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Reflections and Future Directions for Multi-Hazard Risk in the Context of the Sendai Framework and Discussions Beyond

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Abstract. Multi-hazard events pose increasingly complex challenges to societies worldwide, as natural hazards interact in cascading and compounding ways that amplify risks beyond individual hazards. Understanding these complex interactions is critical for effective disaster risk management, preparedness, and response strategies. National and international frameworks have increasingly recognised these risk dynamics, most notably the Sendai Framework for Disaster Risk Reduction 2015-2030. With the Sendai Framework approaching its conclusion, there is a pressing need to address current shortcomings and contribute meaningfully to shaping the next generation of global disaster risk reduction (DRR) frameworks. Acknowledging this need, the 3rd International Conference on Natural Hazards and Risks in a Changing World took place on June 12-13, 2024, with the objective of strengthening the integration of multi-hazard risk into scientific research and policy practice in support of the Sendai Framework for Disaster Risk Reduction. Here, we document the arc of the scientific discussions held at the conference, synthesise the main findings from sessions, and set forth expert knowledge on how state-of-the-art science can fill gaps outlined by the Sendai Framework Mid Term Review by identifying four perspective themes: (1) assessments and tools for risk understanding and decision-making; (2) complex risk landscapes; (3) emerging technologies for risk and resilience; and (4) multi-level governance for coordinated risk management. Ultimately, there was a strong call from the conference for moving beyond siloed thinking toward greater integration of multi-hazards, vulnerability dynamics, multi-level governance, stakeholder engagement, and scientific disciplines across spatial and temporal dimensions, while recognising that the challenge ahead lies in finding the optimal balance between sufficient integration and manageable complexity. This perspective emphasises that effective DRR must initiate transformative processes to build resilience against increasing global challenges while informing the development of post-2030 frameworks and supporting broader Sustainable Development Goals.

1 Introduction

In March 2011, northeastern Japan experienced a devastating cascade of hazards when a magnitude 9.0 earthquake, the Great East Japan Earthquake, triggered a tsunami that breached protective barriers leading to the Fukushima nuclear disaster (Mimura et al., 2011; Ranghieri & Ishiwatari, 2014). This was a tragic example of the complexity and interconnected nature of multi-hazard events and their subsequent catastrophic impacts on society. Understanding and managing disaster risk in all its dimensions requires consideration of complex interplays between natural hazards and society, as emphasised in the Sendai Framework for Disaster Risk Reduction 2015-2030 (UNDRR, 2015). Complex interactions may take many forms: hazards such as earthquakes, flooding, heatwaves, or windstorms may have direct and tangible impacts (e.g., injuries, deaths, infrastructure damage), and indirect or intangible impacts (e.g., long-term economic or social disruptions) (Ducros et al., 2024; Gall et al., 2015; Knittel et al., 2024; Mandel et al., 2021; Peduzzi, 2019; Ward et al., 2020; Weichselgartner & Pigeon, 2015). Often, these hazards are interconnected through triggering, amplifying, and compounding relationships that create complex risk landscapes, as demonstrated by examples such as heatwaves and droughts increasing wildfire risk or seismic events causing landslides (Ciurean et al., 2018; Claassen et al., 2023; de Ruiter et al., 2020; Gill & Malamud, 2014, 2016; Libonati et al., 2022; Takagi et al., 2019).

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The multitude of hazards that a region faces, and the different ways in which they interact, are more broadly understood as multi-hazards (UNDRR, 2017). As of 2025, the UNDRR/International Science Council Hazard Information Profiles (Murray et al., 2021) has been updated to encompass a multi-hazard context for an improved perspective on assessments of possible impacts (Gill et al. 2025). The inherent complexity of multi-hazards challenges the management and governance of their impacts, either in a preparatory or responsive sense; societies still recovering from one event likely have less capacity to cope with another (De Angeli et al., 2022). In the context of multi-hazard emergence, human activities and development patterns need explicit consideration that is not only centred around exposure and vulnerability assessments but also captures ways in which multi-hazards can push systems to and beyond their capacity to adapt and recover (Juhola et al., 2022).

Improving our understanding of these complex interactions is critical for reducing the societal risks and impacts of (multi-)hazards by facilitating effective disaster risk management (DRM), preparedness and response strategies (Ward et al., 2022; White et al., 2024). National and international frameworks have increasingly stressed the importance of these dynamics, most notably the Sendai Framework for Disaster Risk Reduction 2015-2030 (UNDRR, 2015). Currently in practice, this framework represents a paradigm shift in DRM by emphasising the need for a multi-hazard and systemic risk assessment approach. The framework focuses on preventing the creation of risk, reducing existing risks, and enhancing resilience, through four priorities: (1) Understanding Risks; (2) Strengthening Governance to Manage Risk; (3) Investing in Disaster Risk Reduction (DRR) for Resilience; and (4) Preparedness for Response and "Building Back Better (BBB)" for recovery. Additionally, the framework has seven global targets (A-G), of which four address reduction of impacts via (A) global mortality of disasters, (B) people affected, (C) economic losses, and (D) damage to infrastructure, while the other three targets focus on an increase in (E) risk knowledge, (F) international cooperation and (G) availability of multi-hazard early warning systems (MHEWS).

One of the guiding principles of the Sendai Framework is the recognition of systemic risks that emerge from the interconnectedness of multi-hazards and their cascading effects on society, economy, and the environment (Hochrainer-Stigler et al., 2023; Sillmann et al., 2022). It also highlights the need for a comprehensive, multi-level governance and stakeholder approach to disaster risk reduction. This involves decisions not just from governmental actors, but also the private sector and civil society/the community level. To achieve its goals, the Sendai Framework targets require integrating DRR into all levels of risk governance. This includes enhancing global preparedness and responding to the growing and diversifying hazards of a changing world that is driven by climate change, population growth, more valuable and widely distributed assets, and resulting increases in exposure to hazards. The framework emerged through an unprecedented integration of scientific input into policy development, culminating in the 2016 UNISDR Science and Technology Conference, which established a formal partnership to leverage multidisciplinary research networks and address knowledge gaps in understanding disaster risk (Aitsi-Selmi et al., 2016; Dickinson et al., 2016). Nearly a decade after its inception, the framework has been instrumental yet imperfectly realised in shaping how risk-related actions have been implemented across multiple scales.

The Sendai Framework Midterm Review (MTR) (UNDRR, 2023) recognised many positive strides in fostering international cooperation, such as improving early warning systems (EWS) and integrating disaster risk reduction into national policies but also revealed that progress in many aspects is lagging. To meet the aims of the Sendai Framework, the MTR identified that more emphasis is required on addressing disaster risk in a multi-hazard context, tackling systemic risk and systemic inequalities, and strengthening cross-sectoral cooperation and stakeholder engagement. This includes developing a shared understanding of risk, improving tools and methodologies, ensuring all-of-society engagement in DRR, and applying emerging technologies to manage complex risks. Furthermore, the MTR emphasises the need to build capacity for integrated decision-making, multi-scale governance, and improving EWS to include multi-hazard contexts. To address these gaps, it is crucial to have a more integrated approach that acknowledges as well as actively manages and addresses the interconnected and evolving nature of multi-hazard risks (Brett et al., 2025; Hochrainer-Stigler et al., 2023; Šakić Trogrlić et al., 2024), which are risks generated from hazard interrelationships and additionally on the vulnerability level for multi-risks (Zschau, 2017). Extreme events continue to increase in frequency and severity, making this challenge particularly urgent. Although various multi-stakeholder initiatives, such as the Global Platform for Disaster Risk Reduction, Early Warning for All, and the Global Initiative on Resilience to Natural Hazards through AI Solutions, have been making important strides, critical implementation gaps remain.

With the Sendai Framework approaching its conclusion in 2030, there is a pressing need to address shortcomings identified in the MTR and contribute meaningfully to shaping the next generation of global DRR frameworks. Acknowledging this need, the 3rd International Conference on Natural Hazards and Risks in a Changing World took place on June 12-13, 2024, with the objective of strengthening the integration of multi-hazard risk into scientific research and policy practice in support of the Sendai Framework for Disaster Risk Reduction. This gathering brought together approximately 280 scientists and practitioners, providing a platform to foster dialogue and collaboration across disciplines and sectors to inform a better integration of science into future DRR Frameworks, while placing special emphasis on strategies for tackling the complexity of multi-hazard DRM research and management. Topics of conference sessions ranged from complex risks, disaster risk management and disaster risk reduction, and hazard impacts, to emerging technologies for addressing multi-hazard (MH) risks. Attendees of this event presented progress in addressing multi-hazards and captured how emerging research and technologies can be harnessed for reducing risks in an increasingly interconnected world. Here, we document the extent of the scientific discussions held at the conference, synthesise the main findings from sessions, and set forth expert knowledge on how state-of-the-art science can address gaps outlined by the Sendai Framework MTR through four identified perspective themes. Additionally, our summarised results of a survey among conference attendees offer a forward-looking take on the next steps that are necessary to meet the diverse challenges posed by multi-hazard events and systemic risk. Our findings identify key areas of attention for scientific research, policy, and practice to develop a more resilient and better prepared society.

2 Methods and Conference Setup

This paper synthesises insights from the "Natural Hazards and Risks in a Changing World" conference, held in June 2024, through a structured methodological approach that combines multiple data collection and analysis techniques to advance understanding of multi-risk management:

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1. Identification of key themes and knowledge gaps in multi-hazard risk research by the organising committee, with themes aligned to address shortcomings identified in the Sendai Framework Mid-Term Review
2. Development and organisation of 14 specialised conference sessions reflecting these priority themes (see Table 1)
3. Conference survey of participants (n=86) to identify perceived barriers to multi-hazard risk research and management
4. Facilitation of the conference with approximately 280 participants from diverse scientific disciplines and areas of practice
5. Collection of session summaries/reports from conveners and rapporteurs, focusing on contributions to novel scientific ideas (Supplementary Information A)
6. Post-conference survey of session conveners for written input on how their sessions can address gaps identified in the Sendai Framework MTR (Supplementary Information B)
7. Thematic organisation of sessions into four 'perspective themes' aligned with Sendai Framework MTR gaps (see Figure 1)
8. Integration and thematic analysis of all inputs (survey data, session reports, expert insights) to identify four key perspective themes (section 3) and outlook (section 4, see Figure 2)

The conference was open to all though the majority of attendees were affiliated with institutes in Europe. It was organised by the MYRIAD-EU project, RISK-KAN, and NatRiskChange. The conference served as a dynamic forum that sparked lively discussions and provided a platform to take stock of advances in disaster risk research, with an explicit focus on multi-(hazard) risks. Building on these exchanges, this paper advances four perspective themes: Complex Risks; Tools and Assessment; Emerging Technologies; and Multi-level Governance. These themes are used to explore how novel science and its applications can address critical challenges in the context of (multi-)hazard risks. Our analysis draws on multiple data sources, including supplementary conference reports, a survey with questions about forward-looking themes that was conducted around the time of the event, and post-conference insights from 35 scientists and practitioners through expert consultation (i.e., the co-authors). These diverse inputs illuminate how the conference, and science more broadly, can contribute to achieving the objectives and filling the gaps (step 6) identified in the Sendai Framework MTR, while setting a robust foundation for future research endeavours.

The conference hosted 14 sessions that reflect the ongoing research in various fields of multi-(hazard) risks (see Table 1). For an overview of all abstracts, see (abstract booklet: Mirenzi & Pijpen, 2024). For an overview of conference reports of the sessions see Supplementary Information A.

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Table 1: Overview of conference sessions and number of abstracts/presentations.

Conference session	**Number of abstracts/ presentations**
How Can **Stakeholder Engagement** and Knowledge Co-Production Enhance Effective Multi-Risk Management?	24
Science for policy and practice: Synergising **Disaster Risk Reduction and Climate Change Adaptation**	18
Recent developments in **multi-hazard early-warning systems**	4
Nature-based Solutions for Disaster Risk Reduction	6
Systemic risk – assessing, modelling, coping	14
Dynamics, interdependencies and interactions **of risk drivers**	22
Health and Disasters	11
Artificial Intelligence and Machine Learning for Multi-Risk Assessment	16
Assessing multi-hazard risk using **Earth-Observation** data	12
Advancing **critical infrastructure** modelling in a complex world	12
Learning from the past: historical perspectives and 'success stories' of DRR	11
Storylines and narratives for multi-hazard, multi-risk decision-making	14
General advances in disaster risk science and compound events	35
Demonstration of **tools** and services	6

Following the conference, the conveners of the sessions provided written input on how the topic of their session can contribute to science and gaps as identified by the Sendai Framework MTR, informed by the talks and reports of the conference, along with their expert knowledge.
Each session was then linked to one of four 'perspective themes': Complex Risks, Assessments and Tools, Emerging Technologies, and Multi-level Governance. Session conveners were asked to respond to specific questions related to their assigned perspective theme (detailed in Supplementary Information B). Noting that these thematic categorisations are not mutually exclusive, many sessions contained elements relevant to multiple perspective themes. For example, AI applications discussions in the Emerging Technologies perspective theme may overlap with methodology advances in the Assessments and Tools perspective theme. At the same time, Complex Risks could reasonably intersect with governance challenges addressed in the Multi-level Governance perspective theme. Moreover, the Critical Infrastructure session could equally fit within Complex Risks as within its assigned category of Emerging Technologies. This interconnected nature reflects the holistic approach needed to address multi-hazard risks, and the categorisation served as a loose practical framework for pragmatic reasons rather than a rigid taxonomy. Drawing from all sources across these interconnected perspectives, we identified two main messages per perspective theme.

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The anonymous online survey of conference participants was conducted in the weeks leading up to the June 2024 conference. From this we obtained 86 unique responses, representing approximately 40% of conference attendees. As questions were not mandatory, per-question sample sizes vary from 32 to 73. Respondents span various career stages, with 66% being Early Career Researchers (PhD students or postdoctoral researchers). Half of the respondents work at universities, followed by another 26% at national research institutes. This academic-heavy representation should be noted as a potential limitation when interpreting the survey findings. Fields of research and practice were highly diverse, spanning the physical and social sciences across disaster risk research, with flooding being the most frequently cited specialisation, followed by multi-hazard, climate adaptation, and infrastructure resilience, along with various other hazards including volcanic, landslides, and extreme weather events.

Within the survey, we used the answers to the following questions to provide insight for our outlook section: “What do you think is the biggest impediment to progress in understanding of multi-hazard risks over the next 5 years?” and “What do you think is the biggest impediment to better managing multi-hazard risks over the next 5 years?”. We conducted a qualitative, thematic analysis of these open-ended responses, identifying recurring concerns and grouping them into key categories that informed our recommendations. For example, when asked to provide an example of a prototype multi-hazard event, respondents most frequently cited the Great East Japan Earthquake and subsequent tsunami that caused the Fukushima disaster. The following sections combine all data sources and are bolstered by an informal review of all relevant-, state of the art literature.

3 Perspective Themes

In this section, we integrate the input from the conference sessions, survey results, and expert insights to gain insights around our four perspective themes on how current state of the art science can help to fill the gaps outlined by the Sendai Framework MTR. First, we outline the structure of this section, which progresses through the four key perspective themes (see Figure 1): (1) assessments and tools for risk understanding and decision-making; (2) complex risk landscapes; (3) emerging technologies for risk and resilience; and (4) multi-level governance for coordinated risk management. For each perspective theme, we begin with an overview of current scientific understanding, then present two key messages—drawing specifically on survey findings and expert contributions from the conference—that highlight critical pathways for advancing disaster risk science and practice.

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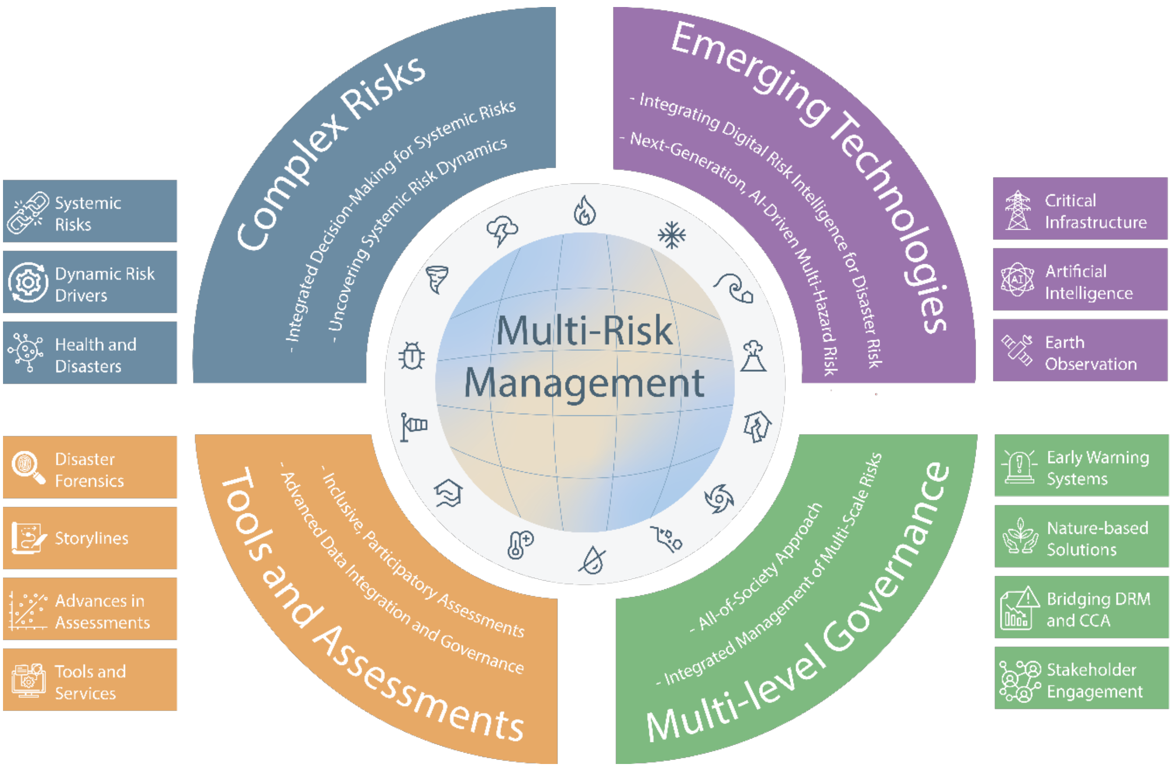

Figure 1: Overview of the four perspective themes and key messages (circle segments) and the connected conference session topics (smaller rectangles at the sides).

3.1 Advancing Risk Science: Tools and Assessments for Resilient Decision-Making

New developments in risk assessment methods and tools, such as improved learning from past events (e.g., retrospective analysis) and the use of storylines, can support an increase in risk awareness and improve risk management capabilities (Keating et al., 2016; Sillmann et al., 2021; UNDRR, 2024; van den Hurk et al., 2023). Disaster risk science is an evolving field that covers a broad spectrum of topics, including hazard assessment, management, impacts, adaptation, and the role of inequalities in social vulnerability (Reid, 2013; Shi et al., 2020; Ward et al., 2020). New tools and technologies demonstrate how complex data can be transformed into actionable insights for better decision-making and proactive risk management (Bastos Moroz & Thieken, 2024; Benson & Twigg, 2007; Marshall, 2020). However, barriers to their widespread application in multi-risk assessment and DRM remain (Šakić Trogrlić et al., 2024), such as usability, skills gaps, access, availability, and/or differing stakeholder needs, interests, and priorities. Overcoming these obstacles requires making tools accessible to a wide range of users, especially non-technical audiences. We have identified two priorities for how science can contribute to the Sendai Framework and beyond for a shared understanding of risk through advanced tools and collaborative approaches.

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3.1.1 Inclusive, Participatory Assessments

Participants underscored, during the conference, that stakeholder engagement is the cornerstone of an inclusive disaster recovery process (Lillywhite & Wolbring, 2022; Villeneuve, 2021). Stakeholder engagement and co-production, from local communities to decision-makers, ensures that recovery efforts reflect diverse needs, build resilience, and foster long-term sustainability (Granville et al., 2016; Mojtahedi & Oo, 2017; van Oosterhout et al., 2023). Effective planning must involve all levels of society, particularly marginalised groups, to address systemic vulnerabilities and power imbalances that can otherwise hinder equitable recovery (Carrasco et al., 2023). This all-of-society engagement begins with participatory processes and elicitation, such as interviews and workshops, recognizing that community knowledge on disaster risk and capacity to prepare and respond is central to shaping risk mitigation and recovery strategies (Haer & Ruiter, 2024; Mortensen et al., 2024; Olonilua, 2022; Petraroli & Baars, 2022).

Storylines—defined here as plausible, narrative-based representations of how risks and event pathways might unfold under different social, environmental, and policy conditions—are increasingly being used to explore uncertainty and support decision-making in DRR (Marciano et al., 2024; Shepherd et al., 2018). Because they are narrative-based, they can be used to facilitate the communication and understanding of complex multi-risk interactions. Moreover, they are flexible enough to enable integration of qualitative and quantitative data, which allows to provide a holistic approach to DRM, as highlighted by many of the session presentations. An essential component of storyline development is stakeholder engagement, which is facilitated through iterative participatory methods (e.g., elicitation, interviews, and workshops). The flexible nature of storylines allows them to be developed together with a range of stakeholder groups, depending on their intended scope. For example, some storylines are co-created at the community level, involving decision-makers and community groups using local knowledge and data. To ensure truly inclusive participation, co-creative processes should be used with the inclusion of marginalised groups, such as those with varying levels of literacy, gender and sexual minorities, people with disabilities, and socioeconomically disadvantaged communities (e.g., Bou Nassar et al., 2021; Mortensen et al., 2025). This enables knowledge sharing, helps acknowledge and reduce potential power imbalances, and engages stakeholders at different levels of decision-making processes.

Involving stakeholders builds trust and collaboration, while also producing context-specific solutions that integrate local knowledge with scientific data and hazard analysis. Subsequently, it allows for reducing the risk of top-down interventions not responding to the local realities and needs of communities (Prabhakar et al., 2024). For example, platforms like FloodAdapt[1] and Urban Digital Twin[2] incorporate local insights to guide interventions and enhance transparency. They encourage open data & citizen input, along with other perspectives on recovery, to ensure just and equitable recovery outcomes. Moreover, DRR frameworks may further support inclusive preparedness and recovery by incorporating multi-sector collaboration. Initiatives like RiskScape (Paulik et al., 2023) and MYRIAD-EU (Ward et al., 2022) aim to exemplify the design of DRR

[1] https://www.deltares.nl/en/software-and-data/products/floodadapt
[2] https://regions4climate.eu/unlocking-efficiency-and-insight-with-digital-twins/

actions that are holistic, context-specific, and adaptive. Such examples show how education, communication, and stakeholder collaboration help build community resilience, while addressing regional research gaps and optimising data collection. However, most importantly, all-of-society engagement is about more than inclusion and agency - it is about ensuring that DRR efforts are context-sensitive, effective, and equitable.

3.1.2 Integrating Risk Assessment Tools in Governance Frameworks

Several talks and tool demonstrations at the conference illustrated how increasing granularity of risk data and governance frameworks permits precise, equitable interventions through the integration of different data sources across hazards and sectors. This can support decision-making, starting with local knowledge and moving to satellite imagery to capture nuanced vulnerabilities at local and regional scales (Migliorini et al., 2019; Montillet et al., 2024; Saulnier et al., 2019). This granularity becomes important with the need for more precise risk management strategies and processing and visualizing data at higher resolutions, such as at the neighbourhood or individual building level. This is particularly important for risks like landslides or urban flooding, where impacts can vary significantly within small spatial extents and where fine-scale topography and infrastructure characteristics determine both exposure and vulnerability (Ferrer et al., 2024; Sieg et al., 2023). The emerging development of digital twins, which are virtual replicas of physical systems (Ariyachandra & Wedawatta, 2023; Hämäläinen, 2021), can empower local decision-makers with actionable insights at these granular levels. However, the choice of resolution must align with the nature of the risk and of the end-users' decision-making needs. For example, overly fine resolutions can possibly lead to a challenge in model validation, increase computational demands, and introduce false confidence or uncertainty if this is not properly contextualised. Therefore, it is essential to balance system resolution, problem scale, and user requirements to develop effective and trustworthy DRR tools.

Equally important is the improvement of data governance, which includes the policies, standards, and accountability frameworks that determine how data is collected, used, and shared, as these underpin the effective use of granular datasets (Kanbara & Shaw, 2022). For example, transparent data governance frameworks enhance the accountability and credibility of decision-makers, actors, and the whole disaster governance system. Such frameworks can also help ensure that data are shared responsibly and used ethically. Subsequently, this strengthens collaborative efforts across sectors and regional data partnership, even though competition for funding and disconnects between research, industry, and government may still persist. These challenges are increasingly being addressed through better stakeholder interaction and inclusive governance approaches that are also tackling vulnerabilities that are otherwise able to undermine resilience-building efforts (Shahat et al., 2020). This is especially the case in dynamic and rapidly changing risk landscapes for which timely and localised data are essential for risk-informed decision-making. Likewise, good practices rely on data standards and interoperability, which would pave the way to enable information exchange across systems, sectors, and regions. Open standards such as those in platforms like the Crisis Management Innovation Network Europe (CMINE) cluster and the Disaster Risk Gateway (https://disasterriskgateway.net) ensure consistency and reliability across different datasets, supporting coherent decision-making in line with global frameworks like the Sendai Framework.

Some sector-specific tools have emerged with the purpose of multi-hazard risk assessments and sectoral integration in disaster risk management. For example, the "Tourism Destination Resilience and Sustainability Scorecard" integrates qualitative expert evaluations with quantitative multi-hazard and multi-risk data to generate a holistic risk profile for tourism destinations. The scorecard covers disaster risk and sustainability and is designed in line with the Sendai Framework's priorities and targets for disaster risk reduction. By embedding these principles, the scorecard operationalises Sendai's priorities in a tourism context, translating high-level multi-hazard goals into actionable local metrics. This approach has been fully implemented for California (https://www.risklayer-explorer.com/region/title=California/overview) and extended to the Canary Islands, which combines stakeholder insights with multi-hazard and multi-risk modelling to inform multi-hazard risk management strategies for island destinations (https://www.myriad-multirisk.eu/showcase/). Such sector-specific applications demonstrate how Sendai Framework targets can be effectively transferred to diverse economic contexts and provide a template for similar risk assessment frameworks in sectors such as agriculture, healthcare, and urban planning. However, sectoral development can itself drive risk by increasing exposure, demonstrated by research showing how flood insurance can incentivise population growth in floodplains (Tesselaar et al., 2023). This highlights the broader challenge that disaster risk management is more developed in some sectors than in others. Thus, there is a need for cross-sectoral tools so that sectors can consider the implications of interventions, planning, and actions they make on other sectors and vice versa.

Furthermore, the ability to turn granular data into actionable insights requires the application of both quantitative and qualitative approaches. Storylines, for example, offer a flexible method for communicating uncertainty and complexity in future risk scenarios (Shepherd et al., 2018). By integrating socio-economic data, exposure, and vulnerability indicators, storylines allow scientists and decision-makers to explore potential hazard and impact trajectories and the outcomes of different interventions based on preferences and risk perception (Goulart et al., 2024; Kunimitsu et al., 2023; Young et al., 2021). This supports better planning and response, while also helping to raise risk awareness and strengthening the capacity of stakeholders, ranging from local governments to community organizations.

These methods represent a step toward more usable, interoperable tools. However, major challenges persist in standardising across sectors and integrating multiple hazards. Many risk assessment tools remain focused on single-hazard, and sector-specific standards - particularly in fields such as insurance - often hinder cross-sector compatibility.

3.2 Complex Risks Landscapes: Analysis and Action

Traditionally, the focus of DRR measures is on short-term risk reduction measures. However, a noticeable shift is occurring toward more forward-looking actions, which are essential in the face of climate change. For example, this includes proactive approaches that incorporate long-term adaptive strategies to prepare communities for evolving and future risks. The 2012 IPCC Special Report on Managing the Risks of Extreme Events and Disasters (SREX) was a key milestone in aligning concepts, frameworks, and methods that framed risk as the interaction between hazards, exposure, and vulnerability. A decade later, the complexity of risk was stressed in IPCC (2023) and the need to account for the multivariate nature of interacting drivers, including hazards, exposures, vulnerabilities, and societal responses, was highlighted. As such, the IPCC risk framework has

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evolved beyond assessing climate change impacts alone to also include risks from ineffective risk mitigation and adaptation responses - evident in unintended side effects or maladaptation beyond sectoral and system-specific boundaries (Malmström et al., 2025). Based on insights from the conference and expert consultations, we identify two key priorities for how science can contribute to further uncovering these complex risk landscapes in terms of systemic risk and highlight the need to integrate decision-making for systemic risks in support of the Sendai Framework and beyond.

3.2.1 Uncovering Systemic Risk Dynamics

Systemic risk describes the process and outcome of cascading impacts, meaning impacts from a shock in one part of the system can cause risks and impacts in other parts of the system or across systems, which can lead to system failure or collapse. Important drivers of systemic risks are often socio-economic vulnerabilities, infrastructure, or other societal system characteristics (Kuran et al., 2020; Stolte et al., 2024). Research has increasingly focused on understanding systemic risks (Hochrainer-Stigler et al., 2023; Santos et al., 2024; Schweizer & Juhola, 2024), while exploring forward-looking approaches (Haasnoot et al., 2024; Jack et al., 2024; Lüthi et al., 2023) or stakeholder engagement methods to address and prevent systemic risks (Syukriyah & Himaz, 2024; Thieken et al., 2023; Zenker et al., 2024).

An important challenge here is the identification of appropriate methodologies to capture and model systemic risks. While there is consensus that systemic risks involve complexity, transboundary effects, and cascading failures, methodological challenges often remain in delineating system boundaries and determining analytical focal points. Sillmann et al. (2022) offer a comprehensive review of systemic risk attributes and emerging methodologies. One of the key issues in uncovering systemic risks is defining system boundaries and determining when to use quantitative, qualitative, or mixed-method approaches (Hochrainer-Stigler et al., 2023). In doing so, researchers must decide whether to frame analysis around the entire system, a specific hazard, or a triggering event. Furthermore, the temporal dimensions of systemic risks are important yet often neglected. This is challenging because risk drivers change at different rates; for example, climate hazards tend to increase gradually while socioeconomic vulnerabilities can change rapidly following policy shifts or economic disruptions (de Ruiter & van Loon, 2022; Haasnoot et al., 2013; Vogel et al., 2024). Various approaches, including forward-looking storylines (Lüthi et al., 2023), surveys (Thieken et al., 2023) and case studies (Brouwer, 2024; Sairam et al., 2025; Syukriyah & Himaz, 2024) contribute critical insights into systemic risks.

The dimensions of vulnerability as identified by de Ruiter and van Loon (2022)—such as underlying structural drivers, vulnerability during prolonged disasters, and the compounding effects of consecutive events—are challenging to capture due to their complex, dynamic, and context-dependent nature, often unfolding across varying spatial and temporal scales. Data availability poses a major challenge here, particularly regarding vulnerability data, which frequently vary in quality and quantity across regions and over time. Moreover, data accessibility remains restricted due to privacy regulations (von Szombathely et al., 2023) and the lack of standardised formats (Poschlod et al., 2021). One benefit of qualitative studies is their ability to provide more granularity and insights into local process-based understanding within specific geographical contexts. Yet the challenge of generalising these findings across different spatial contexts remains (Sparkes et al., 2024).

Furthermore, short-term and longitudinal data that track changes of vulnerabilities and exposures over time are particularly scarce, limiting our ability to understand systemic risk dynamics (Bubeck et al., 2020; Geiß et al., 2024; Hudson et al., 2020). While hazard projections often span multiple temporal scales, corresponding exposure and vulnerability projections rarely achieve comparable temporal resolution. Addressing those dimensions for sudden onset disasters requires data that captures changes in exposed assets and population dynamics at high temporal resolution (hourly to daily). For instance, data on daily mobility patterns of socio-economic groups in cities has been shown to enhance multi-hazard exposure modelling and urban resilience assessments (Haraguchi et al., 2022; Pittore et al., 2017, 2023). Post-disaster longitudinal surveys are methodologically challenging and remain limited in number, which is equally limiting (Bronstert et al., 2018; Hudson et al., 2020; Thieken et al., 2023). Yet, they are crucial for our understanding of long-term impacts, such as mental health effects after major disasters (Sairam et al., 2025; Syukriyah & Himaz, 2024; Zenker et al., 2024). Developing methodologies that can capture these varied temporal scales—from rapid-onset events to slow-developing hazards or long term political/conflict stressors—is essential for comprehensive risk management (Jurgilevich et al., 2021; Matanó et al., 2022).

Ciullo et al. (2025) argue that an integrative framework is needed to connect climate change, natural resources, human development, and societal stability through complex, dynamic pathways. For example, agent-based modelling may be a promising avenue for simulating interactions between environmental and social systems as it enables stakeholders to assess systemic risks and implement DRR strategies (Aerts, 2020). Also, social and causal network analysis (system dynamics models) can map dynamic risk drivers and tipping points for stakeholder engagement. Bayesian networks may provide an opportunity to include information about stakeholder perceptions of risk and preferences to risk assessments (Kunimitsu et al., 2023).

3.2.2 Integrated Decision-Making for Systemic Risks

Uncovering systemic risks, however, challenges traditional risk governance models, which are often compartmentalised and sector-specific (Schweizer & Juhola, 2024). Therefore, an integrative governance approach is needed - one that combines interdisciplinary analysis with adaptive, inclusive, and transparent decision-making. Schweizer & Juhola (2024) propose such a governance framework that incorporates systems analysis, reflection, iteration, inclusion, transparency, and accountability. Although DRR and climate change adaptation (CCA) are deeply interconnected, in practice there are still large siloes, limiting the potential for integrated, coherent responses to such evolving risks. Important frameworks like the Sendai Framework for DRR and the Paris Agreement's Global Goal on Adaptation are taking steps to try to bridge these gaps, and science needs to facilitate this.

Interoperability challenges between data, models, communication channels, and governance structures may hinder integrated DRM, highlighted by Schröter et al. (2024). The Risk-Tandem Framework introduced by (Parviainen et al., 2025) is directly responsive to this challenge and further emphasises transdisciplinary knowledge co-production to enhance risk governance. This approach facilitates improved stakeholder engagement, science-based dialogue, and the development of an open-source federated data infrastructure. In doing so, it consolidates diverse data sources and analytical tools that address the need for better risk assessment and governance (Hochrainer-Stigler et al., 2024; Parviainen et al., 2025; Schröter et al., 2024). Ciullo et al. (2025) advocate for a systemic risk governance approach that views climate hazards, disaster risk, and sustainability as interconnected. This includes developing and utilising vulnerability scores from the Sustainable Development Goals (SDGs), which allows for modelling complex socio-economic networks while, for example, studying how the impacts from weather extremes are propagating through systems. By advancing the methodologies and governance frameworks listed here, systemic risk research can better inform policy and enhance societal resilience in the face of future climate and nature-related challenges.

3.3 Emerging Technologies for Risk and Resilience

Emerging technologies such as Artificial Intelligence (AI), Earth Observation (EO) instrumentation, and digital risk modelling are transforming risk assessment and management in multi-hazard, systemic risk contexts (Kuglitsch et al., 2022; Lagap & Ghaffarian, 2024). Since society's disaster risks are increasingly complex and interconnected, these technologies are needed for better risk assessments, infrastructure resilience optimisation and informed decision making (Khan et al., 2020). For example, the need to integrate multi-model risks as assessed by AI, remote sensing, and digital modelling may not only reduce uncertainty around risk characteristics but also enhance the effectiveness of risk reduction strategies across multiple scales (Cao, 2023; Cheng et al., 2024; Rezvani et al., 2024). Based on the conference and expert consultation, we identified two key priorities regarding how science can contribute to the progress of the Sendai Framework and beyond, leveraging emerging technologies, such as AI and digital twins, to refine risk modelling for a smart and resilient society.

3.3.1 Next-Generation, AI-Driven Multi-Hazard Risk Assessment

To move from single to multi-hazard risk assessments, there is a need for a holistic approach and a better shared, cross-disciplinary understanding and management of risks surrounding complex disasters in which multiple hazards often interact with compounding impacts (Jäger et al., 2024). AI can play a vital role in this and was one of the main topics during the conference. Emerging technologies—especially advanced AI and machine learning—are now capable of processing vast, multi-dimensional datasets that capture this dynamic interplay of multiple hazards, sometimes in real time, and can provide predictive insights for more informed multi-hazard risk management (Kolivand et al., 2024; Kuglitsch et al., 2022; Ogie et al., 2018). However, as conference participants emphasised, it is important to note the limitations of AI, including potential biases in training data (Gevaert et al., 2024; Láng-Ritter et al., 2025), challenges of interpretability, and the risk of reinforcing existing inequalities when AI systems are deployed without careful consideration of diverse stakeholder needs and geographical contexts (McGovern et al., 2024).

For example, AI offers innovative solutions to longstanding challenges, such as real-time responses to cascading disasters (AghaKouchak et al., 2023; Dunant et al., 2021). These AI models—such as long short-term memory (LSTM) networks for fast onset predictions (e.g., floods, landslides)—have been harnessed to integrate sensor data and climate models, enabling

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more accurate predictions of imminent flood events (Prakash et al., 2023). Moreover, for slow onset predictions, models such as XGBoost are used for predicting droughts and food security (Busker et al., 2024). In terms of susceptibility, deep learning techniques have been applied to analyse the intersection between hazards and socio-economic and infrastructure data, allowing researchers to pinpoint communities and regions that are most susceptible to multi-hazards and disaster impacts (Ferrario et al., 2025). Finally, natural language processing tools, such as large language models (LLM) and text mining, can also be used to analyse textual information in policy documents but also other media outlets, such as newspapers and social media, to detect and quantify hazard impacts (Diemert & Weber, 2023; Madruga de Brito et al., 2020; Sodoge et al., 2023).

One of the identified gaps of the Sendai Framework MTR is increasing the granularity of data and creating hazard maps and tools for collecting data on vulnerability, particularly relevant in high-risk rural areas (UN, 2024). Advanced AI and remote sensing technologies enable the collection of high-resolution, location-specific data. AI can be used to produce fast and accurate downscaling in complex topography, which is key to reduce uncertainty in extreme event prediction in future climate projections, particularly relevant for indicators that have sparse ground measurements (in combination with space-based EO). Additionally, foundation models can be trained with specific applications through transfer learning, for example in the contexts of specific regions (Bommasani et al., 2022; Zhuang et al., 2021), and data augmentation techniques can be used in areas of low data coverage (Alzubaidi et al., 2023). In-situ impact data are essential for supporting these advances and remain a bottleneck in many cases.

As the field of AI and multi-hazard research are both fast developing topics, we outline some future steps that may be crucial for better understanding, monitoring and communication of risks. For instance, emerging tools (e.g., graph diffusion models, causal AI, hierarchical Graph Neural Networks and field theory) go beyond static predictions, while enabling the discovery of causal relationships and feedback mechanisms in complex Earth systems that can inform anticipatory humanitarian interventions and reveal context-specific vulnerabilities across different spatial and temporal scales (Cerdà-Bautista et al., 2023; Tárraga et al., 2024; Tesch et al., 2023). Moreover, physically informed AI bound to scientific principles enhances the reliability and interpretability of predictions (Zheng et al., 2023), while probabilistic machine learning reduces the uncertainty of model outcomes to better inform risk estimates (Zhou et al., 2022). AI and participatory approaches, in some ways two ends of a spectrum, may both contribute to ensuring robustness of model outcomes in societal context (Kuglitsch et al., 2022; Pham et al., 2021; Ye et al., 2021), especially with the rise of explainability of AI frameworks (Ghaffarian et al., 2023). Understanding the role of the risk factors in the AI model allows for the application of these models to analyse stress to the system, like for future risk scenarios, where input data taken from climate projections may lie outside the distributions over which the model was trained. This high-level critique of AI data sources, cost functions, and output sanity is essential and, again, is often substantially aided by incorporating in-situ data and input from local communities. By integrating high-resolution EO data, explainable AI frameworks, and probabilistic models, these tools can be used to refine our risk assessments on resilience priorities and enable anticipatory, adaptive decision-making in increasingly complex disaster scenarios.

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3.3.2 Integrating Digital Risk Intelligence for Disaster Risk Management

Improving multi-hazard risk assessments at the local level—where impact-based forecasting and risk reduction planning are often most effective—requires the development of local asset databases (UNDRR, 2015), a need clearly emphasised in the conference discussions. Remote sensing in combination with AI has in recent years been instrumental in creating digital global built-environment databases that are detailed, standardised, and interoperable. The next challenge is to develop procedures for automated building characterisation to link this more directly with physical vulnerability and quantifiable economic losses (Aravena Pelizari et al., 2021). Furthermore, Earth Observation techniques allow continuous collection of spatiotemporal data for large areas (Khan et al., 2020; Li et al., 2023). This information helps disaggregate coarse exposure data into finer spatial resolution and augment various risk parameters, including for example by intersecting with high-resolution socio-economic data (Geiß et al., 2023).

However, to enhance localised risk and impact assessments, these vast amounts of data need to be integrated into meaningful digital representations of risks (Ariyachandra & Wedawatta, 2023). The field of digital risk modelling, such as digital twins, is quickly evolving and creating a space for highly detailed, tailor-made assessments (Yu & He, 2022). Digital twins are in principle able to provide real-time monitoring, scenario testing, and informed decision-making for disaster risk reduction, especially in combination with AI or EO (Fan et al., 2020; Ford & Wolf, 2020). The enormous quantities of data produced by (semi-overlapping) remote-sensing missions, together with the multidimensional specifications, uncertainties, spatiotemporal coverages, and other considerations that vary by mission, make AI-powered data-harmonisation tools particularly attractive in the digital risk field (Fan et al., 2021).

Complementing these technological advances, Volunteered Geographic Information and crowdsourcing are increasingly contributing to disaster risk data generation and response capacities (Moghadas et al., 2022). Digital volunteering networks, including Humanitarian OpenStreetMap Teams, map affected areas during disasters, and Virtual Operations Support Teams provide real-time social media analytics to emergency operation centres during crises for situational awareness and decision-making (Fathi & Fiedrich, 2022). These community-driven approaches fill critical data gaps and demonstrate how resilience may emerge from bottom-up information systems that complement top-down risk assessment frameworks.

Another crucial component for disaster risk preparedness and response is accurate data transformed into estimates of digitalised risk for critical infrastructures (Argyroudis et al., 2022). When functioning effectively during an extreme event, this framework can significantly mitigate negative impacts and support response and recovery efforts. Conversely, infrastructure failures can aggravate the consequences of a disaster; critical infrastructures can function as “impact conveyors”, where infrastructure failures in hazard-affected areas trigger cascading effects that extend beyond the hazard zone (Liu & Song, 2020). Transitioning from theoretical models to real-world analyses, especially when moving from assessing single infrastructure impacts to modelling complex failure cascades, requires vast heterogeneous datasets that include socio-economic data (Nirandjan et al., 2024). Even though the greater availability of data nowadays is already heightening the possibilities of critical infrastructure modelling, the demand is far from being met (Schotten et al., 2024). Ultimately, investing in resilient infrastructure and

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capturing them in digital risks, with spatial and temporal dynamics, is crucial to addressing systemic risks from multi-hazard threats, such as floods, droughts, wildfires, extreme heat, and pandemics (Argyroudis et al., 2020).

The Sendai Framework states that Member States must ensure that multi-hazard, vulnerability, and exposure analysis are used to inform high-level, multi-year socio-economic planning. This requires integrating multi-hazard risk assessments into decision-making processes, highlighting how hazards interact and cascade. Many EO products are now open-source to maximise operational relevance and long-term improvement. These form the backbone of critical life- and infrastructure-protection services against hazards like earthquakes, floods and forest fires, such as the European Forest Fire Information System (McInerney et al., 2012) or the European Flood Awareness System[3]. Similarly, where hazards are dynamic and involve both natural and managed components, decisions around risk-mitigating infrastructure must be supported by near-real-time information. For decision makers it can be challenging to pinpoint where exactly resources and measures must be implemented to efficiently improve system-wide infrastructure resilience, and digital twins may be vital in these developments.

3.4 Integrating Multi-Level Governance for Multi-Hazard Risk Management

Effectively managing disaster risks requires a shift towards more coherent, integrated approaches that transcend silos, sectors, and scales (Becker & Reusser, 2016). It thus demands more clearly defined roles and responsibilities, better governance, and knowledge co-production to manage trade-offs and synergies in decision-making (Maldonado et al., 2010). Fragmentation may prevent disaster risk management from being integrated and could subsequently limit its ability to anticipate and respond to complex, cascading, and systemic risks (Schweizer, 2021). To this end, it is crucial to strengthen coordination across actors and scales to ensure that strategies are both actionable and inclusive, for example by communicating good practices and providing risk-management frameworks to a broad range of users, including non-technical audiences. This helps develop a shared understanding of concepts and challenges (Gill et al., 2022; Hochrainer-Stigler et al., 2023; Šakić Trogrlić et al., 2024) and may ultimately reduce vulnerabilities and enhance resilience (Munene et al., 2018). Based on the conference and expert consultation, we identified two key priorities regarding how science can advance the Sendai Framework and beyond—noting synergies with the Paris Agreement's Global Goal on Adaptation— to facilitate a more coherent and integrated risk management and build capacity for risk-informed decision making.

3.4.1 Coherent and Integrated Management of Multi-Scale Risks

A lack of clearly defined actor roles and responsibilities hinders a more coherent and integrated management of disaster risks, including bridging DRM and climate change adaptation (CCA) (Liss et al., 2024). As the Sendai Framework MTR points out, such risk management is needed. To achieve this, we should first encourage aligning and coordinating efforts with several ongoing initiatives. The UNDRR programme on Comprehensive Disaster and Climate Risk Management (CRM) can offer a vehicle to increase coherence, as it seeks to integrate risk-centred approaches into National Adaptation Plans (NAPs), and

[3] https://www.copernicus.eu/en/european-flood-awareness-system

climate/scenario information into national and subnational disaster risk reduction strategies. Risks need to be explicitly assessed for trade-offs and synergies for effective management. Moreover, capacity building of DRM and CCA actors is essential to develop skills in multi-risk thinking, methods, and approaches that can capture interactions in time/space between hazards, vulnerability, and exposure, thereby supporting pathways to decision making (Schlumberger et al., 2022). Examples of such approaches are co-produced evaluation frameworks (Schlumberger et al., 2024); the Dynamic Adaptive Policy Pathways for Multi-Risk (DAPP-MR) approach to co-develop multi-hazard risk reduction pathways; in-depth stakeholder interviews (van Maanen et al., 2024); evidence-based tools to support bridging DRR and CCA communities' capacity (Poljanšek et al., 2022); and the stochastic multi-criteria acceptability analysis (Jäpölä et al., 2024).

Second, multi-scale risk management requires additional governance capacity to strengthen relationships among actors and enable collaborative mechanisms (e.g. boundary spanning staff or joint funds) for generating knowledge, policies and interventions that harness the aforementioned synergies and avoid trade-offs across sectors, domains and scales (Cumiskey et al., 2019). Overarching and vertical coordination and knowledge sharing are needed to bridge crosscutting DRR and CCA issues; however, complex and inflexible governance mechanisms should be avoided (Zuccaro et al., 2020). Recent studies show how collaborative efforts and tools that address cascading and systemic risks through shared insights and actions can contribute to this (Dai & Azhar, 2024; McCullagh et al., 2023). For instance, spatial perspectives, participatory mapping, and transboundary collaborations illustrate how stakeholders can harmonise global strategies while addressing localised needs.

Nature-based Solutions (NbS) exemplify how disaster risk governance can be strengthened by applying established ecosystem management principles within participatory, multi-stakeholder processes across sectors, domains, and scales (Nithila Devi et al., 2025; Sudmeier-Rieux et al., 2019, 2021). For example, they contribute to flood protection, while providing an array of co-benefits such as fisheries and carbon sequestration (Barbier et al., 2011; Mortensen, Tiggeloven, Haer, et al., 2024; Tiggeloven et al., 2022). Furthermore, they contribute to global targets of the SDGs-particularly SDG 14 and 15-and the Paris Agreement by increasing ecosystem resilience and reducing vulnerability to natural hazards, making them appropriate for inclusion in governance at all levels.

3.4.2 Early Warning Systems and Risk-Informed Decision-Making in an All-of-Society Approach to Risk Management

Reflecting the above points, the consensus view at the conference called for all-of-society risk management - integrated stakeholder engagement, improved early warning systems, and risk-informed decision making. This includes hazard interactions and warnings being communicated and acted upon at all levels (Budimir et al., 2025). To foster an all-of-society approach to risk management, it would be essential to enhance inclusive stakeholder engagement where the values and perspectives of policymakers, researchers, nonprofit organizations, and local as well as indigenous communities are reflected (Seddon et al., 2021). In addition, knowledge co-production may also promote ownership, empowerment, trust and representation, which in turn would make risk management strategies more equitable, actionable and context-sensitive, and would encourage societal actors to contribute to reducing disaster impacts (Liss et al., 2024; Mercer et al., 2012).

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Presented examples of methods to achieve this include qualitative systems dynamics modelling (e.g. causal loop diagrams) that can help to build a shared understanding among multiple actors of the complex social, economic, environmental, and political interactions (Hanf, 2024). Studies by Michellier et al. (2024) and Villeneuve (2021) show how participatory methods prioritise high-risk groups' needs by integrating lived experiences with scientific evidence. Similar insights emerge from the Early Warning System (EWS) community, where a growing body of knowledge highlights the effectiveness of including the most vulnerable in EWS (Hermans et al., 2022; UN.ESCAP et al., 2023) – particularly through community-based efforts, such as building a low-cost and effective local-level EWS (Rai et al., 2020). Similarly, the Missing Voices Approach developed by Practical Action (Brown et al., 2022) focuses on the inclusion of the most marginalised people (e.g., based on sex, gender, race, sexual orientation, ethnicity, wealth, and/or geographic location). We recommend the more widespread use of such approaches in DRM studies to better leverage the benefits of an all-of-society approach.

The current state of Multi-Hazard Early Warning Systems (MHEWS) distils many of these challenges. A MHEWS consists of a warning value chain with multiple actors from the weather modellers and agencies who are generating forecasts to end users who receive these warnings (Golding, 2022). In a perfect warning chain, the warning received by the end user would contain precise and accurate information that perfectly meets their needs. Yet, weather and hazard forecasting models—and their communication effectiveness—remain imperfect. Forecasting multi-hazard events is particularly complex, as impacts often depend on infrastructure performance or operational decisions that are difficult to model due to stochasticity or information of an intricate, internal nature (Budimir et al., 2025). Various projects, presented at the conference, are developing protocols to evaluate EWS (e.g. The HuT project, HiWeather project), and these form a good starting point to improve and expand MHEWS to account for multi-hazard interactions and response trade-offs (Homberg & McQuistan, 2019). As in other aspects of multi-hazard risk science, stakeholder engagement and knowledge co-production contribute significantly to improving MHEWS. Research presented by Msigwa & Makinde (2024) and Siu (2024) demonstrates how combining community-driven insights, vulnerability data, and new technologies has made these systems more effective and actionable in different geographic settings. Participatory approaches bring local contexts into early warning systems and promote cross-boundary coordination, while collaborative efforts make warnings more timely, more widespread, and more usable to enable communities to act proactively.

4 Implications and Future Directions

As the global community begins shaping the post-2030 DRR framework, our contribution to this dialogue highlights innovations in science and technology that advance global DRR priorities. The 2024 conference provided a timely platform to gather community perspectives and explore future directions, and this resulting paper highlights how emerging risk assessment tools and inclusive, participatory approaches are transforming our understanding of multi-hazard risks, reflecting the rapid evolution in multi-hazard risk research and practice over the past decade. In addition to a forum for presentations and idea formulation, the conference thus served as a checkpoint for evaluating the research community's views on future directions.

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Our findings align with broader community perspectives: a recent survey of natural hazards researchers identified similar challenges, including shortcomings in risk knowledge and inadequate translation of science to policy and practice (Šakić Trogrlić et al., 2022). From the demographics of our survey respondents, these results primarily reflect a cross-section of opinions among academic multi-hazard researchers (see Figure 2).

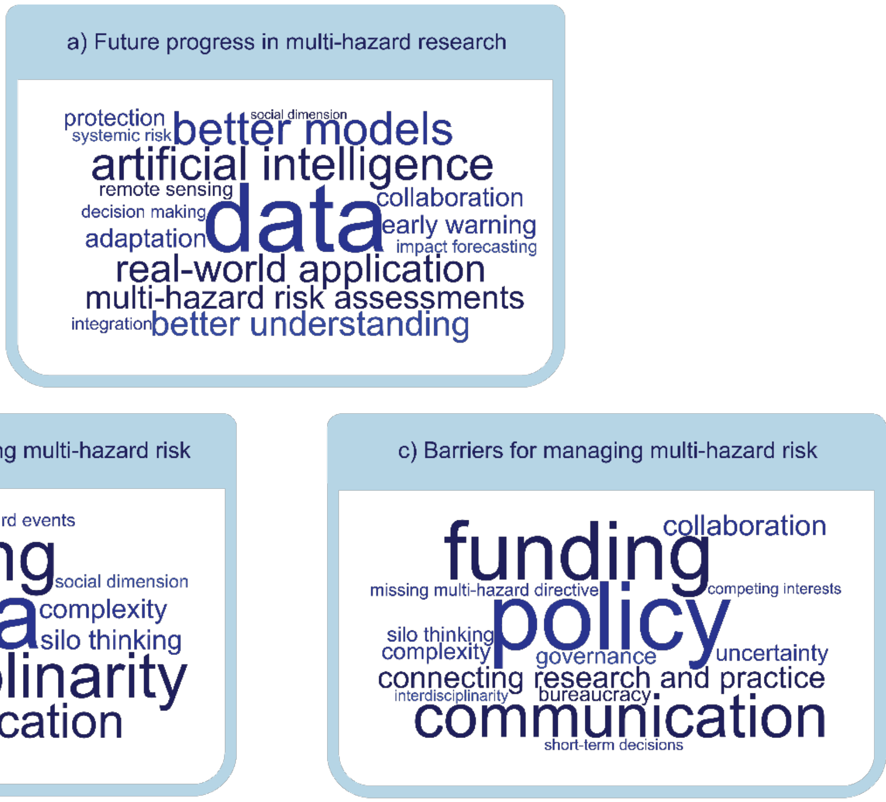

Figure 2: Word clouds depicting survey responses on multi-hazard risk research priorities and barriers. Survey respondents (n=86) identified key themes for (a) future progress in multi-hazard research, emphasising the need for better models, data integration, and artificial intelligence applications; barriers to (b) understanding multi-hazard risks, highlighting funding constraints, data limitations, and interdisciplinary communication challenges; and barriers to (c) managing multi-hazard risks, focusing on policy gaps, funding issues, and communication between research and practice. Word size reflects frequency of mention across open-ended survey responses.

We consolidate these views into three key points. Firstly, effective risk management for multi-hazards requires institutions that are both capable and committed to making long-term, large-scale investments in knowledge generation, policy development, and concrete actions across domains and geographies. These efforts should both inform and be informed by relevant physical and social science research as interpreted, integrated, or indeed enhanced by qualified boundary-spanning organisations as part of an all-of-society approach. Additionally, cultural and political perceptions - both within the research community and among broader public - are crucial considerations for effective DRM. Dynamic vulnerability is especially challenging to capture in the times and places where its understanding is most critical, as it depends on context-specific, fine-scale socio-economic conditions and their changes over time—such as shifting livelihoods, coping capacities, and institutional

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responses—which are often poorly understood or insufficiently captured in available data (de Ruiter & van Loon, 2022). Other major impediments include coordination and communication both across scientific fields, and between research, policy and practice—a situation driven as much by practical constraints as by ingrained 'siloed' thinking. Additionally, governance frameworks across sectors and scales need better alignment to enable coherent multi-hazard risk management.

Secondly, delivering on the promise of current and emerging science to enhance societal well-being requires a robust, multidisciplinary environment of actors spanning research, policy, and practice-developed through conferences, training programmes, research grants, and similar initiatives. The greatest enthusiasm lies in the increasing integration of efforts across the research-to-action or research for policy spectrum, which holds potential for reducing multi-hazard impacts through improved prevention, preparedness, predictions, adaptation planning policies, and other risk-management pathways. Such advances are understood to hinge on progress both in technical areas - such as data quantity, quality, accessibility, and harmonization with modelling approaches - and at the organisational or governance level, including through structurally embedded transdisciplinary collaborations, horizon scanning exercises, coordinated programmes across policy areas, and other types of strategic initiatives. The translation of knowledge into management strategies for multi-hazard risks is perceived to be primarily constrained by insufficient attention to developing science-informed multi-hazard policies, as well as by barriers to the bidirectional exchange of ideas between research and practice. Multi-hazards' inherent complexity, models of funding and publishing, and misalignments between actual and perceived risks are lesser but still salient considerations.

Thirdly, emerging technologies such as digital twins, AI-driven frameworks, and participatory tools can drive the development of integrated and adaptive models that deepen knowledge and enhance decision-making. Such an environment could naturally integrate concepts, share data and methods, and build from foundational multi (-hazard) risk concepts toward a more fully realised risk-management meta-strategy that responds to current needs while anticipating those that may yet be over the horizon. However, implementing this is likely to be significantly challenging, particularly due to persistent data limitations which remain a major obstacle to advancing our understanding of multi-hazard risks, as cited by nearly half of survey respondents.

Ultimately, we call for moving beyond siloed thinking toward greater integration of multi-hazards, vulnerability dynamics, multi-level governance, stakeholder engagement, knowledge co-production, and scientific disciplines across spatial and temporal dimensions - while recognising that the key challenge lies in striking the optimal balance between sufficient integration and manageable complexity. Approaches like storylines, explainable AI, advanced data analysis, and community engagement can help navigate this complexity without resulting in unmanageable frameworks. These findings and recommendations not only address current gaps in the Sendai Framework MTR but also seek to inform the development of its post-2030 successor, emphasising that effective DRR must initiate transformative processes to build resilience amid growing pressures from climate change and other global challenges—ultimately supporting broader efforts to achieve the Sustainable Development Goals (SDGs) through enhanced societal resilience.

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Competing interests. The authors declare that they have no conflict of interest.

Ethical statement. The work performed in this study is original, reflects the authors' understanding, and does not involve human research participants in the traditional sense. However, this research did include two forms of data collection from human subjects: (1) a questionnaire distributed to conference attendees, and (2) expert consultation completed by the co-authors of this study. Both data collection activities were conducted with informed consent as participants were made aware of the research purpose and their voluntary participation. The questionnaire and expert consultation was focussing on professional opinions and expertise rather than personal or sensitive information. All responses were handled confidentially and used solely for the purposes of this research.

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Appendices

Appendix A: Conference reports

General advances in disaster risk science and compound events

This area drives a nuanced understanding of disaster risks and compound events, recognising interconnected risks and scientific breakthroughs (which directly supports Priority 1 and 4 of the Sendai Framework). The session “General advances in disaster risk science and compound events” highlighted many forms of single and multi-hazards, covering both meteorological and hydrological, geohazard, societal and biological types. Disaster risk science is a fast-evolving field where progress is being made for a diverse range of topics, including hazard assessment, management, impacts, adaptation, and the inclusion of inequality in social vulnerability. Valuable steps to advance this dynamic field include enhancing communication strategies to better engage decision-makers and the public, addressing data gaps through targeted collection efforts in the Global South, and maximising the potential of existing datasets by fostering innovative approaches to their integration and analysis. The need for addressing disaster risk in an increasingly inclusive (e.g., multi-hazard context and all-inclusive world) manner holds a key opportunity to address the systemic nature of hazards without unnecessary complexity. There is a need for the compound risk communities to communicate and collaborate with those in the disaster risk reduction field to work around this complexity.

Dynamics, interdependencies and interactions of risk drivers

Understanding how risk drivers interlink and amplify each other is crucial for systemic resilience, underscoring the need for comprehensive, integrative risk analysis methods (which directly supports Priority 1, 2, and 4 of the Sendai Framework). The session "Dynamics, interdependencies and interactions of risk drivers" detailed these complexities and stressed the value of coordinated risk reduction strategies. Although, the session was marked by single-hazard studies, and difficulties in including dynamics in risk assessments, many promising developments in the field of dynamic risk assessments are emerging. For example, novel qualitative assessments may give new insights into vulnerability and risk, such as causal loop diagrams and risk profile scenarios, but introduce complexities and challenges in transferring findings across locations or scaling across spatial levels. For quantitative analyses however, data limitations, uncertainty in quality/biases significantly restricted the scope of the research, which could lead to creating a paradox where increased focus demands even more precise information. Future scenarios, while uncertain, highlight that present choices shape potential outcomes, underscoring the need to consider evolving risk drivers, socio-economic trends, and unintended impacts in risk assessments.

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Systemic risk – assessing, modelling, coping

Evaluating systemic risk across interconnected domains emphasises the need for coordinated risk assessments in a multi-hazard context. This approach advances understanding of complex risk interactions, addressing gaps in data and governance to manage risks across sectors (Priority 1: Understanding Risk and Priority 2: Governance). The session "*Systemic risk – assessing, modelling, coping*" explored the challenges of addressing multi-hazards and the need for cross-sector collaboration. A key challenge is to identify and potentially streamline approaches for capturing and analysing systemic risk. While several features of systemic risk set risks apart from other risks, e.g. complexity as well as transboundary and cascading effects within systems, across systems or systems domains, a key methodological challenge remains with regards to setting system boundaries and defining what is considered inside or outside a system and, hence, the analytical focus. Another key methodological challenge is on starting points for systemic risk analysis, such as whether to focus on the system, hazard, or trigger event, and how to balance quantitative with qualitative data for meaningful insights. Furthermore, there is a need for harmonising diverse case study approaches and improving models by integrating simulations with real-world observations, but also for paying attention to societal impacts and distributive justice issues. Finally, a key take-away of the session is that researchers should not only focus on academic puzzles but also provide scenarios, models, and tools that are useful for policymakers, interest groups and the public for answering societally relevant questions.

Advancing critical infrastructure modelling in a complex world

Modelling critical infrastructure (CI) interdependencies helps mitigate risks to essential services in multi-hazard scenarios. Progress here is critical for both reducing exposure and building resilient systems (Priority 2: Governance, Priority 3: Resilience Investment). The session "Advancing critical infrastructure modelling in a complex world" was characterised by a high degree of diversity, on the one hand through a wide variety of applied methods, but also through the coverage of various CI (e.g., transportation networks, ports, health infrastructure, airports, and electricity grids) and different hazard types (e.g., floods, multi-hazards, volcanic eruptions, storms), although no man-made hazards. One of the key challenges is to approach CI from an all-encompassing and systemic perspective of the interconnected nature of CI and resulting cascading effects not only on the physical level but including social and economic factors. Another, yet scarcely addressed challenge is the inclusion of the temporal dimension (short and long-term) in CI impact modelling. Data availability remains a bottleneck, but the growing access to public data is improving CI modelling, shifting from theoretical to more empirical, real-world-based approaches. Future research should focus on deepening the understanding of complex CI interactions further, especially in the face of multi-hazard and cascading effects beyond hazard boundaries, for example by using novel methods such as deep learning algorithms and agent-based modelling seems promising to make use of the growing data availability.

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Artificial Intelligence and Machine Learning for Multi-Risk Assessment

AI and ML improve predictive capabilities for multi-risk assessments, which may enhance early detection and response strategies. Rapid advancement in these fields is essential for furthering the understanding (Priority 1: Understanding Risk and Priority 4: Preparedness and "Build Back Better"). The session "Artificial Intelligence and Machine Learning for Multi-Risk Assessment" emphasised the transformative role of AI in synthesising complex hazard data for more adaptive risk management, and covered applications of AI methods on very different aspect of risk analysis, starting from hazard analysis and forecasts, exposure and vulnerability factors and integrated multi-risk approaches. Recent advancements in machine learning, including deep learning (e.g., convolutional neural networks and Transformers) and ensemble models (e.g., Random Forest and XGBoost), have been applied to a range of problems such as multi-hazard susceptibility mapping (that integrates climate and geophysical hazards), downscaling techniques, water quality assessment, and analysing the relationship between food security, social conflicts, and weather factors. A key recent development in the field is the growing emphasis of explainability of AI, with many methods, such as feature importance, SHAP values and Partial Dependency plots, being used to understand the role played by risk factors in the analyses. One of the challenges is the integration of the multi-hazard context into risk analysis applications of AI, however more attempts are lately recently made. Furthermore, the role of Large Language Models and Generative AI in climate services, highlight the potential of Deep Reinforcement Learning (DRL) to optimise the adaptation process and Multi-Modal Generative ML to identify specific adaptation options addressing multi-risks.

Assessing multi-hazard risk using Earth-Observation data

Earth Observation (EO) data supports real-time monitoring and allow for spatially detailed risk assessments (Priority 1: Understanding Risk and Priority 4: Preparedness and "Build Back Better"). The session "Assessing multi-hazard risk using Earth-Observation data" provided an in-depth look at EO's potential in capturing dynamic, overlapping hazards with precision covering a wide array of hazards (among them volcanic eruptions, floods, landslides, earthquakes, and heavy cloud cover) and geographies. One of the benefits of using satellite data is the global coverage and advances in imaging and data analysis that enable detailed earth science at building or field scales, even in traditionally data-poor areas. Oftentimes on-site collaboration with stakeholders helps guide problem identification and contribute crucial local knowledge about both the relevant processes and the impacts of the events in question. However, attributing risk in multi-hazard scenarios and distinguishing their cumulative impact (such as spatial correlations in geography) remains a significant challenge to consider hazards that are not just multiple but correlated. To address these challenges, future directions could include refining methodologies, promoting satellite use for disaster studies, and leveraging interpretable AI to develop standardised multi-sensor comparison products for multi-hazard risk analysis.

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Health and Disasters

Integrating health considerations into multi-hazard assessments is vital, as disasters often exacerbate health risks, including disease outbreaks like waterborne illnesses post-floods or vector-borne diseases like malaria. Strengthening health resilience within disaster risk reduction directly supports Sendai Priority 2 and 4 by emphasising preventive measures and rapid response to safeguard populations. The session "Health and Disasters" highlighted critical intersections between disaster risk and public health, addressing both immediate and long-term risk assessments. In recent years, it has proven quite a challenge to bring together the disaster risk and health research domains, which made clear that there are still improvements to be made in integrating health and disease research into disaster risk science. However, a lot of studies, ranging from climate models to identify potential heat mortality extremes, mental health, systemic effects on healthcare facilities to practitioners discussing real-life impacts, are taking important steps to address these challenges. One of the main needs is for practitioners and scientists to work together to advance the integration of these research domains, and to produce actionable research outputs on health and disasters. A key opportunity is to not only learn from the risk as we have seen it in the past, but also potential health implications that the world could face in the future, such as intensified heat extremes and the potential expansion of the endemic area of diseases, in which storylines have proven to be a specifically useful tool.

Recent developments in multi-hazard early-warning systems

MHEWS play a critical role in preventing disasters and facilitating anticipatory action by providing timely, reliable warnings that empower communities to respond proactively. Progress in expanding and integrating MHEWS is urgent to enhance community resilience (Priority 4: Preparedness and "Build Back Better"). The session "*recent developments in multi-hazard early-warning systems*" highlighted a list of key challenges and opportunities in early warning systems (EWS), especially for multi-hazard early warning systems (MHEWS). Small Islands Developing States (SIDS) are often overlooked in EWS research, and there is a need to avoid getting caught in terminology, instead focusing on addressing multi-risk within EWS. It is essential to ensure a clear link between modelling activities, hazard intensity thresholds, and warning criteria, theoretically embedded within the disaster warning model itself. On the opportunities side, soft adaptation measures show promise, particularly in the context of SIDS. MHEWS should also expand beyond natural hazards to consider other systems, such as health and human-induced risks. The UNDRR's "first mile" approach, which emphasises local engagement for those directly impacted, should be widely adopted, and standardisation of MHEWS approaches is necessary to streamline efforts.

Nature-based Solutions for Disaster Risk Reduction

Nature-based Solutions (NbS) integrate ecosystem-based approaches to reduce disaster risks while promoting environmental sustainability. Their role in fostering resilience aligns with investments in long-term DRR measures (Priority 3: Resilience Investment, Priority 4: Preparedness). The session "Nature-based Solutions for Disaster Risk Reduction" explored the benefits and challenges of implementing ecosystem-based approaches in hazard-prone areas. This is a powerful approach building on

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nature enhancement, ecosystem restoration, and protection, which can help societies to adapt to climate change and reduce disaster risk while providing numerous additional benefits such as health, recreation, food, and clean water. However, their implementation is hindered by an array of gaps in the knowledge base, preventing them from delivering their full potential. Some challenges relate directly to stakeholders involved in NBS projects and to better understand how stakeholders interact within debates, their roles, and the values they share, to facilitate future coalition building and enhance acceptance of NbS. Continued research on stakeholder attitudes, acceptance, and investment willingness is crucial and providing stakeholders with evaluation frameworks can further facilitate NBS implementation. Literature on NbS is complex and entails different terminologies and heterogeneous approaches to evaluate their performance, while novel methods allow for new risk frameworks that can include NbS.

How Can Stakeholder Engagement and Knowledge Co-Production Enhance Effective Multi-Risk Management?

Stakeholder engagement and knowledge co-production are essential for developing inclusive, effective risk management strategies, enabling communities and experts to work collaboratively to build greater resilience (Priority 2: Governance, Priority 4: Preparedness). The session "How Can Stakeholder Engagement and Knowledge Co-Production Enhance Effective Multi-Risk Management?" underscored the importance of knowledge co-production and stakeholder engagement in understanding multi-risk contexts and capturing the interrelationships necessary for developing adaptable, context-specific risk management solutions. Connecting local and scientific knowledge, including systemic, orientation, and transformation knowledge, enhances the effectiveness of these efforts. One of the key challenges in effective engagement is ensuring equity and enabling interdisciplinary collaboration, as well as transdisciplinary work with stakeholders such as policymakers, technical practitioners, and local communities in a multi-sectoral, multi-hazard setting. Additionally, ethical considerations are crucial, and collaborators should be involved at every stage, with special attention to sensitive contexts like conflict settings where sensitive data must be handled carefully. In doing so, building trustworthy relationships may slow progress, but the long-term value is clear. Capacity-building for interface roles – those who support dialogue and co-creation - is critical yet often undervalued.

Science for policy and practice: Synergising Disaster Risk Reduction and Climate Change Adaptation

Science-driven strategies help bridge DRR and climate adaptation, strengthening policies and frameworks to address intersecting risks. Advancements here drive systemic understanding and proactive responses (Priority 1: Understanding Risk, Priority 2: Governance). The session "Science for policy and practice: Synergising Disaster Risk Reduction and Climate Change Adaptation" was characterised by challenges, novel approaches and recommendations that enhance resilience by linking DRR and Climate Change Adaptation by using methods such as participatory approaches, the co-creation of knowledge, and the communication of risks to non-scientific actors. One of the biggest challenges is the increasing complexity of quantifications and inherent uncertainties of managing risks in a multi-hazard decision-making context, where present-day

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risks and long-term future risks need to be considered. Oftentimes, the relevant planning timelines across risk-relevant sectors and governance levels rarely align as they might be influenced by election cycles being shorter than planning cycles, thus requiring additional interfacing capacity to proactively seek synergies and integration. Recent tools and approaches are incorporating innovative ways to co-create future scenarios in a participatory way following a systematic understanding of present and future risks, like the gradual introduction the complexity of the multi-hazard risk context to non-scientific actors, and the potential of stronger qualitative or semi-quantitative approaches such as system dynamics and agent-based modelling. Improved communication and mainstreaming the benefits of addressing DRR and CCA together will help minimise the risk of maladaptation and lock-ins while simultaneously reducing future risks through DRR and addressing current risks through CCA (REF).

Storylines and narratives for multi-hazard, multi-risk decision-making

Narrative-based scenario planning helps communicate complex risks, increase risk awareness and informed decision-making among diverse stakeholders (Priority 1: Understanding Risk, Priority 2: Governance). The session "Storylines and narratives for multi-hazard, multi-risk decision-making" discussed the important role of storylines and narratives as an approach to explore complex and cascading risks and unprecedented events, including direct and indirect impacts across different sectors and contexts, such as the humanitarian sector and hazard specific contexts. There are many definitions of the term storyline, the frameworks and the methodologies applied to create storylines, as well as varying methods and tools including narratives and elicitation, timelines, scenarios, modelling, impact chains and causal networks, often tied to the local context. One of the key challenges is the intersectionality of the physical and social sciences and the role of the interdisciplinary and transdisciplinary approaches for storylines that include the social drivers. Furthermore, there is a challenge of integrating quantitative evidence into the qualitative storylines, or what qualitative data can bring to quantitative analysis. The iterative nature of storyline development is an essential component of storyline development, such as stakeholder engagement through participatory engagement (e.g. elicitation). Finally, a challenge of visualising storylines remains, including how to communicate complex graphical models to diverse audiences and incorporate temporal components, and an opportunity exists in exploring the role of arts and humanities, like illustrations, to make the science more accessible.

Learning from the past: historical perspectives and 'success stories' of DRR

Historical perspectives offer valuable insights into effective DRR strategies, emphasising the importance of building on past successes to inform present and future actions (Priority 1: Understanding Risk, Priority 4: Preparedness). The session "Learning from the past: historical perspectives and 'success stories' of DRR" highlighted how historical analysis can guide improvements in current DRR practices. One of the key challenges, however, for disaster forensics is incorporating climate change and urbanisation as multi-hazard drivers into assessment frameworks. In the response phase there is a need for hazard-specific response capacity and recovery planning, including evacuation facilities and long-term housing, while also identifying

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synergies with other sectors. More education and public communication are needed to improve public safety in the face of climate change-influenced hazards, which can enhance the effectiveness of warning, response, and recovery measures, including severe and infrequent "black swan" events. Currently, there is a research gap in addressing topics such as evacuation, large-scale recovery analyses, and the role of insurance in recovery and adaptation needs in the field of disaster forensics. However, while there may be opportunities and benefits for learning across regions, barriers to transferring lessons learned remain and more harmonisation is needed to contextualise these lessons.

Demonstration of tools and services

Demonstrations of new tools underline their impact in translating complex data into actionable insights, supporting informed decision-making and proactive risk management (Priority 1: Understanding Risk, Priority 4: Preparedness). The session "Demonstration of tools and services" showcased innovative tools and services enhancing data-driven decision-making for multi-hazard resilience. The barriers in the use of new technology-based solutions for multi-risk assessment and management may relate to usability, skills gaps, access, availability, and stakeholder interests, needs, and priorities. Ensuring these tools are accessible to a diverse range of stakeholders, using tutorials, and addressing technological challenges based on stakeholders' needs, especially for non-technical users, can enhance engagement, for example through initiative like the Disaster Risk Gateway. Early discussions with stakeholders about their information needs, especially for tools like Digital Twins, and integrating these tools into planning processes, particularly for urban planners, can significantly improve their relevance and usability. Maintaining open-mindedness, understanding data barriers, and ensuring that platforms are designed by and for the users can enhance their effectiveness and adoption.

Appendix B: Expert consultation on how science can contribute Sendai Framework progress

Assessments and Tools

The "Assessments and Tools" perspective focuses on enhancing the understanding and management of disaster risk through inclusive, data-driven, and technology-enabled approaches. This includes developing a shared understanding of risk, improving tools and methodologies, and ensuring all-of-society engagement in disaster risk reduction (DRR). The following themes aim to gather insights on how the topic and focus of your session can contribute to advancing these goals:

1. **Enable more inclusive recovery**: Highlight the role of tools and assessments in ensuring recovery processes are inclusive and aligned with Building Back Better (BBB) principles, supported by legal frameworks.
2. **Develop a shared understanding of risk**: Explore how your topic/session contributes to better data availability, stakeholder engagement, and multi-hazard risk management to inform planning and decision-making.
3. **State-of-the-art tools**: Share advancements in tools or methodologies that enhance risk analysis or decision support for DRR.
4. **Enhance granularity in risk data and information**: Explain how your topic/session addresses the need for disaggregated data that captures vulnerabilities and impacts across different groups and indicators.

5. **Improve data standards, governance, and technology**: Provide insights on how your topic/session supports better data interoperability, governance, and integration into decision-making platforms.
6. **Enable all-of-society engagement and participation**: Reflect on how the research of your topic/session promotes community involvement, stakeholder collaboration, and the use of open and local data for DRR.

Complex Risks

The "Complex Risks" perspective focuses on understanding and addressing the interconnected and multi-layered nature of risks in today's world. This includes systemic risks, health and disease-related risks, and the challenges posed by technological advancements and rapid change. This perspective will also highlight the need for improved collaboration between DRR and statistical communities, enhanced granularity of data, and strengthened communication and awareness to build resilience and support governance. The following themes aim to gather insights on how the topic and focus of your session can contribute to advancing these goals:

1. **Enhance knowledge and understanding of the systemic nature of risk**: Reflect on how your topic/session supports systemic evaluations (address health and disease-related risks or risk drivers) and promotes stakeholder engagement to manage interconnected risks.
2. **Improve collaboration between disaster risk reduction and statistical communities**: Share examples of how collaboration between statistical and DRR practices can improve data collection, analysis, and risk assessments.
3. **Emerging technologies**: Discuss what the role of scientific and technological advancements in addressing or managing complex risks for your topic.
4. **Enhance granularity in risk data and information**: Explain how the research of your topic/session contributes to creating disaggregated data sets to capture vulnerability, exposure, and impacts across diverse groups and indicators.
5. **Strengthen risk awareness and communication**: Provide insights on how your topic/session improves public or stakeholder understanding of risks and fosters a culture of prevention and resilience-building.

Emerging Technologies

The "Emerging Technologies" perspective focuses on leveraging transformative tools and advancements to expand our capacity for risk assessment, resilience-building, and disaster preparedness. This includes improving infrastructure resilience, fostering a shared understanding of risk, enhancing data quality and granularity, and applying emerging technologies to manage complex risks. The following themes aim to gather insights on how the topic and focus of your session can contribute to advancing these goals:

1. **Invest in resilient infrastructure and systems**: Describe how the research of your topic/session contributes to developing, upgrading, or incentivising resilient infrastructure systems that integrate risk assessments and support public investment mechanisms.
2. **Develop a shared understanding of risk**: Share insights on how your topic/session promotes multi-hazard, vulnerability, and exposure analysis to inform planning, budgeting, and financing for disaster risk reduction.

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3. **Emerging technologies**: Highlight the role of innovative technologies, such as AI or scenario-planning tools, in improving risk assessments and managing complex risks.
4. **Enhance granularity in risk data and risk information**: Discuss how the research of your topic/session advances the development of disaggregated datasets to capture diverse vulnerabilities, and disaster impacts across multiple indicators.
5. **Improve data standards, enhance data governance, and invest in data technology**: Reflect on how your topic/session emphasises the importance of interoperable data systems, enhanced data governance, or the integration of advanced tools for risk analysis and decision-making.

Stakeholder Engagement and Disaster Risk Management

The "Stakeholder Engagement and Disaster Risk Management (DRM)" perspective highlights the critical role of inclusive governance, cross-sectoral collaboration, and community-based approaches in managing and reducing risks effectively. It emphasises building capacity for integrated decision-making, multi-scale governance, and improving early warning systems. The following themes aim to gather insights on how the topic and focus of your session can contribute to advancing these goals:

1. **There is a need for more coherent and integrated management of risks**: Reflect on how the research of your topic/session supports adaptive governance and coordinated risk management across sectors, domains, and scales, considering the evolving scope of hazards and risks.
2. **An all-of-society approach to risk management**: Describe how your topic/session fosters inclusivity by engaging diverse stakeholders, including scientific, private, local, and Indigenous communities, with a focus on addressing the needs of high-risk groups.
3. **Multi-scale risk management**: Discuss how your topic/session contributes to connecting risk governance structures at local, national, regional, and global levels to strengthen risk reduction efforts.
4. **Building capacity for integrated risk-informed decision-making**: Share insights into how your topic/session builds technical capacity and supports pathways or storylines to inform decision-making across all phases of the risk management process.
5. **Increase the coverage and performance of early warning systems**: Highlight how your topic/session contributes to improving Multi-Hazard Early Warning Systems (MHEWS) by incorporating vulnerability data, integrating regional and community-level insights, or leveraging cross-boundary collaboration.