AUTHORS' RESPONSE TO THE REVIEWER#1 COMMENTS

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

RC1: 'Comment on nhess-2023-142', Anonymous Referee #1

This manuscript presents a framework for implementing multi-risk assessments in practice. The approach is demonstrated for Lima, Peru, in the case of a tsunami following an earthquake. The authors also provide a helpful overview of the motivation for shifting practical disaster risk reduction to a multi-risk framing, in the introductory section. The content is timely and would be of interest to readers of the journal. However, there are several comments provided below that I think the authors should address before the manuscript can be deemed publishable in my opinion.

We thank you very much for the recognition of the paper's relevance. We would like to express our gratitude for your valuable comments and suggestions for improvement. We are committed to enhance the quality of our manuscript based on your comments and aim to carefully consider all concerns and incorporate the suggestions in an improved version of the manuscript. Please find our comment-by-comment feedback in the following. The lines indicated correspond to the PrePrint: https://nhess.copernicus.org/preprints/nhess-2023-142/nhess-2023-142.pdf

Main comments:

1. Novelty: The authors claim to present a new conceptual approach to multi-risk assessment. But (despite what is implied by line 156), all the tools used for conducting the fundamental risk calculations have been developed in previous studies. Furthermore, the end-to-end calculations conducted in this study do not represent an advancement over the numerous frameworks for multi-risk assessment that have already been proposed in the literature (and that are referred to in the manuscript itself, for example around line 90). I think the authors should frame the novelty of the approach more accurately in terms of its practical relevance.

Thank you very much for this comment. We highly appreciate your feedback about the practical relevance.

We agree that individual results of the paper have already been published, in particular the ones entitled as "elements of risks" (see section 2.2.2; e.g., exposure and vulnerability modelling as published by co-author Gómez Zapata et al.). In this paper our focus was to present the overall conceptual approach (which has not been published in such details yet) and not on diving into details of research already published. With this, we feel that it is valid to name the approach as novel.

As you kindly pointed out, the approach is in particular relevant due to its practical relevance and the user-centred design. The tool was developed in close cooperation and consultations with users in an iterative form. In doing so, we paid attention to involve the users in crucial stages of the project, such as the story design. We integrate existing local knowledge in what the potential users are already used to work with (e.g., colour schemes, visualizations of results, etc.). Considering this local knowledge and additional feedback asked by questionnaires and observed during hands-on sessions, we constantly implemented improvements (e.g., side-by-side scenario comparison).

We will take care that in a revised version of the manuscript, the novelty of the approach is described accordingly, such as:

Line 146: *"Considering the aforementioned guidelines and strategies in the context of disaster risk reduction (DRR) and disaster risk management (DRM) as well as the outlined research needs, we* *present a generic framework developed within the research projects RIESGOS and its successor RIESGOS 2.0 (Schoepfer et al., 2018). The projects focused on the development of innovative scientific methods for the assessment of multi-risk situations with the aim of designing an approach that meets the needs of users at the local level. In addition to the German team coming from various disciplines, the project collaborated with a variety of research institutions and public authorities in Chile, Peru and Ecuador. This collaboration, both with users and local actors, is one key aspect while framing the overall approach towards its practical applicability. 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). During these two steps, 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). It has to be noted that during the course of the projects individual results have been published and are cited accordingly. In this paper, we put particular focus on the user involvement and feedback showing the practical relevance of the overall approach and the designed tool. We are convinced that such a user-oriented approach for exploring, describing and quantifying different What-if scenarios can constitute a valuable and user-accepted tool for understanding complex multi-risk situations and to prepare for such situations."*

<u>2. Scope:</u> Related to the previous comment, the approach has only been demonstrated in the context of a very narrow definition of multi-risk assessment (i.e., one set of interacting hazards where one hazard triggers the other and for which there are well established models that capture the underlying interactions at the hazard and impact levels). Section 2.2.3 seems to suggest that, despite the decentralised architecture of the system, its design is inherently dependent on the multi-risk story selected. Point vi of the conclusions seems to confirm my doubts about the generalisability of this approach to other contexts. (Furthermore, is the approach limited to hazards that interact through triggering?) I think the authors need to provide a more honest description of the limited scope of this study near the start of the manuscript. This is merely a first (straightforward and somewhat simplified) demonstration of a practical approach for facilitating user-centred multi-risk assessment. Furthermore, I believe the manuscript could benefit from a discussion about the challenges associated with expanding or enhancing this type of system for more complex contexts, e.g., involving more than two hazards and/or where there is less well-established means of capturing their interactions.

Thank you for raising these issues. We agree that in this paper the approach is presented for two hazards (with one triggering hazard, i.e. earthquake, and one triggered one, i.e. tsunami). We have also tested our approach also for a situation on volcanic activities with compound hazards, i.e. ashfall and lahars, with damage on buildings and impact on the power network. The case study was located in Ecuador (Cotopaxi volcano). We have focused on the description of one case study in the manuscript, but we will add another paragraph to briefly mention the capabilities of the approach, such as:

"It should be noted that we tested the approach also for a multi-risk story on volcanic activities with compound hazards, i.e. ashfall and lahars, with damage on buildings and impact on the power network. The case study was located in the area of the volcano Cotopaxi in Ecuador (cf. Gómez Zapata et al., 2021a)."

We can confirm that our approach is dependent on the chosen multi-risk story as it was altogether decided with the local actors. The conditional probabilities between hazards have not been considered (multi-hazard risk). However, the approach can be extended for such conditional probabilities before the analysis of the dynamic vulnerability. We would like to mention that we deliberately chose the multi-risk approach using a defined story with multiple scenarios. This was mainly due to the joint work with users for whom this approach is easier to understand and to follow (and who are not part of the scientific community) than working with a probabilistic approach.

We will add a paragraph in Section 2.2.1 in the revised version, e.g.:

"In summary, the selection of the multi-risk story is of crucial importance. It is the basis of our designed multi-risk approach. It is important to note that conditional probabilities between hazards are not currently considered (multi-hazard risks)."

Furthermore, we will rework the discussion on the decentralized architecture and add another discussion point regarding the transferability of the approach, such as:

Line 554: *"vi. Decentralized architecture: The selected decentralized architecture certainly has advantages ranging from (1) updated information, as the data and models in the specialized institutions are usually refreshed on a regular basis, (2) modularity, flexibility, scalability of multi-risk situations to (3) easier data exchange between institutions as data remain at their point of origin / host. However, despite the use of international standards such as the geospatial WPS defined by the OGC, the integration of new web services into the tool requires adaptations of the underlying orchestration structure. Thus, the (re-)combination of web services to form a new multi-risk chain calls for in-depth knowledge. We do see the potential of the approach for other multi-risk stories, e.g., landslides after an earthquake, failure of drinking water infrastructure, evacuation of the affected population, but recommend to analyse in advance the transfer efforts."* ~~*if other stories, are suitable following the proposed approach.*~~

"Transferability: The approach was presented for a multi-risk story using two hazards where one hazard (earthquake) is used as the trigger of the second event (tsunami). The approach has been successfully tested for compound hazards (two hazard events happening in parallel). 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)."

<u>3. User input:</u> The user-oriented design of the approach is a welcome feature. However, despite its numerous advantages, there are some "dangers" associated with allowing user input in this type of system. For instance, stakeholders may not be sufficiently educated to appropriate hazard stories, particularly in the context of climate change. A comment on the potential downsides or caveats associated with user involvement should be added to the manuscript, in my opinion.

Thank you for addressing this point on the user-oriented design of our approach. We agree that the user involvement is demanding and must be carried out by experienced professionals. We we emphasize that the process is moderated and the scientific/technical expertise is not outweighed by the user requirements. We did summarize this in the discussion point viii "Co-creation with users" (line 568), and agree that rephrasing and adding more details will enhance the topic on user involvement, such as:

Line 568: "viii. Co-creation with users: Collaboration between researchers, software developers and different user groups definitely helps to develop a tool that is useful in practice. However, collaboration requires a strong engagement from all sides. It requires a moderated process which allows that user demands can be communicated to the researchers and developers without outweighing the scientific *relevance. At the same time, the involved user must be aware and able to cope with trade-offs and compromises, as* not all requirements may be addressed or *they might not* be able to *benefit directly from the tool while it is still under development or in a demonstrator stage. To avoid false expectations and misunderstandings, we emphasize that transparency and clear statements are most important throughout the user involvement process. Additionally, it is important to be aware that users (often) do not have the scientific expertise to adequately describe the individual processes in a multi-risk chain. Since the approach is based on the description of a multi-risk story, this story must always be defined in a joint dialog between users, researchers and software developers."*

We also want to point out to line 285 (section 2.2.3 User involvement) which we will further update, as follows:

Line 285: "(1) Starting point for the approach is the definition of multi-risk stories with the users (Sect. 2.2.1). The joint discussion with the different user groups is intended to ensure the realism and relevance of the stories, thus elaborating a common starting point that will allow structured discussions throughout the design and development process of the tool in order to capture the requirements from the user's point of view. Researchers must ensure that the processes of the multi-risk story are described in a scientifically sound (and possibly abstracted) way. These serve as input, definition and enhancement of the tool and its functionalities."

<u>4. Case Study:</u> This could benefit from a few more details.

a. It seems that the multi-risk story was pre-defined in the case study (i.e., taken from INDECI, 2017), which is not compatible with the user-centered workflow presented in Section 2.2.3.

Thank you for raising this issue. The multi-risk story was defined jointly with users during a workshop held in Lima on 20 April 2018, and aligned based on the users' recommendation with the description of the reference scenario used in Peru. We will rewrite section 3.2 accordingly to better describe the steps taken of the user-centered workflow:

Line 354: *"Following the story-based concept design (Sect. 2.2.1) we characterized the various elements composing the multi-risk situation which was defined in consultations with Peruvian users (workshop held in Lima on 20 April 2018; see section 3.4). During this user consultation process, users recommended to consider the ~~an~~ reference (worst-case) scenario of an 8.8 Mw earthquake off coast of Lima Metropolitan area as documented by INDECI (2017)~~,~~ when ~~we~~ defining the following story: "Strong shaking occurs in Lima Metropolitan area, Peru, during the day time. There are severe damages on buildings and infrastructure, many people are directly affected by building collapses. As the earthquake has the potential to trigger a tsunami, a tsunami warning is issued and evacuation to safe areas is announced. Coastal roads and roads to highlands become progressively congested. In the following a first tsunami wave impacts the coast and starts inundating parts of the harbour area in Callao. Because of the numerous building collapses, city roads become less suitable for prompt evacuation."*

For this defined story, multiple scenarios including historical and observed and stochastically earthquakes, were made available. Each earthquake scenario serves as a trigger for the defined multi-risk chain resulting in different cascading impacts. ~~Based on this reference scenario and consultations with Peruvian stakeholders, the elements of the multi-risk story, which should be addressed by the project were identified. Accordingly,~~ A flow chart (Fig. 5) was created conceptualizing the main logic, its components and information flows of the multi-risk story."

b. How is the size of the tsunami related to the magnitude of the earthquake selected and how is the uncertainty in this size accounted for?

Thank you asking this question. The simulations of the tsunami were generated using the physical generation and propagation model TsunAWI (see below). We will add further information in the respective paragraph in Section 3.3.1, line 388 as follows:

Line 388: "The simulations were generated using the physical generation and propagation model TsunAWI (Harig et al., 2008), which employs a triangular mesh with variable resolution as proposed by Harig et al. (2020). The size of the tsunami is related to the magnitude of the selected earthquake. Generally, larger earthquakes result in larger values of the wave amplitude at the coast and broader inundation area. However, the relation is rather complex, since we account for the vertical displacement of the coastal area due to the earthquake, which might affect the inundation, and additionally, the run-up process is highly nonlinear. Although our approach is scenario-based, we account for uncertainties with regard to the historic earthquake from 1746 which serves as basis for the simulation, by covering a range of magnitudes with simulations. The available outputs including the maximum tsunami amplitude, arrival times and tsunami inundation depth are displayed (Rakowsky et al., 2013; Androsov et al., 2023). Some of these scenario-based tsunami inundation maps are available in Harig and Rakowsky (2021), respectively."

c. What are the outputs (risk metrics) shown? Are all metrics disaggregated per hazard event? Do they account for cascading impacts (as described in the last two paragraphs of Section 2.2.2)? Was there consultation with the end users on the types of risk metrics to be shown in the system? The conclusion mentions that the platform can be used to compare the results of different stories, but the ability to do this (i.e., show multiple sets of results side by side) is not made clear in the case study description.

Thank you for raising these questions. We structure our answer in three parts:

Outputs (risk metrics)

Our approach focuses on physical and systemic vulnerability (Fig. 5 Flowchart). Regarding the physical vulnerability, the outputs of the risk metrics are direct losses in terms of repairing costs in US Dollars. Every damage state of each fragility function assigned to the corresponding building class has a loss ratio, which is a coefficient associating the replacement value to the total cost of the building unit. This means that we are indeed able to disaggregate the losses for each hazard considered in the multi-risk sequence (details of this method can be found in Gomez Zapata et al., 2023). Dysconnectivity of the nodes that make up the critical infrastructure system (i.e. electric power networks) was the metric selected to assess systemic vulnerability. It was calculated from Monte-Carlo simulations, and the related output per selected hazard scenario are provided in terms of probability of system failure on selected areas (details can be found in Rosero-Velásquez et al., 2022a). A quantitively assessment of cascading effects (e.g., effects on drinking water, failure of telecommunications) were not considered quantitatively mainly due to the scarcity of data, but the possible effects were brought into consideration during the user involvement process. This was transparently communicated following a qualitatively approach.

We will add further information in Section 3.3.1 as follows:

Line 393: *"In order to assess the exposed elements of interest (e.g. residential buildings), exposure models are constructed. They provide information on the location, spatial aggregation and typologies of the residential building stock of Lima Metropolitan area (Yepes-Estrada et al., 2017). Each building typology has associated a fragility function (Villar-Vega et al., 2017) for both hazard-vulnerability schemes (earthquake and tsunami), as documented in Gómez Zapata et al. (2021b). The demonstrator is able to serve these exposure and fragility models through the scripts Assetmaster and Modelprop (Pittore et al., 2021b), which are used as two web services. In order to assess the damage states of the* *residential buildings and losses (in terms of repairing costs of the corresponding building class in US Dollars) after the occurrence of the selected earthquake the so-called damage exposure update (web) service DEUS is triggered (Brinckmann et al., 2021). Using an updated exposure model that includes earthquake-induced damages, and simulations of tsunami inundation depth as inputs, once again the DEUS web services is initiated in order to approximate the expected cumulative damage and disaggregate the losses per hazard event (Gómez Zapata et al., 2023). This methodology makes use of inter-scheme damage compatibility matrices, that can be consulted in Gómez Zapata et al. (2022c); and a set of state-dependent tsunami fragility functions (Gómez Zapata et al., 2022d), that for the case of Lima Metropolitan area were constructed after having modified the analytically derived ones originally proposed in Medina (2019)."*

Consultation with the end users

As we are dealing we multi-risk risk, we need to have a risk metric that can be transversally used across the different hazards in order to compare the contribution of each hazard scenario. Because of that we used a numerical metric, i.e. the replacement costs (in US Dollars) of the building portfolio. Regarding the damage distribution a colour scheme is per-se a straightforward way in doing so and a suitable way to communicate it to the users. The implemented colour schemes were discussed and agreed upon with the users during the user involvement process. We made sure that both, the colour scheme for the damage distribution (from the different hazards) and the loss (replacement costs) are comparable and easily understandable. This was important to ensure that the outputs are accepted and understood by the users. We will update the following paragraph in Section 3.4, such as:

Line 444: *"In addition, these hands-on sessions allowed many suggestions for improvement regarding the practical handling of the user interface as well as the visual and descriptive presentation of the results. These included comments on the visualization of damage grades as well as losses (in US Dollars), both on colours used and number of grades."*

Compare the results of different stories (i.e., show multiple sets of results side by side)

Your question regarding the comparison of multiple sets of results side by side is appreciated and raise a valid point. In the manuscript we focused on the expert mode of the demonstrator allowing the full exploration possibilities of the developed tool. We are pleased to add further details and figures showing the possibility of our tool to compare different scenarios side-by-side. We plan to update section 2.2.4 and 3.3.2 with more information, such as:

Line 317: *"In order to address different user needs, the GUI was split in an expert and non-expert viewer. The expert viewer ('demonstrator') allows individual setting and configurations of model parameters and outputs, whereas the non-expert viewer ('demonstrator light') runs with predefined parameters and a simplified visualization of results. The underlying web services are identical. Additionally, the 'demonstrator light' provides three modes which allows side-by-side comparison of two scenarios. The 'demonstrator light' provides three different modes for the user to select from: (1) Analysis of one multi-risk scenario; (2) comparison of two different scenarios within one multi-risk story two (e.g., earthquakes of different magnitudes); and (3) analysis of different time steps within a multi-risk scenario."*

Line 411: "*A graphical user interface (GUI) allows the user to independently explore the different risk scenarios making use of the aforementioned web services. The designed GUI is available for the expert (Fig. 6) and non-expert user (Fig. 7). For the expert view ('demonstrator') the ~~divided into three~~ main display is divided into three areas: the map window in the centre, the configuration wizard that controls each web service on the left, and the results panel on the right. In the configuration wizard, the user is guided through the multi-risk story where he can select different parameters according to his specific* *interests. In the layer control panel, the user can examine and view the processed results and gets more information about the outputs (e.g., legends, detailed descriptions). In order to maintain a solid overview, only the parameters relevant for the currently selected step are highlighted as active which enables intuitive control. In this way, the user does not lose track of the current step in the multi-risk chain, even with a long and complex multi-risk story. In the non-expert view ('demonstrator light') the user can select between three different modes. The viewer shows a reduced configuration wizard including abstracted versions of the results. The split-screen allows the side-by-side comparison of two selected scenarios or the exploration of different steps within one scenario."*

Accordingly, we will also include further screenshots of the GUI of the demonstrator light, for all 3 modes (as described above).

d. I think the manuscript could benefit from more figures of the system, particularly the GUI.

Thank you for your comment. In addition to the textual updates (see comment above), we will include more screenshots of the GUI of the demonstrator.

e. The spatial extent of the case study needs to be described, particularly in the context of cascading impacts (see comment 4d).

Thank you for raising this point. The extent of the case study is Lima Metropolitan area, Peru. We will include the administrative boundaries in the map shown in Figure 4 so that the reader is well aware about the spatial extent. We will also update section 3.1 accordingly:

Line 347: *"The approach is demonstrated for Lima Metropolitan area which is composed of five sectors (INEI, 2022), i.e. Lima Norte (8 districts), Lima Sur (11 districts), Lima Este (9 districts), Central Lima (15 districts) and Callao (7 districts) (Fig. 4). The multi-risk story (see section 3.2) including its cascading impacts is applied for this particular case study area."*

<u>5. Introduction:</u> Despite its strengths, I think the introduction section is a bit disorganised. I think that some of Section 1.3 should be moved forward to Section 1.1, such that all content that provides a general motivation for risk management is contained within one section.

Thank you for your suggestion. We appreciate your feedback regarding the introduction section. We will improve section 1 by following your advice in moving parts of Section 1.3 to Section 1.1 and Section 1.2, where applicable. With this, Section 1.3 refers to the global risk reduction goals only.

<u>6. Questionnaire and user feedback:</u> The link between the results shown in Section 3.4 and the questions in the questionnaire needs to be clearer (I cannot find any of the questions mentioned in Figure 7 in the questionnaire questions provided in the supplementary material). The supplementary material should provide all questions, and the results for all questions should be provided in the main text (at least in summary form).

Thank you for raising this issue. We will update the supplement material accordingly and include the questionnaires from all three years. Regarding the link between the original questionnaires (as listed in the supplement material) and the description in Section 3.4 we like to provide additional clarification: as the versions of the questionnaires have changed slightly over time, we have taken the liberty of rephrasing the wording of the selected questions in the manuscript text (which is also caused by the translation from Spanish to English). In order to find the corresponding questions in the supplement material, we will mark them with asterisks. This will allow the reader to easily identify the questions in the additional material as shown in Figure 7.

We acknowledge the interest in the user feedback. As the questionnaires have changed over time, there are only a limited number of questions which were asked in all three years. As we focus in the manuscript on the evolution of the demonstrator tool over time, we have selected the questions in the short questionnaire which were included in all three years. The long questionnaire, as mentioned in the manuscript, was only created for years 2 and 3. In order to keep the focus of the feedback on the evolution of the tool, we would refrain from including all the results of the questions in the text.

Minor comments:

1. Line 180: end users are mentioned here as a stakeholder category but it is not yet clear why they would be considered a separate category in themselves - any of the other stakeholder categories listed here could also be a potential end user of this type of system. I see that the end users are described in more detail in line 281; this explanation should be moved forward to line 180 for clarity. However, the situation is further confused in the conclusions section (point viii) an Figure 2, where stakeholder groups are described as “user groups”.

Thank you for highlighting this. We will follow your advice to move the sentence in line 281 further up and rephrase it accordingly:

Line 281: *“It has to be noted that the potential users of the tool span all aforementioned stakeholders (section 2.1). A specific focus was put on the so-called end users (e.g., employees of planning and disaster risk management institutions). However, also representatives from the research community (universities and scientific research institutes), institutions operating information and monitoring systems as well as non-governmental were also involved in the user participation process.”*

We will update Figure 2 (“stakeholders” instead of “user groups”) and some changes in the conclusions section, point viii, such as:

Line 568: *“viii. Co-creation with users: Collaboration between researchers, software developers and ~~different~~ potential users ~~groups~~ definitely helps to develop a tool that is useful in practice. However, collaboration requires a strong engagement from all sides. It requires a moderated process which allows that user demands can be communicated to the researchers and developers. At the same time, the involved user must be aware and able to cope with trade-offs and compromises, as they might not benefit directly from the tool while it is still under development or in a demonstrator stage. To avoid false expectations and misunderstandings, we emphasize that transparency and clear statements are most important throughout the user involvement process.”*

When working on a revised version of the manuscript, we will further check the proper wording of stakeholder and users throughout the whole text.

2. Figure 5: A reader may look at this figure and question why an EQ catalogue is an input if we are dealing with a specific earthquake scenario. I think it should be more clearly described in the flowchart that the EQ catalogue is used to choose an earthquake scenario for which the ground motion is simulated (the earthquake scenario itself is currently missing from the diagram).

Thank you very much for raising this question. Our approach is not using one fixed scenario only. The user of the tool is able to select between various different earthquake scenarios. Those different scenarios are furthermore listed in different catalogues. For example, there is a catalogue based on observed earthquakes, i.e. a collection of historical earthquakes events which happened in the past. There is a catalogue which lists earthquake scenarios which were defined by experts containing both real and synthetic events. With this, the initial step is, as displayed in Figure 5, to select an earthquake catalogue. We will follow your advice and include the earthquake scenario as an input in the diagram. Thank you for pointing this out.

Based on your comment we will further update Section 3.2 to ensure that the reader is aware that the approach is not using one fixed scenario only.

Line 354: "*Following the story-based concept design (Sect. 2.2.1) we characterized the various elements composing the multi-risk situation. In order to ensure that the multi-risk situation is described as realistic as possible, we ~~Considering~~ took into account ~~a~~ the description of the reference (worst-case) scenario of an 8.8 Mw earthquake off coast of Lima Metropolitan area as documented by INDECI (2017)~~,~~. Based on this description and additional consultations with Peruvian stakeholders (workshop held in Lima on 20 April 2018; see section 3.4), we defined the following story: "Strong shaking occurs in Lima Metropolitan area, Peru, during the day time. There are severe damages on buildings and infrastructure, many people are directly affected by building collapses. As the earthquake has the potential to trigger a tsunami, a tsunami warning is issued and evacuation to safe areas is announced. Coastal roads and roads to highlands become progressively congested. In the following a first tsunami wave impacts the coast and starts inundating parts of the harbour area in Callao. Because of the numerous building collapses, city roads become less suitable for prompt evacuation."*

For this defined story, multiple scenarios including historical and observed and stochastically earthquakes, were made available. Each of these individual scenarios serves as a trigger for the defined multi-risk chain resulting in different cascading impacts.

~~Accordingly,~~ A flow chart (Fig. 5) was created conceptualizing the main logic, its components and information flows of the multi-risk story."

3. Line 475: I do not believe that a value of 55% could be described as an "overwhelming majority"

Thank you for this comment. We will change the wording accordingly:

Line 469: *"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~~ more than half (55 %) rated it as very highly and 31 % as even totally relevant (Fig. 7b)."*

4. Line 485: it seems that the practical usability of the tool actually decreases over time – e.g., 14% said they are totally likely to use the tool in year 3 versus 18% in year 1. Furthermore, Figure 7d does match with the description of these results provided in the text; it is mentioned that 64% rated the possibility of using the tool as highly likely in year 1, but there is no highly likely colour marked on the bottom bar of fig 7d.

Thank you for raising these issues. First of all, we apologize for the mistake in the text. Yes, you are totally correct. The 64% in year 1 refers to 'highly' likely and not to 'very highly' likely. The figure is correct, the mistake in the text will be corrected accordingly.

With this, we can further justify our interpretation of the increase of the practical usability of the tool (and not a decrease over time). Yes, it is correct that in year 1, 18% said they are 'totally' likely to use the tool versus only 14% in year 3. However, in year 3, 39% replied that they 'very high' likely would use the tool, whereas in year 1 no one replied that they are 'very high' likely to use the tool, but only 'highly' likely. With this, we do believe that it is valid to state that there is an increase regarding the feedback on the practical usability of the tool. We will update the paragraph accordingly:

Line 484: *"With regard to possible practical applicability, the question was asked how likely it is that users would use the tool for their practical work. For the V0.1 version presented in year 1, 18 % of the users rated the possibility of using such a tool as moderate, 64 % as ~~very~~ high and 18 % as totally. In year 2 (version V1.0) users responded that it is very less (4 %) and less (4 %) likely of using the tool in their practical work. The majority of users rated the likelihood of using the tool as moderate at 21 %*

and high with 59 %. While 8 % of users considered this to be very high, 4 % answered that they totally would use such a tool. The practical applicability of version V2.0 in year 3 ~~compared to very V1.0 increased significantly~~ was rated as follows. 8 % of users said they would be moderately likely using the tool, while 39 % said they would be highly likely and 39 % very high likely would use it. Finally, 14 % of users said that they totally likely would use the tool if it was available. Even though there was a slight decrease in the totally likelihood of using the tool (year 1: 18%, year 3: 14%), we believe that is valid to state that the overall likelihood has increased, as 39% were very likely to use the tool in year 3, while this answer was not given at all in year 1 (Fig. 7d)."