

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 and overall narrative structure
- 3) More explicitly acknowledging limitations in geographic and sectoral representation
- 4) Improving the transparency of our methodological approach

We believe these issues are addressable through substantial revision rather than fundamental flaws in the underlying research. For example, the diverse expertise represented in our conference discussions and the alignment with Sendai Framework priorities suggest there is valuable content that could contribute meaningfully to the disaster risk reduction literature provided the major comments are addressed as we describe below.

We would welcome the opportunity to address these concerns through major revision if the editorial team finds merit in the core contribution. This detailed feedback provides an excellent roadmap for strengthening the manuscript's methodological rigor and analytical clarity. We will use the referee's annotated manuscript thoroughly to address further comments.

(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 in our mind to guide the thought process that arose discussions during the conference, and can include these explicitly. These expand upon and link with gaps identified in the Sendai Framework Mid-Term Review (MTR). These questions will 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 will explicitly define key terms such as "framework", as well as providing more detailed context on the Sendai Framework MTR progress and gaps, and this 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 will be clarified with the inclusion of the research questions. We will structure the revised manuscript around these research questions, and directly address the question and conclude with specific and actionable recommendations for both research and policy. The introduction of the manuscript will introduce these 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 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*)

(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 will include critical engagement with the concepts and recommendations that are presented. In more detail, we will address the following issues:

- 1) We will explicitly address implementation barriers and challenges for each recommendation, and subsequently provide a critical discussion throughout. For example, we will 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 will therefore add a critical reflection on when data/modeling approaches add value versus when simpler, community-based approaches may be more appropriate and sustainable. The manuscript will better distinguish 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 will be highlighted more explicitly. These include for example the following (among other) aspects that will be identified more explicitly:
 - Integration of causal AI and graph neural networks for anticipatory risk assessment (section 3.3.1)
 - Volunteered Geographic Information as 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)
- 4) Additionally, we will include more references at reference scarce places, but we would also like to note that currently we are already referencing around 190 articles, which is already above average for similar papers and demonstrates a deep engagement with the literature.

In the revised manuscript, these revisions will transform 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 have developed the four perspective themes inductively from conference discussions rather than 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 will revise the methods section to make this analytical sequence clearer and emphasise the emergent nature of our framework. To better understand how we can frame the methods, we have already extended the methods and for convenience copied the methods below with bold text the most prominent changes.

"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 is 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 analytical 'perspective themes' based on the synthesis 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 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 framework. 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 framework 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 specializations, conference logistics, perceived barriers to multi-hazard research and management, and examples of multi-hazard events. The survey was distributed via email to all registered conference participants 2 weeks before the conference, with reminders sent. Beyond the demographic questions, the survey and this study primarily focused on forward-looking perspectives to identify future research priorities and implementation barriers, which directly informed our outlook section (Section 4).** 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 organising projects) and academic skew represent limitations that we will address more explicitly in our revised manuscript. These characteristics may limit the generalisability of some findings and underrepresent practitioner perspectives. We allocated, however, 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 substantial 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 comprehensive thematic representation within the European research community.

Nevertheless, we will revise 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 that there is a lot of really good information in the paper and we hope we get the chance to comprehensively address the referee's concerns in a round of revisions.