

# Author's Reply: Reflections and Future Directions for Multi-Hazard Risk in the Context of the Sendai Framework and Discussions Beyond

## Referee 1

I wanted to thank the authors for putting together such a wide ranging paper on what seems like a very interesting conference. The paper summarises the conference, highlighting areas where better data and modelling might be useful to reducing disaster risk. I have provided a very critical review, as the paper at the moment is very disjointed and lacks a clear set of research questions. The paper also seems to be based on circular reasoning with some major issues of bias in the methods. I think there is the potential to develop a really interesting perspective here, particularly with the work that has been done, but at the moment it is not suitable for publication, so I am recommending that the paper be rejected. I have attached an annotated manuscript with specific comments. To summarise my major comments:

We would like to thank the referee for the thorough review and constructive feedback. We appreciate the recognition of the conference's value and also the potential for developing an interesting perspective from this work.

We have carefully read and noted the referee's concerns regarding the paper's structure, methodological presentation, and potential biases. This useful feedback highlighted important areas for improvement that we had not fully considered in the previous manuscript, in particularly around:

- 1) Clarifying the inductive nature of our analytical framework to address concerns about circularity
- 2) Better articulating our research questions, overall narrative structure, and key recommendations
- 3) More explicitly acknowledging limitations in geographic and sectoral representation
- 4) Improving the transparency of our methodological approach

We are grateful to have had the opportunity from the editor to address these concerns through major revision. The referee's detailed feedback has provided an excellent roadmap for strengthening the manuscript's methodological rigor and analytical clarity. We have used the referee's annotated manuscript thoroughly to address further comments. Subsequently, the manuscript has changed a lot. We reply to the reviewer's individual comments below.

(1) Research questions: The paper as a whole lacks a clearly defined research question(s), which results in the paper wandering over a lot of issues without discussing anything in depth. The paper variously mentions wanting to make recommendations to the future beyond Sendai, to discuss better frameworks (although the term is never defined), to summarise the discussions of the conference. I would suggest that, if this paper is a critical review of the future of Sendai, that the paper highlights the major themes, progress (as highlighted by the MTR and other papers), and where the research and policy gaps that need to be filled.

We thank the referee for their comment and acknowledge that the manuscript would benefit from clearly defined research questions. While carrying out the research we did have four research questions (see list below) in our mind to guide the thought process that arose through discussions during the conference. These expand upon and link with gaps identified in the Sendai Framework Mid-Term Review (MTR). However, we acknowledge that we only used these to guide our thought process and therefore they were not explicit in the paper. We agree that adding them explicitly will strengthen the paper and we have done so in the revised manuscript. These questions provide the analytical structure needed to organise our findings systematically and furthermore to ensure that each perspective is discussed with an appropriate depth.

Additionally, in the revised manuscript we explicitly define key terms such as "framework", as well as providing more detailed context on the Sendai Framework MTR progress and gaps, which will subsequently situate our contributions within the broader DRR policy landscape. However, it should be pointed out that the paper is not intended as a review of the Sendai Framework, which has already been carried out very well in the UNDRR MTR; we believe that this is clarified with the inclusion of the research questions. We have structured the revised manuscript around these research questions, directly address them in the perspective section, and conclude with specific and actionable recommendations for both research and policy.

The questions are:

- 1) How can inclusive, participatory assessment approaches and advanced analytical tools bridge the gap between scientific risk knowledge and actionable decision-making across diverse stakeholder communities? (*Assessments and Tools for Risk Understanding and Decision-Making*)
- 2) What methodological advances are needed to capture and model the systemic, interconnected nature of multi-hazard risks, including their temporal dynamics and cascading effects across social-ecological systems? (*Complex Risk Landscapes*)
- 3) How can artificial intelligence, digital twins, and earth observation technologies be integrated to enhance multi-hazard risk assessment capabilities while ensuring accessibility and interpretability for decision-makers? (*Emerging Technologies for Risk and Resilience*)
- 4) What governance frameworks and institutional arrangements are most effective for enabling coherent, integrated risk management that spans sectors, scales, and disciplines while maintaining operational feasibility? (*Multi-Level Governance for Coordinated Risk Management*)

We now also provide a discussion with key recommendations, insights and critical barriers that came out of answering these questions, as follows:

#### *"4.1 Synthesising Science-Policy Priorities for the Sendai Framework and Beyond*

*Our analysis across four thematic perspectives reveals interconnected challenges that require integrated solutions. Table 2 provides an overview of the critical barriers and strategic interventions we discussed in our thematic analysis. Collectively, these barriers demonstrate that technical innovation alone cannot advance disaster risk reduction without addressing fundamental governance, equity, and capacity dimensions.*

Addressing these interconnected barriers requires systemic interventions operating across multiple scales and timeframes. We synthesise here immediate priority actions that should be pursued both to accelerate progress toward the 2030 Sendai targets and to contribute to broader discussions on post-2030 disaster risk reduction governance. These insights span the technological, governance, social, and physical-scientific realms; further details are provided in Table 2.

Table 2: Critical barriers and key priority action for the Sendai Framework and discussions beyond.

Themes	Critical barriers	Strategic interventions
<b>Assessment and Tools</b>	1. Usability barriers limiting non-expert uptake	1. Co-develop tools with end-users through iterative participatory design that integrate into existing operational workflows
	2. Fragmented data governance preventing integration	2. Establish interoperability standards and open-access repositories
	3. Resource constraints perpetuating inequalities	3. Invest in boundary organisations to make science actionable and link tool adoption to funding mechanisms
<b>Complex Risk Landscapes</b>	1. Methodological gaps in capturing dynamic vulnerabilities	1. Develop integrated methodological frameworks orchestrating multiple methods for temporal dynamics
	2. Data limitations constraining high-resolution temporal assessments	2. Invest in transdisciplinary knowledge co-production bridging science-policy-practice;
	3. Governance silos between DRR and climate adaptation	3. Transform governance structures enabling coordinated multi-level, cross-sectoral integration
<b>Emerging Technologies</b>	1. Algorithmic biases and limited interpretability undermining trust	1. Advance responsible AI frameworks prioritising interpretability, accountability and community engagement
	2. Infrastructure costs excluding resource-constrained regions	2. Build accessible interoperable infrastructure through open-source platforms and data-sharing frameworks
	3. Integration challenges between automated systems and local knowledge	3. Develop hybrid methodologies combining automated monitoring with human-in-the-loop decision-making
<b>Multi-level Governance</b>	1. Vertical misalignment where authority/resources concentrate nationally while responsibilities fall locally	1. Develop integrated multi-risk indicators embedding vulnerability through participatory threshold-setting
	2. Incommensurable frameworks operating on incompatible timescales	2. Institutionalise multi-scale coordination through statutory frameworks and partnership funding
	3. Weak accountability preventing community input	3. Invest in knowledge brokers translating across scientific-local knowledge systems and across governance levels and scales

However, to realise these recommendations, we are faced with substantial obstacles that extend beyond technical or financial constraints. Power asymmetries embedded in existing institutional structures resist redistribution of authority required for genuine multi-level coordination. Moreover, we have to bridge disciplinary silos that is perpetuated by academic incentive structures, funding mechanisms, and professional identities that hinder the transdisciplinary collaboration essential for systemic risk management. Acknowledging structural barriers is essential for designing realistic, incremental pathways toward transformation rather than assuming smooth implementation of recommendations.

Nonetheless, these strategic interventions would directly advance Sendai Framework objectives across all four priorities. For example, Priority 1 (understanding disaster risk) can benefit from integrated methodological frameworks capturing systemic interactions, and multi-risk indicators embedding vulnerability dynamics. Statutory multi-level coordination mechanisms and knowledge brokers facilitating vertical knowledge flows are examples that could contribute to Priority 2 (strengthening disaster risk governance). Priority 3 (investing in

*DRR for resilience) should be supported by interoperable infrastructure, open-access repositories, and hybrid methodologies combining technological innovation with local knowledge Priority 4 (enhancing preparedness for effective response and “Build Back Better”) can be advanced through participatory early warning indicator development and human-in-the-loop decision-making frameworks.*

*While we recognise that international frameworks do not automatically translate into effective on-the-ground disaster risk reduction, which is particularly evident in resource-constrained contexts where implementation gaps are substantial, the Sendai Framework MTR nevertheless provides a valuable structure for identifying where scientific advances can support policy objectives and prioritise research investments.*

(2) Lack of criticality: Throughout the paper many concepts are presented without a critical voice. For example, there is a call for better multi-level governance, but no discussion of why this has not been achieved, nor what the challenges to achieving this might be. Similarly, better data and models are often mentioned as a solution but this is presented without a critical view (e.g. I know many effective DRR examples that have been created with very little data and no modelling, similarly I know a lot of very good models that sit on a shelf and are never used). The paper recycles a lot of fairly well established academic theory without clearly establishing what is new. Also the referencing is pretty light in many places.

We thank the referee for this constructive comment and acknowledge this important critique. In the revised manuscript we have included critical engagement with the concepts and recommendations that are presented. In more detail, we have addressed the following issues:

- 1) We have explicitly addressed implementation barriers and challenges for each recommendation, and subsequently provide a critical discussion throughout. For example, we now discuss and provide insights from the conference and the range of expertise and experience across the author team in the multi-level governance section, why coherent governance remains elusive despite widespread recognition of its importance. For example, this may include institutional inertia, competing jurisdictional priorities, resource constraints, and political economy factors that maintain sectoral silos.
- 2) We acknowledge the valid point that effective DRR can occur with limited data/modeling, while at the same time more sophisticated tools may remain unused. In the revised manuscript, we therefore have added a critical reflection on when data/modeling approaches add value versus when simpler, community-based approaches may be more appropriate and sustainable. The manuscript now better distinguishes between technical potential and practical implementation, including discussion of accessibility, capacity constraints, and the risk of technological solutionism.
- 3) While we draw on established frameworks, we would like to emphasise that synthesising how these approaches specifically address Sendai Framework MTR gaps through contemporary applications is where the manuscript’s main contributions lie. Therefore, in the revised manuscript these novel elements are highlighted more explicitly.
- 4) Additionally, we have included more references at reference scarce places.

In the revised manuscript, these revisions have transformed the paper from a synthesis of recommendations into a more critical, nuanced analysis that is acknowledging trade-offs and implementation realities in advancing multi-hazard risk management.

(3) **Circularity:** The paper discussed 4 themes that are key to the future. In the methods these themes are discussed as being prescribed prior to the conference. Then the work that emerges and the questionnaires support these themes, and recommendations. So rather than emerging from discussions, it appears that the data collected supports the themes that have been pre-ordained as being important. Maybe I missed something, and if so this needs clarification. In general, the methods section is not adequate for a paper of this type.

We acknowledge the reviewer's concern about apparent circularity. To clarify, we developed the four perspective themes inductively from conference discussions rather than being predetermined. Conference sessions were organised around expert-identified priority topics, discussions were documented independently, and only then did we analyse these materials to identify emergent themes. We subsequently mapped these themes to Sendai Framework gaps to demonstrate policy relevance. We have revised the methods section (included in full below, with new text in bold) to make this analytical sequence clearer and emphasise the emergent nature of our research.

#### *"2 Methods and Conference Setup*

*This paper synthesises insights from the "Natural Hazards and Risks in a Changing World" conference, held in June 2024 in Amsterdam, through a structured methodological approach that combines multiple data collection and analysis techniques to advance understanding of multi-risk management. **The conference was organised by the MYRIAD-EU project, RISK-KAN, and NatRiskChange, and abstract submission was open to all, though the majority of attendees were affiliated with institutes in Europe. Our methodological approach progressed through the following sequential steps:***

- 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 **by expert session conveners** reflecting these priority themes (see Table 1)*
- 3. **Pre-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. **Inductive thematic analysis of conference outputs developed to identify emergent themes and knowledge priorities***
- 7. **Retrospective mapping of emergent themes and themes assigned to gaps identified in the Sendai Framework MTR***
- 8. **Development of four 'perspective themes' based on the cross-comparison of conference discussions and Sendai Framework gaps: Complex Risks; Assessments and Tools; Emerging Technologies; and Multi-level Governance***

9. *Post-conference survey of session conveners for **detailed** written input on how their sessions can address gaps identified in the Sendai Framework MTR (Supplementary Information B)*
10. *Integration and thematic analysis of all inputs (survey data, session reports, expert insights) to **refine/discuss** four key perspective themes (section 3) and outlook (section 4, see Figure 2)*

## **2.1 Conference Structure and Participants**

*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. 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.*

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

## **2.2 Analytical Framework Development**

*Following the conference, we conducted a systematic, inductive analysis of the 14 session reports to identify recurring themes, methodological approaches, and knowledge gaps that organically emerged from conference discussions. This bottom-up analysis revealed four major thematic clusters, and subsequently we have organised these into analytical perspectives. We then mapped these emergent themes against gaps explicitly identified in the Sendai Framework Mid-Term Review (UNDRR, 2023) to situate them within the policy context. This retrospective mapping demonstrated strong alignment between conference priorities and policy needs, validating both the relevance of conference discussions and providing a framework for organising our synthesis.*

*Building on these exchanges, the four perspective themes emerged from the convergence of bottom-up conference insights and top-down policy priorities rather than being predetermined. These themes are: **Complex Risks; Tools and Assessment; Emerging Technologies; and Multi-level Governance**. Each perspective was then articulated as a research question (see Section 3 introductions) to provide analytical structure for our synthesis.*

## **2.3 Post-Conference Expert Consultation**

*Following the conference, we assigned each session to one of the four perspective themes based on the primary focus of the session content and its strongest alignment with our analytical approach. Session conveners of the 14 sessions were asked to respond to specific questions related to their assigned perspective theme (detailed in Supplementary Information B). These questions were designed to elicit insights on how their session topics contribute to addressing the specific research question associated with their perspective theme.*

*We acknowledge that these thematic categorisations are not mutually exclusive as 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 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 practical analytical approach rather than a rigid taxonomy. The assignment of sessions to perspectives was conducted by the lead authors and validated through discussion with session conveners during the post-conference consultation process. Drawing from all sources across these interconnected perspectives, including session reports, convener responses, pre-conference survey data, and literature review, we synthesized two main priorities per perspective theme through iterative discussion among the author team.**

#### **2.4 Survey Design and Analysis**

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.

**The survey consisted of 20 questions covering demographic information, research specialisations, conference logistics, perceived barriers to multi-hazard research and management, and prototypical examples of multi-hazard events. Illustrative of multi-hazard complexities, respondents most frequently cited the 2011 Great East Japan Earthquake and subsequent tsunami that caused the Fukushima nuclear disaster — a vivid intersection of geological, hydrometeorological, and human-systems forces. The survey was distributed via email to all registered conference participants two weeks before the conference, with several reminders sent.**

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 survey responses provided insights into perceived barriers and future priorities that directly informed the outlook recommendations in Section 4, with thematic patterns emerging around institutional capacity, coordination challenges, and technical limitations. The integration of survey insights with conference discussions and expert consultations provided triangulation of findings**

*across different data sources. The following sections combine all data sources and are bolstered by an informal review of relevant-, state of the art literature.”*

(4) Bias: This paper is based on discussions at a conference that mostly included European researchers from a few specific projects, only a few of these researchers responded, most of them work on floods. This must introduce significant bias, as evidenced by the number of recommendations that found a solution that was more data or better modelling. Being skeptical, is this a paper written by data scientists and modellers suggesting we need more data and modelling to support DRR. I think this paper would be stronger if that bias were indicated from the start, i.e. a review of how and where data and modelling can improve DRR going forward or something similar.

We acknowledge the reviewer's concerns about potential bias in our sample and appreciate the opportunity to clarify several points.

We recognise that the European-heavy participation (reflecting the conference location in Amsterdam and the organising projects) and academic skew represent limitations that we have addressed more explicitly in our revised manuscript. These characteristics may limit the generalisability of some findings and underrepresent practitioner perspectives. We would like to note that we did allocate travel grants to accommodate and reduce, within our capacity, this European bias.

However, we respectfully disagree with the characterisation of a narrow disciplinary bias. Our author team spans social sciences, governance, policy analysis, and applied practice across diverse hazard types including seismic, volcanic, hydrological, climatological, and technological risks. While flooding was the most frequently cited specialisation among survey respondents (25%), this was followed by multi-hazard approaches (21%), DRM/DRR (18%), climate adaptation/change/risk (18%), and infrastructure resilience (8%), with additional representation across other hazard domains (11%) such as wildfires, landslides and volcanic disasters.

The prominence of data-related recommendations that were independently identified and discussed during the conference and beyond reflects gaps that were also explicitly identified in the Sendai Framework MTR rather than disciplinary bias. The same gap has also been identified as one of the top priorities of the 2025 UNDRR platform outlook (<https://www.undrr.org/news/leave-no-one-behind-global-platform-2025-champions-inclusive-disaster-risk-reduction>). This emphasis on data integration emerges from policy-identified needs rather than only researcher preferences. Next to data, our four perspective themes encompass governance frameworks, stakeholder engagement, institutional arrangements, and social dimensions, which extend well beyond technical solutions.

While broader geographic and sectoral representation would strengthen our findings, the substantive diversity of expertise, analytical approaches, and thematic coverage provides robust foundations for identifying research priorities relevant to global disaster risk reduction challenges. The conference's open participation structure and diverse session topics ensured broad thematic representation within the European research community.

Nevertheless, we have revised the manuscript to more clearly acknowledge these limitations while maintaining that our findings represent valuable input from a significant portion of the multi-hazard research community on globally relevant policy challenges.

I think there is a lot of really good information in this paper, but the current version is not of sufficient quality and organisation to make a strong contribution to the already wide literature in this area. I think there is a good core in there, and would recommend the authors rethink the approach around clear research questions.

We thank the referee for their kind words and we hope we have comprehensively addressed the referee's concerns in the revised manuscript.

## **Referee 2**

The study "Reflections and Future Directions for Multi-Hazard Risk in the Context of the Sendai Framework and Discussions Beyond" aims to summarize the outcomes of the 3rd International Conference on Natural Hazards and Risks in a Changing World. The conference summary is supported by a survey of participants to identify perceived barriers to multi-hazard risk research and management. Analysing multi-hazard risk remains challenging, hindered by a lack of tools, decision-support systems, governance mechanisms, and adequate data, among other factors. This study is a valuable attempt to address such challenges. However, as a piece of scientific literature, the article currently suffers from an unclear contribution and insufficient discussion of the results in relation to real-world examples. I encourage the authors to consider the following points before the manuscript can be considered for publication.

We thank the referee for their review and encouraging words. We acknowledge that the contribution can be more clearly attributed and that the discussion can benefit from more real-world examples. Therefore, we have revised the manuscript by addressing these two major points, as addressed in more detail in the point-by-point responses below.

The study's unique contribution is not clearly articulated. In the background, the authors focus heavily on the Sendai Framework, emphasizing its recommendations. For instance, the authors note that "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." However, numerous studies have already explored the quantification of multi-hazard interactions and associated risks. The key question is how the outcomes of the 3rd International Conference on Natural Hazards and Risks in a Changing World advance knowledge beyond what is already established. The authors should critically evaluate the existing literature to identify clear gaps that this study seeks to fill.

We thank the referee for their comment and acknowledge that we could more clearly articulate the novel intellectual contributions of our work. Therefore, we have restructured the manuscript around four specific research questions, with each of these questions aligning with one of our perspective themes that emerged from the conference, and which link with and expand upon gaps identified in the Sendai Framework Mid-Term Review (MTR). These questions provide the analytical structure needed to organise our findings systematically and

furthermore to ensure that each perspective is discussed with an appropriate depth. Additionally, we have provided more detailed context on the Sendai Framework MTR progress and gaps that link to the research questions, and this will subsequently situate our contributions within the broader DRR policy landscape. The revised manuscript directly addresses the questions and concludes with specific and actionable recommendations for both research and policy. The introduction of the manuscript now introduces the following research questions:

- 1) How can inclusive, participatory assessment approaches and advanced analytical tools bridge the gap between scientific risk knowledge and actionable decision-making across diverse stakeholder communities? (*Assessments and Tools for Resilient Decision-Making*)
- 2) What methodological advances are needed to capture and model the systemic, interconnected nature of multi-hazard risks, including their temporal dynamics and cascading effects across social-ecological systems? (*Complex Risk Landscapes*)
- 3) How can artificial intelligence, digital twins, and earth observation technologies be integrated to enhance multi-hazard risk assessment capabilities while ensuring accessibility and interpretability for decision-makers? (*Emerging Technologies for Risk and Resilience*)
- 4) What governance frameworks and institutional arrangements are most effective for enabling coherent, integrated risk management that spans sectors, scales, and disciplines while maintaining operational feasibility? (*Multi-Level Governance for Multi-hazard Risk Management*)

In the revised manuscript we have included critical engagement with the concepts and recommendations that are presented. In more detail, we have addressed the following issues among others:

- 1) We have explicitly addressed implementation barriers and challenges for each recommendation, and subsequently provide a critical discussion throughout. For example, we now discuss and provide insights from the conference in the multi-level governance section, why coherent governance remains elusive despite widespread recognition of its importance. For example, this includes institutional inertia, competing jurisdictional priorities, resource constraints, and political economy factors that maintain sectoral silos.
- 2) While we draw on established frameworks, we would like to emphasise that synthesising how these approaches specifically address Sendai Framework MTR gaps through contemporary applications is where the manuscript's main contributions lie. Therefore, in the revised manuscript these novel elements will be highlighted more explicitly. These include for example the following (among other) aspects that are identified more explicitly:
  - Integration of causal AI and graph neural networks for anticipatory risk assessment (section 3.3.1)
  - Volunteered Geographic Information as a complement to top-down assessment frameworks (section 3.3.2)
  - Risk-Tandem Framework's federated data infrastructure approach to interoperability challenges (section 3.2.2)

- Sector-specific operationalization of Sendai targets through tools like the Tourism Resilience Scorecard (section 3.1.2)
- Evolution from static risk assessment to dynamic, storyline-based approaches integrating temporal vulnerability dimensions (sections 3.1.1, 3.2.1)

We believe that through these revisions, the manuscript now has transformed into a more critical, nuanced analysis that acknowledges trade-offs and implementation realities in advancing multi-hazard risk management.

Point 3 in the methodology section requires further elaboration. How was the survey designed? What types of questions were asked? How were participants selected? What were the key findings, and how did they contribute to achieving the aims of the study? Greater transparency here is necessary.

We acknowledge that the survey design details could be more explicit. The pre-conference survey was distributed via email to all registered conference participants and covered demographic information, research specializations, and forward-looking questions about barriers to multi-hazard research and management. We have expanded section 2.4 to include: (1) the full survey structure and question types, (2) distribution method and timing, (3) a summary of key findings from barrier questions, and (4) explicit explanation of how survey findings triangulated with conference discussions to inform our four perspective themes and outlook recommendations. We also clarified the distinction between this participant survey and the post-conference expert consultation described in section 2.3. It now reads as follows:

#### *“2.4 Survey Design and Analysis*

*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 (25%) being the most frequently cited specialisation, followed by multi-hazard (21%), DRM/DRR (18%), climate adaptation/change/risk (18%), and infrastructure resilience (8%), along with substantial representation across other hazards (11%) such as volcanic disasters, landslides, and wildfires.*

*The survey consisted of 20 questions covering demographic information, research specialisations, conference logistics, perceived barriers to multi-hazard research and management, and prototypical examples of multi-hazard events. Illustrative of multi-hazard complexities, respondents most frequently cited the 2011 Great East Japan Earthquake and subsequent tsunami that caused the Fukushima nuclear disaster — a vivid intersection of geological, hydrometeorological, and human-systems forces. The survey was distributed via email to all registered conference participants two weeks before the conference, with several reminders sent.*

*Within the survey, we used the answers to the following questions to directly inform our outlook section (Section 4): “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. From the survey responses thematic patterns emerged around institutional capacity, coordination challenges, and technical limitations. The integration of survey insights with conference discussions and expert consultations provided triangulation of findings across different data sources. The following sections combine these data sources and are bolstered by comparison with recent literature.”*

Section 3.1 (Advancing Risk Science: Tools and Assessments for Resilient Decision-Making): The discussion of barriers to developing prototype tools and decision-support systems is useful, but the manuscript would be strengthened by including examples of such tools from existing studies. This would help contextualize the discussion and provide practical insights.

We thank the reviewer for this suggestion and agree on the value of these practical points. We therefore have revised the manuscript and included the following examples among many others:

- *“Several decision-support tools have emerged to address the challenges of making tools accessible for a wide range of users. For example, DAPP-MR employs interactive visualisations of Dynamic Adaptation and Policy Pathways to facilitate multi-hazard risk decision-making under uncertainty (Schlumberger et al., 2024, 2025). Similarly, open-source platforms like RiskScape enable rapid assessment of risks from multiple hazards including volcanic eruptions, earthquakes, and floods (<https://www.riskscape.org.nz/>), while CLIMADA provides comprehensive climate risk and adaptation modelling capabilities (<https://climada.ethz.ch/>). The MYRIAD-EU software platform offers modular, open-source tools for multi-hazard and multi-risk scenario generation (Daniell et al., 2025).”*
- *“To support practical implementation, the British Geological Survey has developed an online repository of storylines and storymaps on multi-risk decision-making, which provides guiding questions and frameworks to support stakeholder engagement in applying storyline approaches to examine the interacting nature of multi-risk systems, raise awareness of multi-risk events, and support with drafting forward looking adaptation pathways for plausible future events (BGS, 2025). The visualisations of these storymaps make them highly attractive and understandable for engaging with the general public.”*
- *“To address these governance and interoperability challenges, several platforms have emerged to facilitate data sharing and knowledge exchange. The MYRIAD-EU dashboard guides users through systemic risk frameworks for multi-hazard assessment and management (Hochrainer-Stigler et al., 2023; <https://dashboard.myriadproject.eu/>), while the Disaster Risk Gateway provides an open-access wiki for DRM definitions and tools (<https://disasterriskgateway.net/>). The Climate ADAPT platform similarly supports climate resilience through shared adaptation knowledge (<https://climate-adapt.eea.europa.eu/>). Additionally, toolboxes*

such as the CLIMAAX CRA toolbox provide risk workflows for compiling regional climate multi-risk assessments (<https://www.climaaax.eu/handbook/toolbox/>), and the CCDDR toolbox enables quick risk screening (<https://gfdr.github.io/CCDDR-tools/home.html>), while emerging data space initiatives such as the EU Green Deal Data Space (<https://www.greendealdata.eu/>) and UN Data Commons (<https://unstats.un.org/UNSDWebsite/undatacommons/>) are exploring federated governance models for cross-border data sharing.”

- “Beyond tourism, enhanced data granularity has improved assessments across multiple sectors and examples of these include the commercial flood impacts in France using balance sheet data (Bossut & Tyagi, 2024) and drivers of flood hazard types through detailed inventory research in Serbia (Petrović, 2024).”

Section 3.1.2: While the importance of improving data governance is highlighted, the current state of data governance is not clearly explained. The authors should discuss what current practices exist and what specific improvements are needed.

We thank the reviewer for the comment and in the revised manuscript we have included the current state of data governance more explicitly. The revisions now read:

- “The DELTA Resilience system (Disaster & Hazardous Events, Losses and Damages Tracking & Analysis) exemplifies this integration by enabling nationally owned disaster tracking that links hazardous events to disaggregated losses and damages across sectors and scales, supporting both risk-informed planning and accountability through standardised, interoperable data structures.”
- “Despite growing recognition of data's critical role in disaster risk management, current data governance practices face several significant challenges. One of these challenges is the fragmented nature of data policies and distribution mechanisms. For example, there is institutional competition for funding and accountability advantages that often prevent data sharing across organisations and sectors. Furthermore, the predominant focus of existing datasets on single hazards further reflects the domain-specific nature of most institutions, while the need for integrated multi-hazard data is continuing to grow (Ward et al., 2022; White et al., 2025). Another example of a challenge for data governance can be found in the Earth Observation (EO) domain, as satellite datasets from national space agencies are provided in multiple formats with inconsistent documentation and are often scattered across various mission-specific websites, which can create substantial friction for users seeking to understand available measurements, compare similar datasets, or develop practical applications. Additionally, pre-processing of Earth Observation (EO) data for larger analyses usually involves downloading large amounts of data, requiring a user to have substantial coding skills and access to an external server where the data can be pre-processed before they are ready to be used. While many EO products are freely available, there are also products that would be incredibly useful for scientific research, such as the high-definition product of NASA's VIIRS Black Marble Nighttime Light data, that are currently only available to collaborators on funded projects. Similarly, insurance and risk datasets marketed to homeowners and businesses are typically proprietary and opaque, with methodologies going undocumented and key assumptions remaining unquestioned, even when different providers present sharply conflicting metrics for identical risk assessments. These

*governance gaps are further complicated by emerging technologies such as AI and IoT sensors, which generate actionable data but lack established frameworks for integration, standardisation or in the case of AI lacking ethical frameworks and responsible usage for DRM (Tiggeloven et al., 2025)."*

- *"However, addressing these challenges requires fundamental improvements to data governance, which includes the policies, standards, and accountability frameworks that determine how data are 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 partnerships, even though competition for funding and disconnects between research, industry, and government may still persist."*

Sections 3.1–3.4: These sections primarily summarize the gaps identified at the conference. To strengthen the manuscript, the authors should link these gaps to real-world examples and/or findings from existing studies. Doing so would provide greater depth and make the discussion more relevant for researchers and practitioners.

In the revised manuscript, we have included real world examples or findings from existing studies to the manuscript among many others:

- Section 3.2.2: *"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. Externalities and non-economic impacts, such as the health and public-safety implications of power outages, are rarely taken into account when regulating utilities in the US, directly leading to underinvestment in resilience as revealed by the fragility of the Texas power grid to widespread cold waves."*
- Section 3.2.1: *"Emerging from system structure and dependencies, these risks are highly connected "keystone" elements or dynamic vulnerabilities that makes them particularly challenging, as subtle changes can trigger system-wide failures (Mechler et al., 2025; Schweizer & Renn, 2019). Important drivers of systemic risks are often socio-economic vulnerabilities, critical infrastructure dependencies, institutional fragmentation, and unequal power distributions that shape how shocks propagate through systems (Bakhtiari et al., 2025; Kuran et al., 2020; Stolte et al., 2024). The 2024 Swiss floods and landslides, which destroyed entire villages and triggered cascading infrastructure failures across Alpine communities, illustrate how systemic risks unfold through interconnected vulnerabilities."*
- Section 3.1.1: *"It also aids identification of potential shortcomings in preparedness. For example, during a series of snowstorms in March 2023 in the Southern California mountains, lack of advance coordination across emergency response, road-maintenance teams, and utility companies contributed to 2-3 m of snow accumulation on roadways as the snow accumulation of the previous storm remained"*

*to be cleared. Subsequently, tens of thousands of residents were homebound for up to two weeks as roads eventually became impassable. Food and medicine had to be airlifted and hand-delivered at great expense, and numerous fires occurred due to gas leaks in houses buried under snowdrifts.”*

- Section 3.3.1: *“2024's Hurricane Helene caused devastating flooding in Southeast US mountain communities, nearly all of which occurred along small, steep, poorly observed and modelled watercourses, leading to a major underestimation and communication of high-end flood risk.”*

The sentence “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.” appears to reference the Sendai Framework, but this is not made explicit. The authors should clarify this point.

This sentence indeed references the Sendai Framework and we have clarified this in the revised manuscript as follows:

*“Currently in practice, the Sendai Framework represents a paradigm shift in DRM by emphasising the need for a multi-hazard and systemic risk assessment approach. This framework focuses on preventing the creation of risk, reducing existing risks, and enhancing resilience, through four priorities.”*