We thank the reviewer for the thorough evaluation of our manuscript and the helpful comments. We respond to these comments as follows:

Review of the paper “Fostering interoperability of data, models, communication and governance for disaster resilience through transdisciplinary knowledge co-production” The paper discusses how disaster risk management (DRM) and climate change adaptation (CCA) are hindered by a lack of interoperability between data, models, communication, and governance. It provides a comprehensive overview of the technical, legal, operational, communicative and institutional barriers hindering effective responses. To overcome these barriers in the domains of data and models, communication, and governance, the authors suggest a transdisciplinary approach. They introduce frameworks such as a Risk-Tandem Framework or a Data Fabric to improve interoperability and facilitate knowledge co-production, aiming to enhance disaster resilience through integrated systems and governance.

[1] The paper addresses the importance of improving disaster resilience by highlighting gaps in interoperability across various systems, including data, models, communication, and governance. This comprehensive, multi-dimensional approach provides value to a diverse range of stakeholders. However, the paper lacks depth regarding the practicalities of implementation. This is partly due to the fact that tests of the Risk Tandem and the Data Fabric are still pending. However, the transdisciplinary approach is not only costly in terms of resources, but also terms of the willingness of participants on all levels. In practice, securing the necessary resources and fostering cooperation between stakeholders could be challenging, even if highly desirable. The authors should elaborate in more detail, how participants and institutions can be motivated. In general, the paper would benefit from examples or practical instructions on how to overcome the barriers mentioned.

The motivation of this invited perspective paper is to present our perception of the critical role of interoperability at different levels in multi-hazard risk management and climate change adaptation and to discuss trans-disciplinary knowledge co-production as a means to foster interoperability in a multi-dimensional approach. The intention of the paper is to put this idea to an open debate in the scientific community for collecting suggestions and further thoughts. It is beyond the scope of this invited perspective to provide comprehensive tests of the suggested tools (i.e. Data Fabric and Risk-TANDEM), which is still the subject of ongoing research. Further papers discussing these developments in detail and the practicalities of implementation are currently under review in other journals. We agree that our presentation would benefit from additional examples to illustrate the issues addressed and the underlying ideas of the concept and tools. As this point is also raised in other comments in the reviews, we make suggestions for examples in the answers to these comments, including also examples for practicalities of implementation, see [R1-7, R2-16] and willingness of participants [R2-16].

[2] One aspect that could be discussed in addition is that different aspects are often relevant for different stakeholders. For example, a scientifically robust model is based on many parameters. However, only a fraction of these are relevant for political decision-makers. However, this does not mean that the model can be reduced to these few parameters. Note that specific parameters are meaningful without context. Indeed, trans-disciplinary product development is a meaningful tool to overcome such challenges.

We agree that the importance of different aspects varies for different stakeholders. We will pick up this point with regard to models in [section 2.1 ll 165]:

“Furthermore, even if all data is interoperable and well documented by metadata, it remains challenging to use it in practice as users can rarely be experts in all the fields required to adequately judge the fitness for purpose. The crux of data and model interoperability rests on finding the right balance between model complexity and the granularity of input and output, harmonized with **stakeholder specific preferences** as well as collective contextual understanding and discernment. An overabundance of detail in data and metadata can obscure vital insights, and an overly intricate and complex model at one stage may be suboptimal to the performance of subsequent applications. The objective is to **reflect on important aspects for different stakeholders** and to supply the appropriate amount and level of data and contextual knowledge sharing necessary to inform the next stages in modelling or decision-making processes. While several technical solutions such as the definition of data standards are prerequisite for this objective, direct exchange between experts of connected models and data is often the only way to achieve maximum interoperability.”

With regards to communication and knowledge transfer in [section 2.2 ll186]:
“Translating data and knowledge into action is often missing due to a lack of understanding of user needs and the integration of different **stakeholders perspectives and aspects**, knowledge and disciplines. This can compound the lack of collaboration between data providers themselves as well as with users and other **stakeholders** and lead to a dismissal of values and norms that inform decision-making and therefore affect the uptake and application of data and information as they may not be fit for both purpose and context.”

In addition, interoperability is not only important in regard to models and communication and knowledge transfer but also in regard to governance processes that need, as we argue, to be jointly embedded within a knowledge co-production process to identify and overcome potential interoperability gaps. The identification of such gaps are a cornerstone for determining appropriate tools and processes to overcome them, either within models or governance processes or importantly between them. Therefore, we suggest to also add the aspect of stakeholder perspectives with regards to governance in [section 2.3 ll 244]:

“Therefore, stakeholder and public engagement in risk governance are motivated by the realisation that these groups provide crucial information for assessment from diverse standpoints and **perspectives**, including scientific knowledge and other knowledge systems (Fischhoff, 1995).”

In addition, I have listed some minor comments concerning different aspects throughout the paper.

[3] Line 33: Please provide a source for the statement made in the sentence “In the absence of historic flood observation or due to a lack of local flood experiences [...].”

We propose to add Kreibich, H., et al. 2017 (https://doi.org/10.5194/nhess-17-2075-2017, 2017) and Bertola et al. 2023 (https://doi.org/10.1038/s41561-023-01300-5) as a references for this statement.

[4] Line 199 to 203: The content described here seems repetitive.

We assume that this refers to repeating statements from the previous section 2.1 on data and model interoperability. We propose rephrasing ll 190 as follows:

“As such, technical data interoperability must be accompanied by efforts to support the interoperability of the information and communication channels and approaches seeking

to address these issues. Issues of communication also emerge from **data and model interoperability (cf. Challenge 1 in section 2.1)** ~~a lack of collaboration between data providers which may contribute to, or propagate errors and replication in data (cf. Challenge 1), thus leading to increasing complexity.~~

[5] Line 313: I doubt that running different models necessarily enhances trust. It can also lead to confusion due to conflicting results that do not always point to different realities but may instead be caused by model effects. To get to the bottom of such effects requires in-depth knowledge of the model. This does not seem to me to be the desirable goal, but rather that trust is built between the different stakeholders.

We realise that our statement is not clear. Building trust in the context of co-production is a multifaceted idea, which requires additional explanation. We think that in the context of our perspective paper two main aspects need to be considered: a) trust in models in the sense that the models are fit for the intended purpose, and b) building trust among stakeholders and decision makers in data and models who build their decision on the outcomes of available data and models.

Regarding a), we agree that running different models does not inherently enhance trust, in particular when outputs are highly uncertain and variable. At the same time, one of the main ways for scientist to build trust in models that are only hardly verifiable (such as risk models of the future, e.g. Merz et al. 2024) is to have several, distinct modelling approaches building up to shared evidence and a common understanding. For instance climate models may lead to very large variance in outputs for global temperatures for the same emission trajectories. Confidence in the climate models is established by pooling the information from several, distinct models. This confidence was build thanks to a large-scale interoperability effort lead by the CMIP team. We argue that this type of multi-model angle is not only required on the physical modelling side where it is already common, but through the whole chain of information. This also relates to the question what models can be used for which purpose. Indeed each model has to clearly state its limitations as well as advantages and additional models usually targeting a different set of questions to overcome some limitations of other models. In case of conflicting results one can then use the above approach of model ensembles or other approaches including climate storylines. We also argue that this complexity, while it requires careful communication, should not be hidden from different stakeholders. In fact, transparently communicating the uncertainty in the modelling by showing the outputs of different models not only increases the robustness of the process, but also builds trust.
However, regarding b) the communication part remains absolutely central to this and requires a lot of care. The proposed knowledge co-production process, i.e. connecting modellers, data providers and its end users, promotes discussions regarding different modelling approaches, and explores user needs vis-à-vis available information in a non-hierarchical manner (see Daniels, et al., 2020). This is expected to increase the usability and accessibility of information by clarifying potential errors, uncertainties and underpinning assumptions embedded in each model for users, in an effort to align available information with needs of planners and decision-makers. In other words, the process is an on-going negotiation between needs and what models can provide, which, insofar as uncertainty is accounted for, also generates trust in data through continuous and transdisciplinary engagement with it (Daniels, et al., 2020). Effective communication plays a pivotal role in establishing trust in DRM and CCA decisions. Uncertainties embedded in underlying modelling can be large, and uncertainty information are often difficult for stakeholders to understand. Since disclosure of uncertainties does not always increase trust and credibility in risk analyses (Doyle et al., 2019), information about uncertainty should be embedded in the co-production process and tailored to the specific audience and consider their perspectives, technical knowledge and concerns (Merz et al. 2024). For the paper we suggest to rephrase the text:

“A possible way to embed this in existing workflows is to build standardized and simplified data and model pipelines, which encapsulate some of the complexity and allow for the easy running of separate models addressing the same question. This allows comparing model outputs of different approaches, which can support building trust in the models to be fit for purpose. Importantly, the co-production process connects modellers, data providers and end users, promotes discussions regarding different modelling approaches, and explores user needs in contrast to available information (Daniels et al., 2020). In this process, effective communication is essential in establishing trust in DRM and CCA decisions. Uncertainties embedded in underlying data and models can be considerable. For stakeholders, uncertainties are often difficult to understand. Therefore, information about uncertainty should be embedded in the co-production process and tailored to the specific audience and consider their perspectives, e.g. Merz et al. 2024 for the example of flood hazard and risk modelling.”

[6] Line 324: Please specify what you envision by “creative and interdisciplinary approaches”. In the current form, this is very ambiguous.

We suggest to add the following sentences which pick-up examples from the papers cited for clarification:

“Interactivity is one of the key principles of knowledge co-production (Norström et al., 2020). Creative approaches can include interactive games to co-explore issues, language and terminology (Daniels et al. 2020) and participatory arts-based methods to support three-way communication between decision-makers, scientists and communities (Stewart, 2024). These aim to clarify and unpack complex and sometimes field-specific knowledges so that they become easily accessible for all stakeholder groups –for instance, with the help of interactive and game-based methods such as tabletop exercises, serious games, or “future-casting” and visioning.”

[7]Line 353: Can you provide an example or specify the “specific roles and capacities needed”?

We propose to add the following example for specific roles and capacities needed:

“These roles support trans-disciplinary knowledge co-production through their capacity to network, communicate, facilitate and convene multiple diverse stakeholders, navigate their different goals/values and synthesise and integrate/broker knowledge to influence policy or practice. This entails identifying champions and facilitators capable and interested in bridging connections between disciplines and knowledges involved (Bharwani, et al., 2024), in consideration of the skills and capacities required for them to enable co-production as described above.“

[8] Line 381: There is something missing at the end of this line.

This is simply a punctuation error. The sentence should read: “Another building block is visualisation, which aims to enable a visual element of information transfer.”

[9] Line 435: You argue that the process is resource-intensive. In my opinion, this primarily comes from the transdisciplinary approach. Therewith, i) and ii) are at least linked and other reasons for the resource intensiveness should be added.

Indeed these two aspects are linked, however, in our context we argue that the resource-intensiveness comes from (i) knowledge co-production that also happens within scientific disciplines (e.g. economic modelling of indirect risks due to hazard events through General Equilibrium Models and Agent -Based Modelling approaches to include long-term and short term-behaviour, respectively, see for example Botzen et al. (2019) or a specific hazard focus, e.g. flood events across different spatial scales and integration of results for a comprehensive flood risk analysis). So in other words, the iterative, reflexive, non-linear nature within a co-production process is already resource intensive even if it is not (yet) trans-disciplinary. In case, as we argue that it should be, that it is trans-disciplinary, additional resources are needed (that may not be needed for point (I)) but are referred to in ii) as for instance, to increase understanding between different scientific disciplines as well as stakeholders and the organization and orchestration of such tasks to manage the additional complexity for knowledge integration.

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