AUTHORS' RESPONSE TO THE REVIEWER#2 COMMENTS

"Between global risk reduction goals, scientific-technical capabilities and local realities: a novel modular approach for multi-risk assessment" by Schoepfer et al.

RC2: 'Comment on nhess-2023-142', Anonymous Referee #2

I thank the authors for their very interesting manuscript on framing multi-risk assessments in the context of a case study in Peru.

I believe that this paper will be an excellent addition to the growing literature on multi-risk assessment, as long as it does not overstate what has been proposed and done, recognises the inherent biases and limitations involved with any such analysis, and considers a bit more strongly the pracitioner stakeholder who might use the methodology proposed (or parts of it).

Below are a series of comments, in no particular order of importance. Although some are slightly critical (the nature of doing a review), most are aimed at making the manuscript more useable and useful by practitioner stakeholders and others who might want to take your learnings and apply them to another region.

Thank you very much for your kind feedback on our manuscript. We appreciate your thorough review and suggestions for improvement. Please find our comment-by-comment feedback (answers in blue; proposed changes in the manuscript in red) as follows. The lines indicated correspond to the PrePrint: https://nhess.copernicus.org/preprints/nhess-2023-142/nhess-2023-142.pdf

1. Title.

a. The paper is much more about your **case study in Peru, so I would expect that to be in the title**.

We agree that the paper is focusing on our case study in Peru. Even though the approach is only exemplified for Lima Metropolitan area, we would prefer in not changing the title. We have also worked in case studies located in Chile and Ecuador (we will briefly report on this in a revised version of the manuscript). Since the approach can be adapted for other regions, we would opt for not including Peru in the title.

b. You use the word **'novel'**. Is this really novel? All the elements have been done previously. I believe the approach and paper are well worth while, just be careful about overstating the originality of what you are doing.

Thank you for pointing this out. Reviewer #1 had a similar comment on the word 'novel'. We agree that individual results of the paper have already been published which we cited accordingly. As the overall conceptual approach has not yet been published in a scientific paper, we felt it justified to characterise the overall approach as 'novel'. It was not our intention to overemphasize the originality. As the opinions of both reviewers are in the same direction, we have reconsidered the title and will delete the word 'novel'.

2. Abstract. This is a bit high level and more a motivation rather than an actual (with metrics such as 'how many' and 'of what') summary of the paper. I suggest you rethink a bit the abstract, and consider more how it is really a summary of the paper.

Thank you for your suggestion. We will rework the abstract carefully in a revised version of the manuscript.

3. Introduction.

a. The introduction does a nice job of bringing in some of the literature, but **I believe there are other major papers** out there that have put into context multi-hazards, multi-risk and multi-impact in the context of natural hazards. Please do a relatively rapid review to ensure you have captured the majority of papers out there that have put into context multi-hazard/risk/impact.

Thank you for your feedback on the introduction. We will include further references, such as:

De Angeli, S., Malamud, B. D., Rossi, L., Taylor, F. E., Trasforini, E., and Rudari, R.: A multi-hazard framework for spatial-temporal impact analysis, International Journal of Disaster Risk Reduction, 73, 102829, https://doi.org/10.1016/j.ijdrr.2022.102829, 2022.

Goda, K. and De Risi, R.: Future perspectives of earthquake-tsunami catastrophe modelling: From single-hazards to cascading and compounding multi-hazards, Front. Built Environ., 8, https://doi.org/10.3389/fbuil.2022.1022736, 2023.

López-Saavedra, M. and Martí, J.: Reviewing the multi-hazard concept. Application to volcanic islands, Earth-Science Reviews, 236, 104286, https://doi.org/10.1016/j.earscirev.2022.104286, 2023.

Šakić Trogrlić, R., Donovan, A., and Malamud, B. D.: Invited perspectives: Views of 350 natural hazard community members on key challenges in natural hazards research and the Sustainable Development Goals, Natural Hazards and Earth System Sciences, 22, 2771–2790, https://doi.org/10.5194/nhess-22-2771-2022, 2022.

Tilloy, A., Malamud, B. D., and Joly-Laugel, A.: A methodology for the spatiotemporal identification of compound hazards: wind and precipitation extremes in Great Britain (1979–2019), Earth System Dynamics, 13, 993–1020, https://doi.org/10.5194/esd-13-993-2022, 2022.

In this way, we hope to find a good balance between a review paper (which is not our aim) and a solid introduction to the topic in the context of our paper. As we incorporate new references in Section 1.2, we will also revise the section's structure.

b. **I did not find it easy to read the introduction due to all the definitions and quotes.** Perhaps consider for the definitions using tables or bullet points so that it is not huge chunks of text with lots and lots of quotes. I've seen half a dozen 'reviews' of the past literature on multi-hazards and multi-risk, and the most useful ones I have seen (from a practical perspective) are those that have tables, figures with timelines, ideas broken out into bullet points, etc. I understand that you do not want to do a complete review of the literature—that is fine, but perhaps one or two table with your key quotes to reduce the text? For example, much of Section 1.3 could be supplemented by a table. Many of the quotes in Section 1.1 could be in a table and then referred to. The studies given in 1.2 would be ideally put in a table, with a few headers to pull out salient parts of the studies, and then discussed in the text.

We will consider your advice and restructure the introduction. We aim to find a balance between in-text citations and the use of tables and/or bullet points. For Section 1.3 we plan to extract the current information on the global strategies from the text and list them in a table, such as:

Table X: Overview of the key global strategies calling among others for reducing risks and damage from disasters

Global strategies	Excerpts and statements	References
2030 Agenda for Sustainable Development; Sustainable Development Goals (SDGs)	- 17 goals for improving human society, ecological sustainability and the quality of life are aiming to contribute to the global risk reduction agenda - 25 targets related to disaster risk reduction in 10 of the 17 SDGs - Among others, the objective of reducing the in number of deaths and people affected as well as decrease of economic losses caused by disasters is addressed in goal 11: "*Make cities and human settlements inclusive, safe, resilient and sustainable*"	UNISDR, 2015a UNISDR, 2015b, p. 2 UNISDR, 2015a, p. 24
Sendai Framework for Disaster Risk Reduction 2015-2030	- Outlines 7 targets and 4 priorities for action to prevent new and reduce existing disaster risks - Priority 1: Understanding of disaster risk "*Policies and practices for disaster risk management should be based on an understanding of disaster risk*	UNISDR, 2015a, p. 14

	in all its dimensions of vulnerability, capacity, exposure of persons and assets, hazard characteristics and the environment" - Calls "*to promote the collection, analysis, management and use of relevant data and practical information and ensure its dissemination, taking into account the needs of different categories of users*" - Advocates "*to support the development of local, national, regional and global user-friendly systems and services*"	UNISDR, 2015a, p. 14 UNISDR, 2015a, p. 16
Paris Agreement	- International treaty on climate change - Calls for *"reducing vulnerability to climate change" in article 7.1* - Calls for the *"importance of averting, minimizing and addressing loss and damage associated with the adverse effects of climate change […]" in article 8.1*	United Nations, 2015b United Nations, 2015b, p. 9 United Nations, 2015b, p. 12
New Urban Agenda	- Addresses various field of action and calls for strengthening resilience in the event of disasters - Envisages cities and human settlements that "*adopt and implement disaster risk reduction and management, reduce vulnerability, build resilience and responsiveness to natural and human-made hazards and foster mitigation of and adaptation to climate change*"	United Nations, 2017 United Nations, 2017, p. 7

4. Conceptual Approach.

a. This is broadly fine, within the limitations of what is presented and has a couple of nice summary figures, but I give a few comments below.

b. **General: Use of the word and approach to vulnerability**. A key part of risk, as you acknowledge, is vulnerability. The word vulnerability comes up 14 times in the manuscript (many of these are part of direct quotes), which is appropriate, but at no place do you define vulnerability (although do mention once physical vs. social vulnerability). For me, a key part of multi-risk (vs. multi-hazard) analyses, is the incorporation of both physical and social vulnerability. I would like to see a more solid defining of vulnerability either in the intro or conceptual approach, along with strengths and limitations of including physical/social vulnerability into multi-risk assessment in terms of data, equations, etc. either when vulnerability is first mentioned or in the discussion. It was not until I got to line 536 that I felt you acknowledged that physical vulnerability only was included and not social vulnerability, and this needs to be acknowledged much earlier.

Thank you for raising this issue. We will indicate on right from the beginning that our approach is focusing on the physical vulnerability and systemic vulnerability only. This will be done at various places throughout the manuscript, such as:

Line 137: *"Following this introduction, Sect. 2 presents the conceptual approach to developing a scenario-based multi-risk assessment tool. With the aim of developing a demonstrator (and not a fully operational system), we focused on analysing the physical vulnerability of buildings (i.e., the likelihood that assets will be damaged or destroyed when exposed to a hazard event), and the systemic vulnerability of electrical power networks (i.e., probability of failure of interconnected systems given hazard intensities). ~~Subsequently,~~ Sect. 3 describes the results and steps taken, including findings from the user perspective ~~evolved to achieve this goal~~. The discussions and conclusions are outlined in Sect. 4."*

Line 152: *"The conceptualization of this overall approach is visualized in Fig. 1. We argue that the starting point of our conceptual approach is a context and stakeholder analysis (Sect. 2.1) to understand the organizational environment and underlying structures. Later, we present a framework to design a multi-risk information system (Sect. 2.2). We selected a story-based concept that allows the description of a specific multi-risk situation and its representation through multiple scenarios (Sect. 2.2.1). As input, the elements of risk (hazard, exposure, and vulnerability) and their impacts on critical infrastructure are assessed, novel scientific and technical approaches developed and considered in terms of their potential implementation (Sect. 2.2.2). It is worth noting that we devoted efforts to study the interactions at the physical and systemic vulnerability levels from cascading hazards, addressing cumulative damage and losses. During the development of the demonstrator, we involved users ~~in the process~~ from the beginning to ensure that the designed tool their requirements and needs (Sect. 2.2.3). For the demonstrator we chose a decentralized system architecture approach built on distributed web services, with a graphical user interface as the frontend (Sect. 2.2.4)."*

Line 535: *"iii. Complexity: Multi-risk situations can become very complex. Obviously, models and scenarios are always incomplete as they approximate complex real situations. The analytical process of the interactions of elements in scenarios is furthermore confined to selected processes. In our approach we focused on the physical elements of vulnerability (buildings, critical infrastructure), but neglected the economic, environmental, political, social and societal aspects of vulnerability. It is important to remember that the overall objective was to develop an approach and to demonstrate its potential. Thereby, we aimed to make the framework and its source code publicly available. With this, data restrictions and data protection issue coming along with the social vulnerability, e.g., of demographic and socioeconomic variables, had to be considered. This limitation ~~this~~ resulted in a considerable limited representation of what would actually happen in a real disaster situation. Nonetheless, it is worth noting that potential users have already rated the potential of the tool as high based on the physical and systemic vulnerability results. In addition, users indicated that the tool has already stimulated them to develop new strategies for capacity building and resilience measures."*

c. Again, like the intro, I found **there was a lot of text to go through in the conceptual approach**, to get to the practical 'how is this being done' parts. Might you break some of the text into bullet points or numbers, to make it easier to read? I'm thinking of the practitioner (who you have aimed part of this paper at) who wants to know what to do, how to do it, and limitations.

We are aware that there is a lot of information provided. Our main target group of this paper is the scientific community and not practitioners. With this, we aimed in providing sufficient details including a wide range of references. We will review the manuscript for possible improvements regarding the use of bullet points or numbering as suggested.

d. Riesgos and Riesgos 2 are mentioned on line 148 (the only place in the text) and then on the data and code availability section. This code seems essential for a practitioner to operationalize the approach suggested here in a pracitical way (and which you do a test case study with peru). **I would suggest you have 1-2 paragraphs outlining more about Riesgos Code Availability and Use (or refer the reader explicitly to the places they can read about how to use it) with text both in this section and then again in the next section (Peru Case Study)** so that they can better understand the theory going into practice, or more importantly, how would they begin to implement the learnings from this paper if they were interested.

Thanks for pointing this out. We will follow your advice and include additional paragraphs on the code availability in Section 2 'Conceptual Approach' and Section 3 'Results', such as:

Section 2.2.4: *"For the developments, both backend (web services) and frontend (graphical user interface), we aimed for open source. This allows others to not only use this software but also to replicate the tool and to develop it further."*

Section 3.3.2: *"The web services and the graphical user interface are published online so that the preconditions for further development into an operational system are given. Details on the code availability on GitHub - a platform for managing, versioning and sharing source code - are provided in the respective section of the paper (see Code and data availability)."*

5. Peru Case study

a. Some very nice figures and flowcharts, but please **reevaluate the white text in Figure 5** (not easy to read on my PDF), and where possible **enlarge font size on figures**.

Thank you for the positive feedback on the illustrations. We will adjust Figure 5 as suggested and check the readability (e.g., adjustments of font size where applicable) of all figures.

b. Broadly I was fine on the approach taken. It does get at a number of interesting aspects of multi-risk (although not social vulnerability).

We are pleased to read that you are generally satisfied with the approach taken. We are aware that the social vulnerability is an important part, which we unfortunately could not cover yet. For demonstration purposes of our approach, and the tool development, we focused on the physical vulnerability. For future developments, we recommend taking the social vulnerability into account. Now that we have been able to show that the approach is overall suitable, this would definitely be an important step in further increasing the added value of the tool.

c. Please state somewhere the **ethical procedures** you went through before working with the human participants.

Thanks for raising the topic of ethical procedures. We will update section 3.4 with additional information:

"During the overall process we respected the ethical principles and guidelines for research involving human subjects (European Commission, 2021). Informed consent was achieved by providing details about the purpose on the research and the roles of the different actors involved. Involved stakeholders were further informed how the information will be used. The participation was voluntary. Above all, we respected the confidentiality as all questionnaires were anonymous and did not allow individuals to be identified. Neither minors nor people with limited capacity were involved in our project."

European Commission: Ethics in Social Science and Humanities. Online: https://ec.europa.eu/info/funding-tenders/opportunities/docs/2021-2027/horizon/guidance/ethics-in-social-science-and-humanities_he_en.pdf, last access: 03 May 2024, 2021.

d. Be careful of **typos**. Lines 374-375. Earthquakes appears twice

Thanks for pointing this out. We will correct the typo accordingly and do another check of the manuscript for typos.

e. Use of **Tables**: This section might benefit by **an additional table summarizing the data used, their sources, key parameters, and any comments such as regarding uncertainty**.

We will follow your suggestion in including an additional table. At this stage we plan to add the following details in section 3.3.1 'Web services and workflow control'. Please kindly note that we will include the references (listed in this table) in a revised version manuscript.

Table 1. System components (web services) with details on input data/model, source and output for the multi-risk story for an earthquake / tsunami event affecting housing and the critical infrastructure power grid. EQ = Earthquake; TS = Tsunami; CI = Critical infrastructure.

Web service	Input data/model and source	Output data/model
EQ catalogue "Quakeledger" (Pittore et al., 2021b)	- Earthquake catalogues as compiled by the SARA project for subduction events (Pagani et al., 2021). - Filter parameters: depth, magnitude, and a geographic area that is defined by a bounding box upon user request.	- List of earthquakes for subduction interface that matches the filter criteria defined by the user.
EQ ground motion simulation "Shakyground" (Weatherill et al., 2021)	- Earthquake source parameters (hypocentral location, depth, and strike, dip and rake angles). - OpenQuake Hazard Library (Pagani et al., 2014) to generate finite fault ruptures as a function of their source properties. - Ground motion prediction equation (GMPE) for subduction interface (e.g. Montalva et al., 2017). - Gridded values of shear wave velocities for the uppermost 30 m depth (Vs_{30}). For Lima, the dataset of Ceferino et al., (2018) was used. It compiles slope-based Vs_{30} (Allen and Wald, 2007), and the seismic microzonation for Lima defined by Aguilar et al., (2013).	- The Demonstrator displays the ground motion fields of mean acceleration values for the target intensities (i.e., peak ground acceleration (PGA)). They are forecasted at each site of the Vs_{30} grid by the selected GMPE. - Additionally, 1000 realisations of ground motion fields with uncorrelated and cross-correlated residuals for PGA and spectral accelerations at 0.3 and 1.0 seconds for six earthquake scenarios (Mw 8.5 - 9.0) are reported in the repository of Gómez Zapata et al., (2021c).
EQ exposure model "Assetmaster" (Pittore et al., 2021a)	- Official census dataset at the block level (INEI, 2017), which contains a few attributes for dwellings. - "Mapping schemes" that relate census attributes, dwellings-to-buildings fractions, and seismic-oriented building classes (GEM, 2014). - Seismic-oriented residential building classes as defined by the SARA project, and their inferred replacement costs (Yepes-Estrada et al., 2017). - Focus maps that spatially combine tsunami inundation and population, which to generate exposure aggregation areas (Gómez Zapata et al., 2021a).	- Exposure model for residential buildings for earthquake risk applications reported in the repository of Gómez Zapata et al., (2021b). They are GEOJSON files that contain the building counts per type spatially aggregated at the block-level, and on CVT-based (Central Voronoi Tessellations) geocells. The metadata of these exposure files match the metadata of the fragility files served by "Modelprop".
Precomputed TS simulations for each associated EQ using TsunAWI (Harig et al., 2008)	- Bathymetry (GEBCO, 1km raster)[1]. - Coastal topography by SRTM[2] (raster data sets at 30m). - TanDEM-X[3] (at 12m) (Krieger et al., 2007).	- Maximum tsunami amplitude (in meters). - Arrival time (in minutes). - maximum tsunami inundation depth (in meters) (Harig and Rakowsky, 2021).
TS fragility model "Modelprop" (Pittore et al., 2021a)	- Building fragility functions for seismic ground-shaking (Villar-Vega et al., 2017). - Two types of tsunami fragility functions for buildings: analytical (Medina, 2019;	- The fragility functions are expressed JSON files. Their metadata matches the exposure models served by "Assetmaster", and the earthquake and tsunami

[1] General Bathymetric Chart of the Oceans (GEBCO), GEBCO 08 Grid, http://www.gebco.net
[2] Shuttle Radar Topography Mission (SRTM), 30m resolution, https://www2.jpl.nasa.gov/srtm
[3] TerraSAR-X add-on for Digital Elevation Measurement (TanDEM-X), 12m resolution, https://www.dlr.de/en/research-and-transfer/projects-and-missions/tandem-x

	Medina et al., 2019), and empirical (Suppasri et al., 2013).	intensity measures of interest for subsequent risk assessment.
1st run of the software DEUS (Damage-Exposure-Update-Service) (Brinckmann et al., 2021)	- Ground motion fields (PGA; SA 0.3; SA 1.0 seconds) served by "Shakyground". - Seismic-oriented exposure model for residential buildings served by "Assetmaster". - Seismic fragility functions served by "Modelprop" (state-independent).	- Spatial distribution of EQ damage in the form of a damage-updated exposure model. The damage scale of EQ is used. - Spatial distribution of direct EQ losses (replacement costs in USD). Example outputs are compiled in Gómez Zapata et al., (2021d).
2nd run of the software DEUS (Brinckmann et al., 2021)	- Raster files of TS inundation depth per EQ scenario, precomputed by TsunAWI. - Damage-updated exposure model (containing EQ damage) served by "Assetmaster". - - Building inter-scheme conversion matrices. They express the probabilistic compatibility between the EQ building classes and the TS ones. They were generated through the taxonomic disaggregation method of Gómez Zapata et al., (2022a). The script is available in Gómez Zapata et al., (2021c). - Damage inter-scheme conversion matrices. They express the probabilistic compatibility between the EQ damage states and the TS ones. They were generated through the method of Gómez Zapata et al., (2023). The script is available in Gómez Zapata et al., (2022b). - State-dependent tsunami fragility functions served by "Modelprop". They are generated by modifying the functions of Medina, (2019). The script and files are available in Gómez Zapata et al., (2022a).	- Spatial distribution of EQ+TS damage in the form of a damage-updated exposure model. The damage scale of TS is used. - Spatial distribution of direct EQ+TS losses (replacement costs in USD). Example outputs are compiled in Gómez Zapata et al., (2021d).
CI System Reliability (Rosero-Velásquez, 2020; 2024)	- Ground motion fields served by "Shakyground". - Seismic fragility functions for power network facilities (e.g., substations and power plants), based on HAZUS (FEMA, 2003) - The power network topology and information were obtained (publicly available or upon request) by OSINERGMIN (2019) and COES (2019), and were adapted to the web service as shown in Merscher (2020). - The calculation of the output is based on a network model for simulating cascading failures (Crucitti et al., 2004; Hernández-Fajardo et al., 2013).	- Probability of service failure (in percentages).

Regarding the uncertainty we can note that we identified uncertainty factors and classified them into aleatoric and epistemic uncertainty. A dedicated paper (Rosero-Velásquez et al.) is currently under preparation.

f. I found the user groups were interesting, but I would like to see

i. **a much better definition of the user groups** given in Figure 2 (which I assume were then used in Peru) and

ii. some **idea of the user group numbers involved and where they were located**—in other words, why were they representative.

iii. I also am **not a fan of the word 'end users'** as everyone in the research community, NGOs, etc., are end users. This is why (see above) I'd like a much better defining of who was actually involved. You have a couple lines on this in in 280-282, but then when we get to Section 3 you do not refer back to this discussion, and it should be more in-depth.

iv. In all of the reporting of the results you state things like "18% of the the users"—I assume this means that you have now put all the users together into one big group. **Remind us in a few strategic place 'how many'. So 18% of the ### users.**

Thank you for your feedback on the user groups. Based on your feedback as well as based on the comments provided by Reviewer#1, we recognise that the user feedback process was not sufficiently described. We also agree that the term 'end user' can be misleading. We will revise the manuscript accordingly. This starts with a better distinction of the stakeholder categories in Section 2.1, such as:

Line 181: *"A stakeholder analysis has been done to identify relevant actors involved in the DRM context, describing their roles, responsibilities, relationships, interests, and relative influence / power. Naturally, the stakeholders belong to different sectors, i.e.: ~~The categories~~ (1) ~~universities and scientific research institutes (~~research community~~), (2) institutions operating hazard information and monitoring systems, (3) institutions operating DRM information ~~monitoring~~ systems, (4) institutions working on local and regional level in DRM contexts ~~non-governmental organizations~~, and (5) institutions working on national planning level ~~end-users were used for systematization~~. Key stakeholders per group were identified and described in detail on different levels ranging from national and regional to local level covering their specific objectives and tasks in the working contexts.*

We also plan to rename the section headings as this should provide better clarification:

Section 2.2.3 'User involvement' => change to 'Feedback process from the user perspective'

Section 3.4 'User feedback' => change to 'Findings from the user perspective'

With this, we will also update Section 2.2.3 (including an update of Figure 2).

Line 271: "*Accordingly, we geared our approach to the needs of potential users and its practicality (cf., user-centered design; Gould and Lewis 1985; Karat, 1997) ~~where the users are involved~~ throughout the design and development process (Fig. 2)."*

Line 278: "*The development of our multi-risk assessment tool is based on a structured and systematic feedback process from the user perspective ~~involving different user stakeholder groups throughout the whole design and development process in various iterations to assure that requirements from the user side are considered from the very beginning (cf., Gómez Zapata et al., 2021a)~~. Thereby the goal was to target various representatives from different stakeholder groups. ~~research community (universities and scientific research institutes), institutions operating information and monitoring systems, non-governmental organizations and the so-called end users (e.g., employees of planning and disaster risk management institutions).~~ The following table shows the stakeholder groups (section 2.1) and key stakeholders involved."*

Table X: Stakeholder groups and stakeholders involved in the feedback process from the user perspective.

Stakeholder group	Stakeholder involved in the feedback process
Research community	- Universities - Research institutes
Institutions operating hazard information and monitoring systems	- Geological institute - Geographical institute - Geophysical institute - Oceanographic institute
Institutions operating DRM information systems	- National institutions for risk analysis, risk reduction and risk mitigation - National civil protection agency
Institutions working on local and regional level in DRM contexts	- Disaster management authorities - Municipalities - Non-governmental organisations (NGOs)
Institutions working on national planning level	- National Center for Strategic Planning - Ministry of Housing, Construction and Sanitation - Ministry of Transport and Communications

In the section in the results, we will provide further details for a better understanding. We will make clear that we have not differentiated between the individual stakeholder groups, but have collected the overall feedback from the users' perspective. Furthermore, we will add the number of participants for a few specific results, such as:

Line 457: *"In year 3 (V2.0), the majority of all respondents (89 % of 37 participants) agreed that the clarity of the information displayed in the demonstrator was highly (62 %), very highly (19 %) or even totally understandable (8 %) (Fig. 7a)."*

Line 468: "*In year 2 (V1.0), already 35 % of the users said that the relevance of the information was very high, while in year 3 (V2.0) an overwhelming majority (55 % of 46 participants) rated it as very highly and 31 % as even totally relevant (Fig. 7b)."*

6. Discussion and conclusions.

a. I found the basic ideas in the discussion and conclusions good, but felt it was rather short and did not bring us back to the overall literature of what others have done. Please relate many of **your key points back to the existing literature**.

Thanks for pointing this out. We will revise this section to better relate to Section 1 and existing literature. For this, we plan to add further details in the discussion section, for example:

"Relevance and acceptance: Users have recognized the relevance of the topic right from the beginning and have expressed a high demand. This is certainly also due to the fact that the topic of multi-risk is becoming increasingly relevant in practice and that there are still few practical options available for dealing with these new challenges. Various users wanted to use the tool directly in its first version as they recognized great potential in communicating scientific results to decision-makers. With this, we emphasize to follow the recommendations on supporting the development of user-friendly systems and services as articulated in the Sendai Framework (UNISDR, 2015a, p. 14-16)."

Regarding the state of the art, we refer to our reply to question 6d) on research needs.

b. The approach relies heavily on the **availability of detailed data** (e.g., about hazards, vulnerabilities, and exposures). In regions where such data may be lacking or outdated, the application of the methodology could be challenging. Might you be able to acknowledge **more these limitations and suggest potential solutions or workarounds**?

Data availability is in fact a controversial topic. We plan to add a paragraph on the data availability in the discussion, such as:

"Data availability and data exchange: As experience shows, data is often available, but data exchange remains challenging. The use of web services is a promising option for the exchange of information between institutions. Data do not need to be stored at a centralized place (and with this gets outdated), but can be updated regularly by the host. An open data policy (FAIR principles) eases this process, but calls for inter-institutional agreements and rules of procedure. Where data availability is still critical (e.g., detailed exposure information) the scientific community can support the creation of enhanced datasets. At this point, it should be noted that users are often satisfied with rough estimates of 'What-if scenarios'. In strongly application-oriented research, it is important to find a balance between maximum accuracy and practical applicability."

c. The paper focuses on a specific case study area, and while this demonstrates the practical application of the methodology, there is **limited discussion on its scalability and adaptability to other regions** with different risk profiles and socio-economic contexts.

We are pleased to take up the topic of transferability and scalability in our discussion and intend to include a paragraph, such as:

"Transferability and scalability: The approach was presented for an earthquake-tsunami multi-risk story. Regarding the transferability to another region we can report that we could successfully adapt the approach for another case study in the coastal area of Greater Valparaíso, Chile. The approach has also been successfully tested for compound hazards (two hazard events happening in parallel). During this study, we also tested again the transferability to another region as the study area was located around the volcano Cotopaxi in Ecuador. However, one should note that this is a first demonstration. The existing framework of the demonstrator tool serves the basis to be transferred to other areas of interest or adapted to more complex risk contexts (see point iii on 'Complexity')."

d. The discussion could be strengthened by a more **explicit identification of gaps in the current approach**. This would not only highlight areas for improvement but also encourage further research in the field of multi-risk assessment.

We are aiming to extend Section 4 'Discussion and conclusions' with further information on research needs, such as:

"In conclusion, we have demonstrated that the tool is capable of calculating and visualizing the cumulative effects of successive hazard events. Despite some limitations, in particular with regard to already standardized planning processes and the exploratory nature of the tool, users see great potential for different fields of application and a high expectation was expressed, especially from the user side in the local pilot area, that the developed tool would be available and applicable locally. Based on these findings, it appears reasonable that the research community continues working with users on the ground. Further research in the field of multi-risk assessment is certainly needed, among others, to improve the physical vulnerability assessment of various hazards. The standardization of damage scales into a transversal one across hazards will be an important aspect for the scientific community to address. Complementarily, the derivation of state-dependent analytical fragility also deserves more research attention to be optimised in the future through more refined approaches. We also recommend

to further work to integrate the social vulnerability. Here, it could be of particular importance to investigate whether and how the social vulnerability of certain demographic groups differs in terms of their response to future crises. Our findings also support the call to science to contribute to an evidence-based policy. ~~At a next step, the impact of such a system in terms of cost-benefit would be interesting to evaluate.~~ After all, the future will tell us how much such a tool can help in planning for catastrophic events and what, in the end, can technologically not be forecasted ~~controlled~~ but is simply fate."

e. **Actionable Recommendations**: Make the recommendations actionable by providing clear, specific steps that can be taken by researchers, practitioners, or policymakers. For instance, instead of broadly stating the need for further research, specify the types of studies or methodologies that could address existing gaps.

The original version of the manuscript was submitted on 31 July 2023. Since then, further work has been done by the team. We have created a 'Policy Brief' which documents lessons learnt and proposes selected recommendations for action. The reference of the document is as follows:

Schoepfer, E., Juzam, L., Lauterjung, J., León, C. D., Riedlinger, T., Spahn, H., and Zambrano, A. (eds.): Policy brief - Multi-risk analysis: What would happen if…? https://doi.org/10.15489/cwgicmtcja61, 2024.

We will put a brief reference to this document in Section 4 'Discussion and conclusions':

"Further lessons learnt and recommendations for action are given in Schoepfer et al., 2024."

Regarding the proposed studies and methodologies, we refer to our reply to question 6d).

f. **Highlighting Implications for Policy and Practice**: Explicitly articulate the implications of your findings for disaster risk management policy and practice. This could include suggesting changes to existing frameworks or identifying new areas for policy development.

Following the previous comment, we are going to refer to the 'Policy Brief' which lists specific recommendation.

7. Overall.

a. While the innovative methodology is a strength, its complexity could be a barrier to its widespread adoption. **The text could benefit from a more simplified explanation in places or additional step-by-step guides that could make the approach more accessible to practitioners who may not have a strong technical background**.

As briefly stated in our reply to Question 4c, we aimed to find a balance in providing sufficient information for researchers and developers, as well as providing details about the potential practical application. The approach cannot be implemented by practitioners themselves, but only be implemented by specialised institutions. With this, we are not addressing the practitioners with this paper. However, we hope that our additional reference to the recently published 'Policy Brief' will be of benefit to readers.

b. Overall there is a high level of writing, **but tending towards VERY long paragraphs, which often could be broken up into two, or better use of bullet points**.

Thank you for pointing this out. We will go through the manuscript and do a thorough revision of the language style.

c. This will most likely go through copy editing, but there are places where text could be improved. Long sentences are often used where they could be broken up into two or shortned. Some examples (there are many) include.

We express our sincere gratitude to you for providing these suggestions. We will update the manuscript accordingly and check for further improvements in readability.

• **Original Lines 19-21:** "The complex relationships between multiple and consecutive natural hazards exposed population and built environment result in a variety of cascading effects which if are often not considered appropriately by decision makers can result to inadequate or even misleading risk management strategies."

• **Suggested Revision in two sentences:** "Complex interactions among multiple and consecutive natural hazards, the exposed population, and the built environment can lead to cascading effects. If not accurately considered, these can lead decision-makers to implement inadequate or misleading risk management strategies."

• **Original Lines 27-29:** "Based on recent scientific and technical capabilities we developed a tool through an iterative participative approach which has allowed users to explore various scenarios of multiple hazards cascading effects and their impacts."

• **Suggested Revision in two sentences:** "Leveraging the latest scientific and technical advancements, we developed a tool via a participatory iterative process. This tool enables users to explore various scenarios, including the cascading effects of multiple hazards and their impacts."

• **Original:** "In addition to immediate crisis management and rapid response during and after a disaster, disaster preparedness is becoming increasingly important."

• **Suggested Revision:** "Beyond immediate crisis management and rapid response, disaster preparedness is growing in importance."

• **Original:** "The shift from managing disasters to managing risk is articulated in the Sendai Framework for Disaster Risk Reduction 2015-2030, which was adopted at the Third UN World Conference in Sendai, Japan, on March 18, 2015."

• **Suggested Revision:** "The transition from disaster management to risk management is emphasized in the 2015-2030 Sendai Framework for Disaster Risk Reduction, adopted at the Third UN World Conference in Sendai, Japan on 18 March 2015."

• **Original:** "An increasing number of people worldwide are exposed to natural hazards, particularly in poorly planned urbanisations, where effective prevention and risk management can save lives and reduce all kinds of losses."

• **Suggested Revision:** "More people globally face natural hazards, especially in poorly planned urban areas where effective prevention and risk management could save lives and minimize losses."

• **Original:** "For instance, in the context of seismic hazard, information on the possible earthquakes that can hit a region in the future needs to be available. For that aim, existing earthquake catalogues are gathered."

• **Suggested Revision:** "For example, in seismic hazard assessment, future earthquake risks require access to existing earthquake catalogues."

• **Original:** "However, the design of information systems or tools that are capable of analytically exploring multi-hazard risk situations and, in particular, dynamically updating the damage on exposed elements due to various hazards with cascading effects remain challenging."

• **Suggested Revision:** "Designing information systems or tools to dynamically analyze multi-hazard risks and dynamically update exposed element damages from cascading hazard effects presents significant challenges."