**Reply to comments of referee#1 on nhess-2021-385**

## General comments:

Overall, this paper provides a potentially interesting study of the tri-lateral area of the upper Rhine basin. The authors adopt an indicator-based approach, and use several datasets from three different countries to assess climatic vulnerability and risk.

I have reservations about the approach that is taken, because 1) different climatic risks are combined, 2) different elements of vulnerability and risk are mixed up and sometimes even double counted, and 3) there is insufficient description of the actual calculations and actual data used, especially for the exposure and sensitivity data.

1) We see it as a challenge to combine different climatic risk since they all affect the region and the people not independently/sometimes all at the time. We first analyzed the main climatic stressors by evaluating a large model-ensemble for the region and then chose seven relevant climatic stressors. This aspect has been repeatedly discussed with experts from the German Weather Service (DWD). We see it as an advantage to be able to reflect the multitude of climatic changes and the associated complexity. We focus on the overall socio-economic dimension of risk in the TMO, so naturally, the scope of the analysis is broader than would be for a single sector.

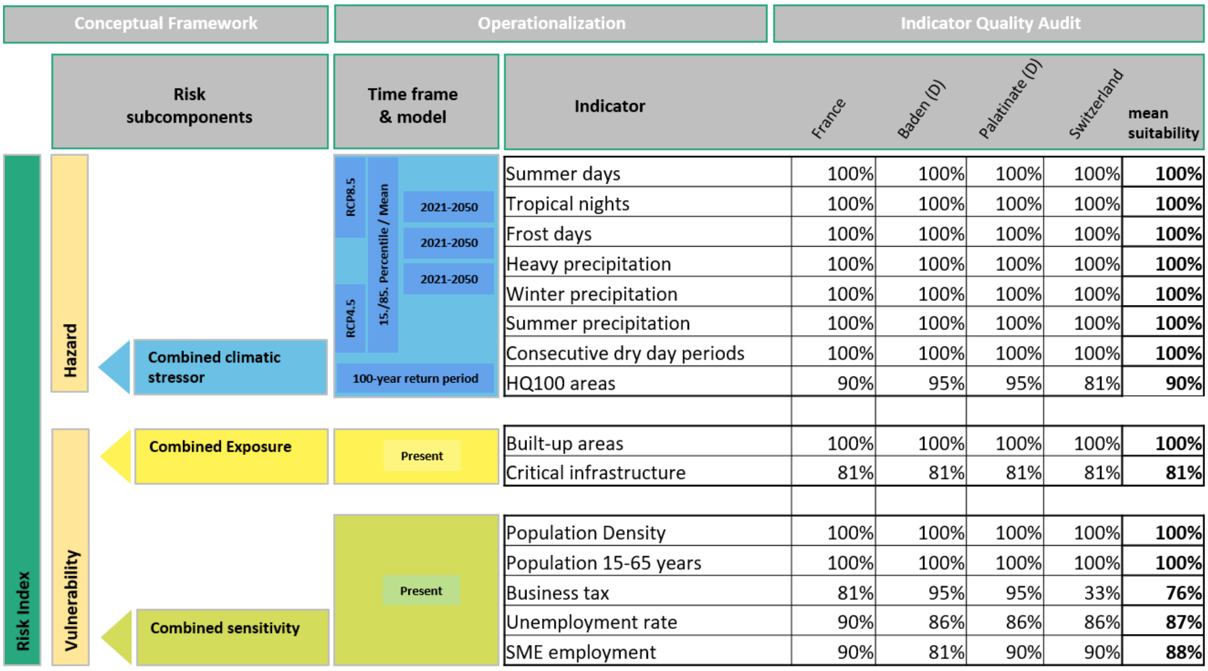
2) We are aware of this subject and the broad theoretical and conceptual discussions. For our operationalized approach we followed the practice-oriented framework of the UBA (2017) that builds on several frequently cited publications (e.g. Füssel 2007, Birkmann 2013) and is mainly used in similar, more quantitatively oriented approaches in the German speaking context. We identified this framework out of the very rich literature because it gave us the opportunity to emphasize the main focus of the paper, namely the difficulty of identifying suitable and comparable data sets in the transnational context. For this reason, we have treated the flood related layers separately from the rest of the climatic stressors because, unlike the climatic data from the model ensemble, they have been generated from different data sources. We are aware that our initial approach exaggerates flood risks and have discussed this in the paper.

   After the reviewers comments we agree that our initial conceptual framework needs improvements/clarification. We redesigned the conceptual framework as follows (see also figure 1):
   - HQ100 areas are moved to the climatic stressors section
   - The flood related combined impacts are dropped to reduce double counting
   - We clarified, that risk is a product hazard and vulnerability. Vulnerability consists of exposure and sensitivity.

Naturally, these major revisions have led to adjustments throughout the paper (recalculations, results) which we will resubmit.

3) The calculation is performed on the basis of simple formula Risk = Hazard*Vulnerability (Exposure + Sensitivity). We will highlight this more prominently.

In fact, we kept the rationale behind the selection of the indicators brief, since an in-depth discussion on the operationalization of our risk framework and the derivation of the indicators has been published by Scholze et al. (2020). We explicitly explain in lines 175ff that we build on this paper to address the specific challenges of the trinational situation, which has an impact on the availability, homogeneity and resolution of comparable data sets. We had split the two articles because we felt it would exceed the page numbers of one article.
We will move the Table from the supplement to the main paper and also explain more in depth why we selected each indicator and what it stands for (Tables 1 and 2).




| Indicator | France | Baden (D) | Palatinate (D) | Switzerland | mean suitability |
|---|---|---|---|---|---|
| Summer days | 100% | 100% | 100% | 100% | **100%** |
| Tropical nights | 100% | 100% | 100% | 100% | **100%** |
| Frost days | 100% | 100% | 100% | 100% | **100%** |
| Heavy precipitation | 100% | 100% | 100% | 100% | **100%** |
| Winter precipitation | 100% | 100% | 100% | 100% | **100%** |
| Summer precipitation | 100% | 100% | 100% | 100% | **100%** |
| Consecutive dry day periods | 100% | 100% | 100% | 100% | **100%** |
| HQ100 areas | 90% | 95% | 95% | 81% | **90%** |
| | | | | | |
| Built-up areas | 100% | 100% | 100% | 100% | **100%** |
| Critical infrastructure | 81% | 81% | 81% | 81% | **81%** |
| | | | | | |
| Population Density | 100% | 100% | 100% | 100% | **100%** |
| Population 15-65 years | 100% | 100% | 100% | 100% | **100%** |
| Business tax | 81% | 95% | 95% | 33% | **76%** |
| Unemployment rate | 90% | 86% | 86% | 86% | **87%** |
| SME employment | 90% | 81% | 90% | 90% | **88%** |

*Figure 1: Revision of conceptual approach*

The authors should have provided the precise formula for constructing the indicators. In indicator construction, the normalisation between highly heterogenous and datasets that have different statistical distributions and absolute values is essential, in order to develop meaningful indicators. No word is spent on this (except "statistical analysis" in Line 179).

We put this information in the supplement because we did not want to overload the paper but agree that this information is very important. For the indicator construction we referenced Scholze et. Al. (2020). We will feature the indicator construction process more prominently in the main part of the paper and also explain more of the data treatment.

Also, I do not understand why different climatic risks are combined. Is for instance extreme wind not relevant? Why is business tax important as exposure metric for tropical nights? Why is only HQ100 used, and not also HQ50 or HQ200? Why is agricultural exposure not included, when you look at rainfall? All these choices seem completely arbitrary. A hazard-specific analysis, with all its limitations, that then combines into a single indicator would have been much more useful. The results also cannot inform any policy for adaptation, except that the urban areas stand out, but that could already have been concluded from a simple map of the area …

The rationale of combining different climatic risks was to capture the complexities that climate change poses on the overall socio-economic dimension on the local scale (communities). Identifying suitable and comparable data sets in the transnational context is a key challenge and thus naturally limits the available data sets. For example, HQ100 is the only common denominator throughout the TMO. HQ10, HQ50, HQ200 and HQextreme exist for some but not all administrative units. Tropical nights indicate Heat stress and lack of nocturnal cooling, which has effects on many economic sectors and processes. Business tax is a measure for the Economic importance of a community. On the local scale (community level), these and other data sets serve as proxies for the complex cross-sector risks in the absence of independent measures for said risk. We will deepen the theoretical reasoning behind the inclusion of data sets in order to avoid the impression of arbitrariness.

We disagree, however, that the results could have been drawn by a simple map of the region. We included a broad number of different indicators, not only population density. We discuss that we are not surprised by the result that urban areas are in general more vulnerable. However, the risk pattern presented in our final maps is not just a perfect correlation with population density. For example there are lesser populated areas in the Vosges Mountains that are ranked "medium" and some areas in the Black Forest are ranked "medium-high" although they have a low population density, and so on.
We would put it like that: the hypothesis of generally more vulnerable urban agglomerations was verified by our study, just like in other similar studies, and complemented by some exceptions and nuances resulting from the interaction of the indicators used.

We thank for all the efforts and remarks, even if we do not agree with some of them. We assume that it is more a question of different disciplines and perspectives. Sometimes the critique is beyond the intended approach.

Kind regards,
NR, NS & RG

## Detailed comments:

Line 4: Here already the concept is mixed up: impact is a product of a single hazard (scenario), combined with exposure (what the authors here confusingly term "spatial occurrence", and sensitivity). So impact can never be an ingredient together with the former three components.
We thank the reviewer for pointing this out and revised it according to figure 1.

Figure 1: This area is in western Europe, not central Europe.
The classification of individual countries as Western or Central Europe differs depending on the context and in some works Germany, Switzerland and sometimes even Eastern France are assigned to Central Europe.

Line 55: This whole section can be shortened. The issues with definitions of vulnerability and risk are well-know, and not the main topic of this paper. These issues should have been described in single short paragraph, and then the authors could motivate and adopt a decision on the approach to be taken. The current discussion is too long, and only distracts.

We felt the need to deepen the theoretical discussion in order to explain why we followed the practice-oriented approach of the UBA (2017). After the mentioned revision, we will shorten this part accordingly.

Lines 74-75: This is not correct. Risk is also regarded in SREX and AR5 as outcome without adaptation (note the typo in "adaption").

Thank you for this comment, we will change it accordingly.

Line 80: Proxies and indicators are not the same. Proxies refer to data, that are used to approximate unobserved processes and have a unit and dimension, while an indicator is (most often) a dimensionless construct made up of some data.

Thank you for this comment, we will change it accordingly.

Line 96: "highly spatial"; highly spatial what?

Thank you for this comment. We will rephrase the sentence so that it becomes clear that risk is distributed differently in space and that maps can contribute to understanding this accordingly.

Line 99: "Local in this sense might be misleading" this is unclear.

Thank you for this comment. Maybe we did not describe our understanding of local-scale clearly enough. We mention this to address different understandings of scales. Local scale is sometimes used to describe the household scale, which we do not address. We will rephrase the sentence so it becomes more clearly that the term local is not used consistently.

Line 104: Here is seems that vulnerability is regarded as inherent property, but it is a construct. So it should be said here that all vulnerability assessments are context dependent.

Thank you for this comment, we will change it accordingly.

Lines 130-132: It is unclear to me why the authors use the term "spatial occurrence", when they mean exposure. Also sensitivity and climatic hazard have spatial occurrence and spatial properties. This adds to confusion.

The guideline for the UBA's (2017) practice-oriented approach (only available in German; https://www.umweltbundesamt.de/sites/default/files/medien/377/publikationen/uba_2017_leitfaden_klimawirkungs_und_vulnerabilitatsanalysen.pdf ) states:

*"The spatial occurrence, i.e., the presence of systems potentially affected by climatic forcing in a study region, should be explicitly examined as in the IPCC 2014 concept, for example, the number of wastewater treatment plants in the flood-prone regions of a city. It changes over time due to land use changes, for example. The term exposure should be avoided because of the different meaning in IPCC 2007 and 2014."*

After the aforementioned revision of the framework, we now adopt the term exposure to avoid confusion.

Figure 2: Why is population density a sensitivity indicator? I would think this is rather an exposure/spatial occurrence indicator. Also, why is HQ100 an impact indicator and not a climatic indicator? It also overlaps with the flood affected population etc. in the same

category. So this would be double counting. Here it becomes clear that the concept seems mixed up. Finally, what is CRITIS in the figure?

Thank you for this comment. We revised the concept as mentioned above.

There are no metrics given for the different indicators. What is the unit of "business tax" for instance, or built-up area? In many studies built up areas would also be differentiated according to density, building values, and so on.

Thank you for this comment. We will feature this information in the main body of the paper instead of the supplement.

We agree that differentiating between building density, building value and more can add interesting insights. This is, however, a question of data availability. As we show in this paper, identifying suitable and comparable data sets is inevitably determined by the lowest common denominator within the trinational context.

What are the precise sources of the data? The paper is much too short on describing the non-climatic datasets, references to the (open source) data or offices where the data were provided are not given. This is not acceptable for a research paper.

Thank you for this comment. We will feature this information in the main body of the paper instead of the supplement. Additionally we add table 1 as an overview.

*Table 1: Indicandi of the data for the the risk index*

| Risk Subcomponent | Indicator | Indicandum | Description |
|---|---|---|---|
| **Combined climatic stressor** | Summer Days | Heat stress, oppressive humidity, cooling energy demand | days/year with a maximum temperature >25 °C |
| | Tropical Nights | Heat stress, lack of nocturnal cooling | nights/year with a minimum temperature >20 °C |
| | Frost Days | Decrease of snow cover | days/year with a minimum temperature <0 °C |
| | Winter Precipitation | Flood risk in winter months | change of mean precipitation in December, January and February in % |
| | Summer Precipitation | Summer drought risk, low-water, water shortages | change of mean precipitation in June, July and August in % |
| | Heavy Precipitation | Damages caused by heavy rain and subsequent flooding | days/year with a precipitation >20 mm |
| | HQ100 areas | flood prone areas in a 100-year-event | percentage of total community area |
| **Combined exposure** | Built-up areas | Location of exposed enterprises and population | built-up area in % per community |
| | Critical infrastructure | Location of exposed critical infrastructure | incl. roads, cross-border bridges, railway lines, stations, airports, hospitals, power lines, power pylons, power towers, substations, power plants and generators |
| **Combined sensitivity** | Population density | Density of the potentially affected population | per $km^2$ |
| | Population 15-65 years | Share of the population at working age | percentage of total population |
| | Business tax | Economic importance of a community | in  per , without Switzerland |
| | Unemployment rate | Economic situation of a community | percentage per community |
| | SME employment | SMEs are more sensitive due to reduced financial resources | percentage of employees in enterprises <200 (F) or <250 employees (D + CH) |

Lines 174-175: This is a too short description of the source of these data.

Thank you for this comment. We will deepen the theoretical reasoning behind the inclusion of data sets in order to avoid the impression of arbitrariness and to highlight more clearly from which sources the data originated. We will move Table 2 from the supplement to the main body of the text.

*Table 2: Data sources for the indicators of the risk index*

| Vulnerability/Risk Subcomponent | Indicator | Source |
|---|---|---|
| **Combined climatic stressor** | | |
| | Summer Days | Model Ensemble provided by the German Weather Service (DWD) and calculated within the EURO-CORDEX initiative (2016). |
| | Tropical Nights | Model Ensemble provided by the German Weather Service (DWD) and calculated within the EURO-CORDEX initiative (2016). |
| | Frost Days | Model Ensemble provided by the German Weather Service (DWD) and calculated within the EURO-CORDEX initiative (2016). |
| | Winter Precipitation | Model Ensemble provided by the German Weather Service (DWD) and calculated within the EURO-CORDEX initiative (2016). |
| | Summer Precipitation | Model Ensemble provided by the German Weather Service (DWD) and calculated within the EURO-CORDEX initiative (2016). |
| | Heavy Precipitation | Model Ensemble provided by the German Weather Service (DWD) and calculated within the EURO-CORDEX initiative (2016). |
| | HQ100 areas | GeoRhena. catalogue. https://sdi.georhena.eu/geonetwork/srv/fre/catalog.search#/home (accessed on 12 June 2018). |
| | | LUBW. Überflutungsflächen. http://udo.lubw.baden-wuerttemberg.de/public/q/bHqz1 (accessed on 11 June 2018). |
| | | Ministerium für Umwelt, Energie, Ernährung und Forsten, Rheinland-Pfalz. Risikokarte HQ10, HQ100, HQextrem. http://www.gdawasser.rlp.de/GDAWasser/client/gisclient/index.html (accessed on 11 June 2018). |
| | | Amt für Geoinformation. Fließtiefenkarte HQ 30/100/300/extrem. https://www.geo.bl.ch/geoshop/ (accessed on 11 June 2018). |
| | | Amt für Geoinformation. Fließtiefenkarte HQ 30/100/300/extrem. https://geoweb.so.ch/geodaten/index.php (accessed on 11 June 2018). |
| | | Kanton Aargau. Fließtiefenkarte HQ 30/100/300/extrem. https://www.ag.ch/geoportal/geodatenshop/datensuche.aspx. (accessed on 11 June 2018). |
| | | Kanton Basel-Stadt. Fließtiefenkarte HQ 30/100/300/extrem. http://shop.geo.bs.ch/geoshop_app/geoshop/ (accessed on 11 June 2018). |
| **Combined exposure** | | |
| | Built-up areas | Copernicus Programme. Corine Land Cover (CLC) 2012, Version 18.5.1. https://land.copernicus.eu/pan-european/corineland-cover/clc-2012?tab=download (accessed on 14 June 2018). |
| | Critical infrastructure | GeoRhena. catalogue. https://sdi.georhena.eu/geonetwork/srv/fre/catalog.search#/home (accessed on 12 June 2018). |
| | | OpenStreetMap Contributers. Planet dump retrieved from https://planet.osm.org, 2018 (accessed on 12 June 2018). |
| **Combined sensitivity** | | |
| | Population density | GeoRhena. catalogue. https://sdi.georhena.eu/geonetwork/srv/fre/catalog.search#/home (accessed on 12 June 2018). |
| | Population 15-65 years | GeoRhena. catalogue. https://sdi.georhena.eu/geonetwork/srv/fre/catalog.search#/home (accessed on 12 June 2018). |
| | Business tax | Statistische Ämter des Bundes und der Länder, Deutschland. Realsteuervergleich: 2015. https://www.statistikportal.de/ (accessed on 15 June 2018). |
| | | Ministère de l'Action et des Comptes publics. Données de fiscalité directe locale 2015. https://www.impots.gouv.fr/portail/statistiques (accessed on 15 June 2018). |
| | Unemployment rate | arbeit.swiss. Durchschnittliche Arbeitslosenquote pro Jahr. https://www.amstat.ch/v2/index.jsp (accessed on 13 June 2018). |
| | | INSEE. Démographie des entreprises et des établissements pour l'année 2015: Répertoire des entreprises et des établissements (REE) - Fichiers détail. https://www.insee.fr/fr/statistiques/2985296 (accessed on 13 June 2018). |
| | | Statistische Ämter des Bundes und der Länder, Deutschland. Arbeitsmarktstatistik der Bundesagentur für Arbeit. https://www.statistikportal.de/ (accessed on 13 June 2018). |
| | SME employment | BFS. Statistik der Unternehmensstruktur (STATENT): 2014 (accessed on 15 June 2018). |
| | | INSEE. Recensement 2014 : résultats sur un territoire, bases de données et fichiers détail. https://www.insee.fr/fr/information/2867866 (accessed on 13 June 2018). |
| | | INSEE. Recensement 2014 : résultats sur un territoire, bases de données et fichiers détail. https://www.insee.fr/fr/information/2867866 (accessed on 13 June 2018). |
| | | Statistisches Landesamt Baden-Württemberg. Unternehmen und Betriebe seit 2006 nach Beschäftigtengrößenklassen: 2014. https://www.statistik-bw.de (accessed on 13 June 2018). |
| | | Statistisches Landesamt Rheinland-Pfalz. Unternehmen 2015 nach Wirtschaftszweigen und Zahl der sozialversicherungspflichtig Beschäftigten. https://www.statistik.rlp.de (accessed on 13 June 2018). |

Line 260: Section 3.2: Socio-economic dimension is a poor term for the various indicators included here. HQ100 areas for instance is mostly a physical variable. Also critical infrastructure and built-up areas have a mostly physical character, that is maybe influenced by some (past) socio-economic processes.

Thank you for this comment. We revised this as mentioned above.