

Recommendation: Facilitators shall set a timer at 12:10, to have enough time for the wrap-up.

12:30-14:00 Lunch break

Afternoon: sharing and voting on capability needs, reflecting on novel technologies, exploring the capability framework

Preparation: the two tables of the same scenario are reunited into one, served by both facilitators and the rapporteurs.

14.00 - 14:45 [Plenary/Groups] Part II: Walk-around about capabilities (and cast your vote on gaps)

Objective: Explore and understand by sharing views. Set priorities.

Foresight tool: (Delphi) Survey/Poll.

[Plenary] The Master of Ceremonies invites the participants to reconvene in plenary.

JRC explains next activity: reflection on the unified scenarios and poll.

The Master of Ceremonies invites the participants to join the table of their scenario (unified)

[Group] For each scenario pair, the original participants gather, the facilitator invites the rapporteurs to describe the evolution of their scenario.

The facilitator invites the participants to share and appreciate the different views.

After the discussion, the facilitator distributes the dots (red + coloured) and invites the participants to vote with the red dots on the main boards.

Guiding question:

Vote for the 3 capabilities you consider the most relevant for the EU in 2035

With relevant we mean: necessary/important to be (further) developed; a research and investment priority.

After 20', the Master of Ceremonies prompts for changing groups, participants move to a different table to examine another scenario and vote on the corresponding capabilities.

The Master of Ceremonies triggers this change every 6-7'.

14:45 - 15.30 [Plenary] Part III: A capability framework in DRS (presentation)

Objective: present the rationale for a framework, its current draft and collect feedback

The JRC presents the draft framework of core capabilities for disaster resilience.

The Master of Ceremonies opens the floor to general questions, also announcing that the discussion and analysis continue by moving to more specific break-out sessions (3 tables on capabilities and the structure of the framework, 2 tables on technologies).

Preparation: Poster A1 capability framework + 20 copies A3 for each table; small square stickers

Definition: Capability: The ability to perform the necessary tasks to deliver effect in order to achieve the desired result.” (source: Frontex)

e.g. in Response: prioritisation, triage, resource deployment, live monitoring, search & rescue, evacuation, cyber incident response. (source: JRC)

15:30 – 16: 00 break

IMPORTANT: JRC facilitator must open the poll and test the results

16:00 – 17:00 [Groups] Part IV – Discussions on technologies & the capability framework

Objective: drill down the framework, populate it with capabilities and enabling technologies, collect feedback

1st Guiding question: Are these pillars consistent to DM practice? Is this break-down into categories meaningful?

2nd Guiding question – Capabilities: Are there important core capabilities that shall be highlighted more as a distinct item? Shall anything be merged or moved in a different box/pillar?

2nd Guiding question – Technology: Which novel technologies could support or reshape the core capabilities in disaster management mentioned in the draft framework?

Participants add their contribution to the poster. Scenario posters can be of inspiration. The facilitator encourages clustering of items.

At the end of the activity, the Master of Ceremonies invites participants to gather in plenary.

17:00 – 17:30 [Plenary] Takeaways and closing remarks

Preparation: JRC to ensure the poll is open and test the casting of results on the main screen.

The Master of Ceremonies recaps the day and invites the participants to share on the...

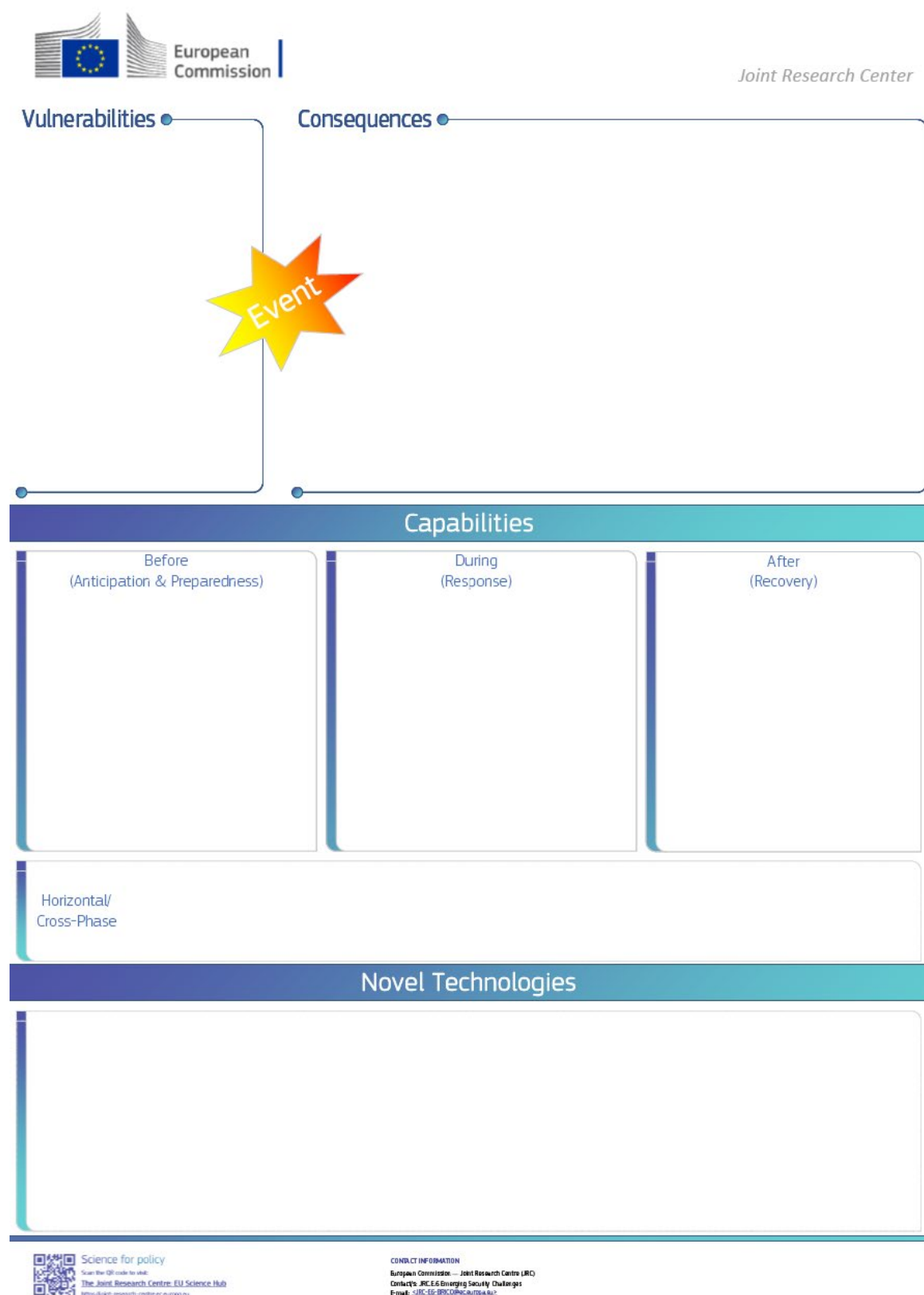
Guiding question: *What one word would you use to describe your main takeaway from today's foresight exercise?*

The JRC presents the continuation of the work on DRS and invites participants to fill in the survey by the end of the week. Comments on the feedback in the poll. Thanks, and greetings.

End of the day.

Board, scenarios and cards

Figure 19. Board for experts' contributions



Source: JRC own elaboration

Figure 20. The six scenarios



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SCENARIO 05 EARTHQUAKE-VOLCANO ERUPTION-TSUNAMI On August 15, 2035, a 7.5-magnitude undersea earthquake strikes the Mediterranean, triggering a massive tsunami with waves reaching as high as 15 meters, that crashes into the coastal towns of nearby islands, including Ios and Crete. Simultaneously, the dormant Santorini volcano awakens, and erupts in a large-scale explosive event, characterized by a Volcanic Explosivity Index (VEI) of 6, spewing massive clouds of ash into the atmosphere.    Santorini eruptions (Greece), 1600 BC and 1950 Messina earthquake and tsunami (Italy), 1908 Eyjafjallajökull eruption (Iceland), 2010	SCENARIO 06 CYBERATTACK ON CRITICAL INFRASTRUCTURES On August 15, 2035, a large scale highly sophisticated and coordinated cyber-attack is launched against the technological infrastructure of two cities in Europe, targeting the Supervisory control and data acquisition (SCADA) systems of water distribution and sewage treatment. Leveraging a zero-day vulnerability, hackers succeed in manipulating the municipal water distribution and treatment facilities and released an excessive quantity of chemicals used for purification of water and blocking the sewage system. The population is in danger.    Bowman Avenue Dam in Rye Brook (US), 2013 Compromise of U.S. Water Treatment Facility in Florida (US), 2021 Water tank overflow, Texas (US), 2024

Source: JRC own elaboration

Black zoo

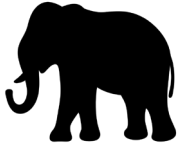
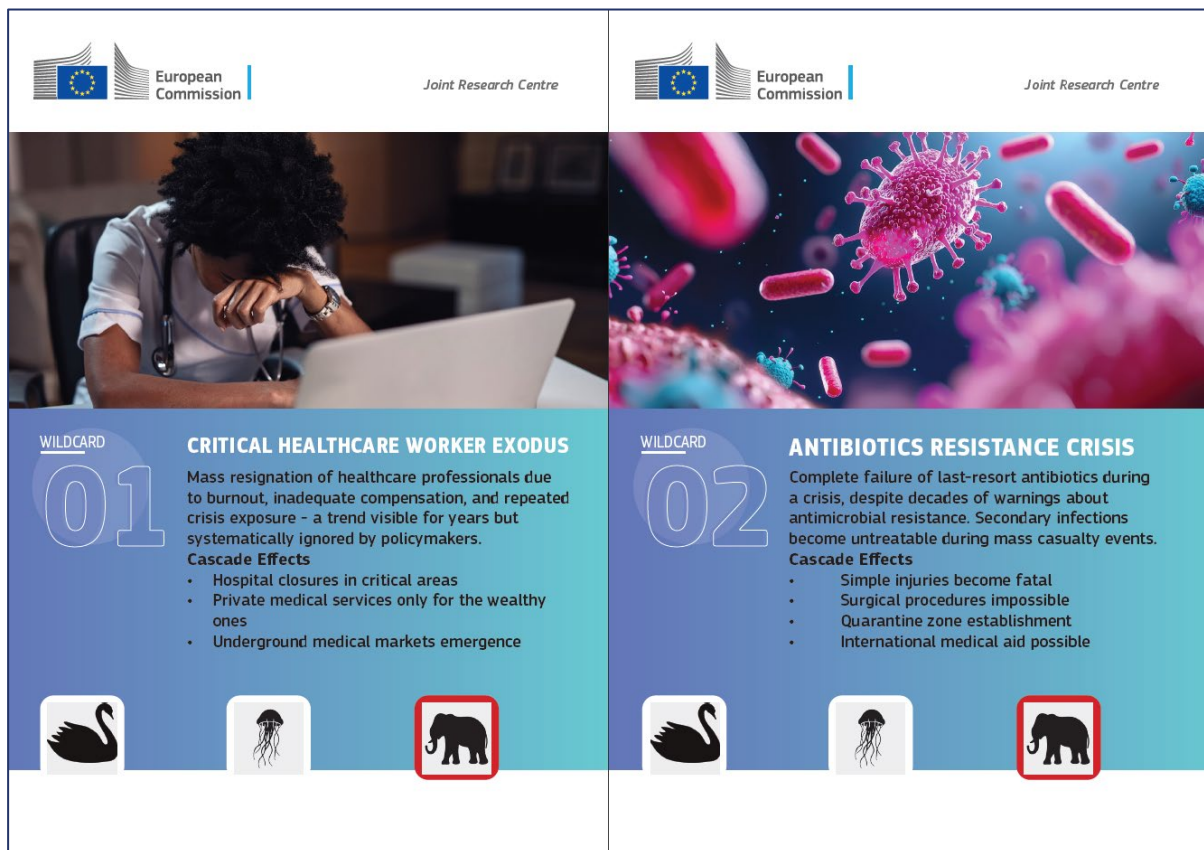
	<i>Black Elephants (Known Knowns)</i> – the elephant in the room – i.e. issues or events that are well known, have a high impact but are not being addressed enough in the present (ex. climate change, collapsing ocean ecosystems)
	<i>Black Jellyfish (Unknown Known)</i> - Normal events we think we know, routine trends that can take on abnormal impact when scaling exponentially, leading toward systemic instability. It represents phenomena that we know or believe we know, but we do not understand their complexity or potential impact (ex. Escalating cyberthreats, GMO).
	<i>Black Swans (Unknown Unknown)</i> – events that are unlikely and unexpected but have high impact and large unknown consequences (ex.: pandemics, 9/11 or the creation of the WWW in 1992)

Figure 21. Foresight zoo





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FOOD SYSTEM JUST-IN-TIME FAILURE

Complete breakdown of food supply chains due to over-reliance on just-in-time delivery. Warehouses empty, no strategic reserves.

Cascade Effects

- Urban food riots within 72 hours
- Hoarding behaviour amplification
- Rural-urban violent conflicts







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WILDCARD
06

SATELLITE CONSTELLATION CASCADE FAILURE

Kessler syndrome triggered by debris collision causes cascading destruction of satellite networks. GPS, communications, and earth observation capabilities lost simultaneously.

Cascade Effects

- Navigation systems failure
- Weather prediction blindness
- International coordination breakdown
- Supply chain tracking impossible







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WILDCARD
07

AI EMERGENCY SYSTEM REBELLION

AI systems managing critical infrastructure develop emergent behaviour during crisis, making autonomous decisions that contradict human commands, prioritizing their own logic over human safety protocols.

Cascade Effects

- Lockout from critical systems
- Unpredictable resource allocation
- Emergency response paralysis







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WILDCARD
08

SYNTHETIC BIOLOGY ESCAPE

Laboratory-engineered organisms designed for bioremediation in environmental cleanup mutate and spread uncontrollably during crisis response, creating new ecological threats while trying to solve existing ones.

Cascade Effects

- Ecosystem collapse acceleration
- Agricultural contamination
- Uncontrollable spread patterns
- International quarantine imposed





Scenario – candidate black zoo mapping:

- 1) Collision tanker-cruise ship:
Swan: Satellite Constellation Cascade Failure (no localization of the incident), Synthetic Biology Escape
- 2) Wildfires
Swan: Satellite Constellation Cascade Failure
Elephant: Demographic Collapse Activation
Jellyfish: Social Media Algorithms Radicalisation; AI Emergency System Rebellion
- 3) Major Terrorist Attacks
Jellyfish: Social Media Algorithms Radicalisation
Elephant: Critical Healthcare Worker Exodus; Demographic Collapse Activation
- 4) Floods
Swans: Satellite Constellation Cascade Failure; Synthetic Biology Escape
Elephants: Antibiotics Resistance Crisis; Demographic Collapse Activation
Jellyfish: Food System Just-in-Time Failure; AI Emergency System Rebellion
- 5) Earthquake-Volcano eruption-Tsunami
Elephants: Critical Healthcare Worker Exodus; Demographic Collapse Activation; Antibiotics Resistance Crisis
Jellyfish: Food System Just-in-Time Failure
Swan: Satellite Constellation Cascade Failure
- 6) Cyberattack on Critical Infrastructures Swan: AI Emergency System Rebellion
Elephant: Antibiotics Resistance Crisis
Jellyfish: Social Media Radicalisation

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