General comments:

The article presents a novel conceptual complex risk assessment methodology named 'Impact Webs'. The authors describe the conceptualization of this new approach to complex risk modeling and how they developed it based on combining the advantages of several existing conceptual risk modelling approaches. The steps for constructing such a 'Impact Web' are also described, and at the end the authors show the results of a complex risk assessment using a case study in Guayaquil, Ecuador to provide proof of concept.

In general, the structure of the paper is rather unfortunate chosen or the headings are simply inappropriate. The authors describe in Section 2 "Methodological development" that they did a literature review and how this inspired the development and conception of their new 'Impact Webs'. Furthermore, they write that they carried out further theory and conceptual synthesis within the research team (but no further information is provided) to develop the concept for the impact webs. They also briefly mention that they tested the concept with stakeholders in five different case studies. And then in Section 2 "Results" the structure of these 'Impact Webs' and the method for constructing such 'Impact Webs' is described. I think that this Section 3 describes the actual method and not the results. And Section 2 is more of a chapter that describes the methodological pre- considerations. And in Section 3.3, an example is given of how such a development of an 'Impact Web' is carried out using a case study. For me, this is rather a "Results" Section, presenting the results of actually applying the new approach in a case study. Overall, I suggest reconstructing and renaming the sections 2 and 3 including the subsections.

While I find this new 'Impact Webs' approach very exciting and interesting and valuable, I think it has not been sufficiently presented by the authors. Some work needs to be done to make it possible to replicate the method in future studies. Please see my specific comments for more details.

There are also some typos in the manuscript. I would advise the author to go through everything carefully again.

Overall, I recommend major revisions.

Authors response: We would like to express our thanks to the reviewer for their time to provide useful, constructive and detailed comments. We are glad to hear that they find the Impact Webs approach exciting, interesting and valuable. We agree with the feedback on the structure and will revise the overall structure of sections 2 and 3 of the paper as per your recommendations. Section 2.1 will become the 'Methodological pre-development: Scoping review of conceptual models of risk for inspiration', and we will significantly restructure the 'Lessons from the review' section based on your comments below. The 'Selection of constitutive elements' & 'Steps for constructing an Impact Web' will be made part of the methodology in sections 2.2 and 2.3 respectively, and we will provide more information and detail of the case studies in the 'Trail in test cases' section, moving it to the end of the methodology in 2.4. We will remove the section on concept development (see specific response below). Section 3.3, where we show our proof of concept, giving an example of how such a development of an 'Impact Web' was carried out using a case study would be the new results section as per your recommendation. Please see the restructured outline below:

1. *Introduction*
2. *Methodological development*

    2.1 Methodological pre-development: Scoping review of conceptual models of risk for inspiration

    2.2 Selection of constitutive elements in an Impact Web

    2.3 Steps for constructing an Impact Web

With this new structure, and additional details on the methodological development, the manuscript will be clearer for replicating the Impact Webs method in future studies. We have responded to your specific comments below.

Specific comments:

1. The authors mention the term 'response risks' in the abstract and later in several places in the manuscript. In lines 52 and 228, they mention this in connection with the literature. But this term is not used in this literature. What do the authors mean by this? Do they mean "human responses", "response options" or "response actions"? Or do they mean here "responses" as a driver of risk (risks due to human responses that not achieve the intended outcome etc.)? If they are introducing a <u>new term</u>, then it should be identified as such.

   Otherwise, the use of direct quotation marks in line 228 is confusing, because, as stated, the term as used by the authors here is not mentioned in the cited literature.

Authors response: We use response risks to refer to the risks arising from responses to risks and impacts (e.g responses not achieving their intended objectives, or having trade-offs). The concept and term were introduced in the paper by Simpson et al. (2021), then adopted and extensively used in the IPCC AR6 WGII report, Chapter 1 'Point of departure and key concepts' (e.g. Figure 1.5-part C). In that report, an explanation of response risk is provided in multiple instances, e.g. "The risks of climate change responses <u>include the possibility of responses not achieving their intended objectives or having trade-offs or adverse side effects for other societal objectives</u>", or "risks can arise from potential impacts of climate change as <u>well as human responses to climate change</u>." To address the comment, we will elaborate on the term to explain how it is defined in the literature in the introduction, following the IPCC point of departure and Simpson et al (2021) referencing, and include reference to AR6 Chapter 1. We will additionally remove the quotation marks on line 228 to avoid confusion.

2. In lines 32-33 the authors talk about "both positive and negative outcomes of disaster risk management practices". What do you mean by that? I suggest rephrasing it to better clarify what you mean by positive and negative outcomes.

Authors response: This is referring to the methodology being useful to evaluate trade-offs in decision making. This is elaborated on in the discussion, lines 495 – 500. To make sure this is clear in the abstract, will update the line to read "The participatory process of developing Impact Webs promotes stakeholder engagement, uncovers critical elements at risk and helps to evaluate trade-offs in decision making by improving understanding of both positive and negative outcomes of disaster risk management practices."

3. In lines 80–82, the authors cite literature on other system mapping approaches on which they base their newly developed Impact Webs: "... such as Causal Loop Diagrams

(Coletta et al., 2024), Fuzzy Cognitive Maps (Gómez Martín et al., 2020) and Bayesian Belief Networks (Scrieciu et al., 2021)." It would be good to provide further references per approach and to put "e.g." in front of them, since these are only mentioned as examples of many others.

Authors response: Thank you for the suggestion, we will do this.

4. When describing the methodological development of the Impact Webs, the authors mention on line 116 that they "show other conceptual risk modelling approaches" that they drew inspiration from, without mentioning, however, that this overview was based on a literature review. It would be helpful to make this clear at this point, since the authors also name the next subsection accordingly.

Authors response: Thank you for the suggestion, we will do this.

5. In lines 121 to 127, the authors explain their literature search conducted as part of the study. But the information given about the process is much too thin. The method is not sufficiently documented to allow a replication of the review. Which search string was used? In which database was the search conducted? Why was this database selected and not others? Was the search restricted to peer-reviewed literature? How many articles were screened in total? What are the exclusion and inclusion criteria? Why was no systematic literature search conducted?

Authors response: While systematic literature reviews have many strengths and allow for replication, they are not pre-requisite for conceptual inspiration and for the creation of new methodological approaches. Adopting a non-systematic scoping review approach gave us exploratory flexibility, for example to include and discuss new publications as we came across them, as well as include aspects of methods that we had used and were familiar with in our past research experience. While scoping reviews are not replicable, they are very helpful for developing initial conceptual frameworks and for concept development general.

To avoid confusion around this stipulation, we suggest to rename the section "Methodological pre-development: Scoping review of conceptual risk models for inspiration" *to emphasize that our review was a scoping review to support evidence synthesis and inspire concept development. We also suggest elaborate on why a scoping non-systematic review was chosen in the text below (Lines 133 – 137). We still feel that the table presents a useful synthesis of conceptual models used in risk assessments, and has merit in being published as it can be useful for other researchers using these methodological approaches in their work.*

6. In Table 1, the authors provide an overview of conceptual risk modelling approaches. I find this table very helpful. I am just wondering what the different approaches are categorized by? The authors start with "Climate Impact Chains" and end with "Participatory System Mapping". It might make sense to categorize the approaches by the degree of integration of quantitative data or the approaches' ability to capture the complexity of the system (from linear to non-linear approaches). Furthermore, I wonder what the key references in the last column are sorted by? Relevance? Does it matter who is listed first? I would suggest sorting them by year of publication.

Authors response: We are glad that Table 1 is found helpful. The different approaches are categorized by how the authors in the selected key references named them. If an author stated in their paper the method they used was Climate Impact Chains or Fuzzy Cognitive Maps for example, we follow this terminology.

While we appreciate there can be other ways to categorize the approaches, we do not think it makes sense to overly complicate this categorization in Table 1, for example, by degree of integration of quantitative data or the approaches ability to capture complexity of the system. We highlight in the table where approaches have strengths for integrating quantitative data, and the columns 'Strengths' and 'Weaknesses' in a complex risk context provide information on the approaches ability to capture complexity of the system. While we do highlight methodological ambiguity and cross-over in approaches (lines 161 – 164), we feel that such a table in a simpler format, categorized by approach name, has value. We propose not to categorize by degree of integration of quantitative data yet will organize the references by year of publication.

7. Furthermore, I doubt that the last category presented by the authors "Participatory System Mapping" is not really a stand-alone conceptual model-risk model development approach. Participatory systems modelling can be done using various systems mapping <u>methods</u> (e.g. FCM or causal loop diagrams) to formalize knowledge. The mapping of conceptual systems can be done both participatory or on the basis of literature research. "Participatory" merely describes the process and the way in which the knowledge is generated. All of the first five approaches could be carried out in a participatory way. See, for example, the studies:
    - Videira et al. 2009. Scoping river basin management issues with participatory modelling: The Baixo Guadiana experience. https://doi.org/10.1016/j.ecolecon.2008.11.008
    - Sahin et al. 2020. Developing a Preliminary Causal Loop Diagram for Understanding the Wicked Complexity of the COVID-19 Pandemic. https://doi.org/10.3390/systems8020020
    - Melles et al. (2021). COVID 19: Causal Loop Diagramming (CLD) of Social-Ecological Interactions for Teaching Sustainable Development. In: Leal Filho, W. (eds) COVID-19: Paving the Way for a More Sustainable World. World Sustainability Series. Springer, Cham. https://doi.org/10.1007/978-3-030-69284-1_16
    - Olazabal et al. 2018. Transparency and Reproducibility in Participatory Systems Modelling: the Case of Fuzzy Cognitive Mapping. https://doi.org/10.1002/sres.2519

Authors response: *Thank you for this observation. We agree and can remove the participatory system mapping category from the table. We suggest to incorporate some of the strengths and weaknesses of participatory system mapping approaches in other categories where their methodological application was relevant, as we feel they are important aspects to draw attention to in conceptual risk modelling approaches, and are equally relevant for these other types of approaches.*

8. The text in lines 131-173 in subsection 2.1 on the "Lessons from the review" does not really fit with the results presented in Table 1. The authors introduce three broad types of approaches following a study by Elsawah et al. (2017) in this section. However, the connection to the categories the authors have identified from their review (presented in Table1) is not entirely clear. I do not see the benefit of introducing this broad classification by Elsawah et al. (2017). The examples in the table are not organized according to this classification. It just seems so disconnected. It would be better if the authors simply focus on the lessons learned from their own review and discuss and compare the strengths and weaknesses of the identified methods, in order to derive what they used for their new approach. The authors do this from line 161 onwards, but it would be interesting if the authors elaborate on this further. I would advise the authors to shorten the section (L132-

173) and focus more on the actual results of their review.

Authors response: We agree, and will restructure this section based on your and other reviewers' feedback. Following your suggestion, we will highlight the different strengths in the approaches presented in table 1 and discuss why we drew on these for Impact Webs. This would make the section more informative of which aspects of different methods we were inspired by, and more logically link the section to the information in Table 1.

9. In line 172 to 173, I do not understand what the authors mean with "of what stakeholder value and want to protect." I am not sure what the word "protect" means in this context. Please consider revising the sentence.

Authors response: We will revise the sentence to be clearer and provide more of an elaboration of what we mean here.

10. In section 2.3, the authors describe the next steps in how they made this methodology feasible for practical application. They briefly state that they tested the methodology with groups of stakeholders in various case studies. What I am missing here is a better overview of the five different case studies. Simply saying that you have five different case studies and giving their names is not enough. Why were five case studies selected? Why these in particular? What characterizes each case study? A table would be nice that provides an overview of the uniqueness and challenges (including the complex risks) of each case study in comparison to the others.
What did the authors learn from each case study?

The authors further describe that there were two workshop rounds with a number of different stakeholders. Were there two workshop rounds in total or two workshop rounds for each case study? This is not entirely clear.

Authors response: We will update this section to give more details of the five case studies, including why they were selected, their characteristics and unique challenges and elaborate on the workshops and provide details on them. Given your and the other reviewer's feedback on restructuring the paper, this section would now come at the end of the methodology, after the scoping review (2.1) selection of elements (2.2) and steps (2.3).

11. In line 179, the authors mention that the identified various theories and concepts were synthesized within a "research team". However, the authors do not provide any further details about this research team. It would be useful to get a clearer sense of how this team and this synthesis process was organized. How big was the team? Did all belong to the same institution? What was the team composition? What disciplines were represented in the team? What about the disciplinary bias of the team? Were there members of this team who led this conceptual development? What was the expertise of these members? And how long did the process of this conceptual development take?

Authors response: We feel it is best to remove this section as it will make the methodology clearer based on the new structure suggested by the reviewers. While developing Impact Webs, we held a number of internal conceptual development discussions within our team (the Vulnerability Assessment, Risk Management and Adaptive Planning section at UNU-EHS) where we brainstormed and critiqued ideas from one another. While this was done to inspire concept development and is part of any research work, the team and synthesis process was not systematically organized. Under the new structure of the paper, where we intend to present the selection of elements and steps for construction in the methodology, rather than as results, we do not feel this section will add much to the reader.

12. As already described in my general comments, I suggest renaming Section 2 and restructuring and renaming Section 3. The current structure is misleading. The way I understand the text, Section 2 contains only preliminary methodical considerations (for example, a preparatory literature search), while Section 3.1-3.2 describe the actual new method/approach of 'Impact Webs'. In fact, I see section 3.3 as a "Results" Section in which the application of the new approach is presented and tested in a case study.

Authors response: As it was structured in the first submission, we intended to present the methodology for making Impact Webs as 'the result', as this is a methodological paper. This was discussed internally among the authors a number of times when drafting the publication, however, given reviewers comments, we agree with your suggestion and will restructure the paper as follows:

1. *Introduction*

2. *Methodological development*

    2.1 Methodological pre-development: Scoping review of conceptual models of risk for inspiration

    2.2 Selection of constitutive elements in an Impact Web

    2.3 Steps for constructing an Impact Web

    2.4 Trail in test cases

3. *Results: Proof of concept*

    3.1 Complex risks linked to COVID-19, concurring hazards and responses in Guayaquil, Ecuador

4. *Discussion*

    4.1 Strengths

    4.2 Limitations

    4.3 Future research direction

5. *Conclusions*

The authors present in Section 3.1 the constitutive elements of an 'Impact Web'. Unfortunately, this is not very illustrative. It would be much better if the authors present these eight model elements in a separate table directly next to Figure 1. It would also be important for the recognition of the individual elements that the elements are not grouped together or named differently. For example, the authors have combined "Interventions & response risks" and "Risks that did non manifest". I would strongly advise against this. It would also be good to use the same colors for the elements in such a table as in Figure 1.

Authors response: Thank you for this suggestion. We can produce a new table next to Figure 1 which includes the elements, how we chose to visualize them, and a short description. We additionally agree to not group the elements, and will separate them.

13. For the model element "Connections between elements", please explain the syntax in more detail. It is not entirely clear from the text what the different line types (solid, dashed) mean.

Authors response: We will do this in the new table you have suggested to include.

14. For the model element "Multiple interacting hazards", please indicate that you use icons in the model.

Authors response: We can do this.

15. For the model element "Direct & cascading impacts", please explain that you distinguish between positive and negative impacts, which are indicated by cross and hook signs. Why did the authors choose these symbols? Wouldn't plus and minus signs be more intuitive?

Authors response: We can do this. We avoided the plus and minus signs to avoid confusion with the symbology in use in other modelling approaches (e.g. causal loop diagrams), where the causal connections between elements is indicative of positive or negative influence between each other. With impact Webs, we demonstrate the cascading effects between impacts, and what their drivers and root causes are, as well as what interventions were taken in response measures and how these create cascading effects themselves.

16. The authors mention in L292 that during the scoping step an important step for selecting the scale to model by looking at geographical or administrative boundaries. It would be interesting to learn more about when the authors would suggest considering geographic or administrative boundaries. Risks can cross administrative boundaries. What would be the argument for looking at administrative boundaries anyway?

Authors response: While we fully agree that risks cross administrative and geographic boundary's (We included multiple scales in the model for exactly this reason) there is always a difficulty when modelling complex/systemic/cascading risks, as there is a challenge of where to start and where to stop. We suggest to start with geographic and administrative boundaries to start with as it is practical, and helps to refine the context and objective of the assessment. This makes more sense to us that starting from a specific sector, as we want to model multiple hazards and their effects on multiple sectors. There is of course, no one correct way to go about it, and we reflect on this in the paper, both in the scoping section (Lines 295 -298) and in the discussion in the limitations section of Impact Webs.

17. L306-307: I don't get what you want to say with this sentence: "This perspective acknowledged that the systems relationships emerge more clearly when under stress, i.e. become more visible and therefore easier to observe." What do you mean with "under stress"? Please consider revising this sentence.

Authors response: With under stress we mean that when impacts become observable in the system, it becomes easier to retrace the complex relationships that explain them and normally building up undetected in the background. Therefore, it made sense to start building from the observation of impacts. We will revise the sentence to be clearer.

18. In lines 364 to 367, the authors mention that they only select one case study to demonstrate the use of the new 'Impact Webs' approach. I fully understand why only one case study was selected. But why did the authors choose the Guayaquil case study and not one of the others? It would be good to provide a justification. Now, reading on, I see that the authors state in Section 3.3. "Step 1: Scoping" why they chose this case study. But perhaps it would be good to make this point earlier.

Authors response: We can include a bracketed section (e.g. See section 3.3. 'Step 1: Scoping') to point to the justification of showing Guayaquil.

19. In lines 386 to 394, the authors summarize the results from step 2,3 and 4 for the Guayaquil case study. But actually, they only mention which elements are included in the final model. That provides no added value. The reader learns nothing about the process, how the elements were selected, how the workshops with the stakeholders went, whether there was disagreement, or how many elements there were initially and how many the model was reduced to in the end? More details about the actual steps 2, 3 and 4 would be extremely helpful for further future applications of the 'Impact Webs'. And also, how long did each step take? Please provide further details in this regard.

Authors response: Section 3.3 in our first submission is a proof of concept from one of the test cases, we included it as we feel it's added value is demonstrating what an Impact Web and narrative storyline actual is in a final format. The process of how we got there is the previous steps in in sections 2 and 3 in submission 1, which we drafted in a manner that showed the overarching process across all of the cases. As we will restructure the methodology based on your feedback, we will provide further details on the workshops and process in the 'Trail in test cases' section.

With regards to your specific questions, it was not our objective in this paper to elaborate in detail how the stakeholder engagement process went with the Guayaquil case (for example if specific stakeholders has disagreements on which model elements to select and how we facilitated such disagreements), as we do not think this adds much to the scientific discussion on the need for new complex risk assessment methodologies and how we developed a new conceptual model to do this. The objective of our paper is to demonstrate the overall methodological development and steps we followed to create a new methodology in Impact Webs. We intend for the publication to showcase Impact Webs, with Guayaquil as our 'proof of concept'

We will include some more details on the stakeholder engagement process in the new submission in the methodology and discussion. However, some of the questions you ask for further details on are of course highly context specific, and elaborating on them would have required a full introduction on the specifics of the case study, thereby diverting from the focus of the paper, i.e. the development of the methodology for Impact webs.

20. In "Step 5: Narrative storyline for Guayaquil, Ecuador", the authors provide the storyline they have developed for this case study. The story is very interesting and important for the later communication with stakeholders. But wouldn't it also be interesting for the reader to learn more about the process of writing this story? Who of the team wrote it? How was the story constructed? Was an overarching storyline followed? Were there difficulties? How often was the story reflected upon with the entire team? How long did the process take?
It would also be good to highlight the "actual story" in the text, for example by using italicized font. If I understand it correctly, the actual story goes from line 402 to 438. Or am I wrong?

Authors response: We are glad to hear that you also think including this result is interesting and important for communication. As stated in response to comment 20, in this section we are demonstrating proof of concept, it is the 'result' of following the previous steps laid out in the article. We can further elaborate on how we derived the storyline in Step 5 of section 3.2, keeping in line with the overarching aims and objective of the article.

21. Figure 3: It would be important if the elements were listed in the same order in the legend as in Figure 1, which presented the basic structure of an 'Impact Web'. It would also be important to use the same terminology. In Figure 3, for example, the authors only refer to "Root cause" instead of "Root cause of risk and vulnerability".

Authors response: We agree, and will do this.

22. In lines 439 to 451, the authors highlighted and described the advantages of the 'Impact Web' approach in the case study of Guayaquil. But that doesn't fit into "Step 5: Narrative storyline for Guayaquil, Ecuador" at all, does it? Wouldn't it be better in a separate paragraph? Somehow it is a bit misleadingly placed.

Authors response: This is a synthesis/concluding paragraph. We can restructure so it fits more closely to the narrative description.

23. In Section "4.1 Strengths", the authors say that the new approach "is useful to conceptualise, identify and visualise networks of interconnected elements across different systems and sectors." To prove this, it would be good to get a brief overview of the challenges and successes and lessons learned from the other case studies. A short overview table would be good for this. It might also be helpful to show the other impact web models of the other 4 case studies in the supplementary material.

Authors response: The strengths and limitations sections in the discussion are summarizing reflections and lessons learned across all of the cases. We can introduce this at the start of the discussion, to elaborate that we are not just reflecting on our 'proof of concept' but from the entire research process that led us to these discussion points, particularly from our methodological development as well, given this is a methods paper. With the inclusion of further details of the other cases in the new section 2.4., we feel twe can substantiate the argument.

24. L472-473: "Given the models effectiveness for mapping the complexity of an event such as COVID-19 suggests that you could equally develop an Impact Web to understand the complexity of climate change risks." I don't understand this sentence. Is it related to what was said in the previous sentence, that a simple cause-effect chain model was developed first?

Authors response: Here we are highlighting that Impact Webs were effective for modelling an event which was highly complex and cross-sectoral (COVID-19), and therefore, could likely be effective for modeling complex and cross sectoral climate change risks. We can restructure the sentence to be clearer.

25. In lines 482 to 484, the authors state that, apart from the outputs (the visual and the narrative storyline), it was rather the process of developing the model that stimulated critical reflection in the modeler and involved stakeholder. Unfortunately, however, we did not learn much about this process when the example of Ecuador was presented. Please elaborate on this in an appropriate place.

Authors response: This is a reflection that we observed through our own process of developing the model and engaging stakeholders in workshops. We are happy to elaborate on this further in the discussion.

Technical corrections:

There are some grammatical errors and typos. I have highlighted the ones I noticed, but I suggest that the authors read the manuscript carefully again.

1. L29: "the methodologies usefulness" ❼ "the methodologies**'** usefulness"
2. L87: "compared with Climate Impact Chains" ❼ "compared **to** Climate Impact Chains"

3. L116: "In section 2, we present our methodological development from Impact Webs." ❼ "In section 2, we present our methodological development **of** Impact Webs."

4. L118: Is the word "trailed" really appropriate in this context?

5. L179: There is a typo: "until we synthesized an agreed" ❼ "until we synthesized an**d** agreed"

6. L217: "Following the inclusion multiple hazards" ❼ "Following the inclusion **of** multiple hazards"

7. L267: There is a typo: "For exmaple" ❼ "For e**xa**mple"

Authors response: Thank you for these technical corrections, we will implement them when offered to re-work the manuscript.