Protocol for the case studies of the UNCHAIN project

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Short summary

This document is the case study protocol of the UNCHAIN project. It aims at providing guidance to case studies on how to address research innovations and questions identified in WP1. The protocol also provides background information on the conceptual framework of Impact Chain and targeted case studies. The final section focuses on data flows management across the case studies.

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Introduction

This document is the case study protocol of the UNCHAIN project. Maimbo and Pervan (2005) motivate the use of case study protocols (in Information Systems Research) as follows, also highlighting the suitability for distributed research activities:

> *A Case Study Protocol (CSP) is a set of guidelines that can be used to structure and govern a case research project (Yin 1994). It therefore outlines the procedures and rules governing the conduct of researcher(s) before, during and after a case research project. In addition, a case study protocol can be particularly useful in research projects involving multiple researchers as it ensures uniformity in data collection and analysis (Yin 1994). CSPs also ensure uniformity in research projects where data is to be collected in multiple locations over an extended period. Apart from procedures, a CSP also contains the research instrument(s) that will be used to collect data during the research project. Depending on the research design and the problem(s) under consideration, the research instrument(s) may either be quantitative, qualitative, or a combination of both, if the research design allows for a pluralist approach (Mingers 2001).*

When designed and used as characterized by Maimbo and Pervan (2005), case study protocols would be a well suitable tool for guiding case study research and enabling a subsequent overarching evaluation.

Since its first publication in Schneiderbauer et al. (2013), the method of Impact Chain based analysis of climate change related vulnerabilities has become popular and has been applied in numerous case studies. Also, the Impact chain framework has been further developed for enabling risk assessment (Rome et al. (2017) and GIZ et al. (2018)) and is partially covered in the ISO 14092 standard. The experiences of the last seven years have revealed strengths of the Impact chain framework and the potential for further improvement. UNCHAIN has defined five areas for further innovation, i.e. the **five research innovations** of the project:

1. to develop and test an approach to assess climate change risks that covers both the short-term need for 'adjusting' within the current societal framework and the possible need for long-term and large-scale efforts of '**societal transformation';**
2. to refine a structured method of **co-production of knowledge** and integrate this into impact modelling to better account for different views on desirable and equitable climate resilient futures;
3. to develop and test an applicable framework for analysing how **societal change** can affect local climate change vulnerabilities, how to conduct an integrated assessment of the combined effect of potential climate and societal changes, and how to better understand the socio-economic consequences involved in local climate change adaptation;
4. to improve the existing methodological approach of IC model for better **integration of quantitative/qualitative/dynamical aspects** and for assessment of **uncertainties** and data reliability. And

5. to explore the possibility of expanding the logic of impact chains along two dimensions: ‘**time & space**’ (i.e. including the indirect or trans-border impacts of climate change) and ‘**scope’** (linking mitigation and adaptation).

This case study protocol addresses four (or actually ‘three and a half’) of these – leaving out research innovation number (1) about **societal transformation**, and the second half of research innovation (5) on linking **mitigation and adaptation**. These two research innovations will have to be followed up as part of the cross-case and cross-country analysis that will be carried out in work package 4 and 5.

The succeeding report is structured as follows. In the **first** part we present the **conceptual starting point** for the case studies. This part contains a brief overview of the concept ‘**climate risk’** as outlined by the IPCC, an overview of the **Impact Chain** (IC) framework as it is currently understood and a list of the cases as they stand today prior to the actual case studies.

In the **following** parts we present the guidance on how to address **research innovations** 1**,** 2, 4 and 5 respectively.

In the final part we present guidance on cross-case and within-case **data management**; also see the appendix for more detailed information about this.

The starting point for the case studies

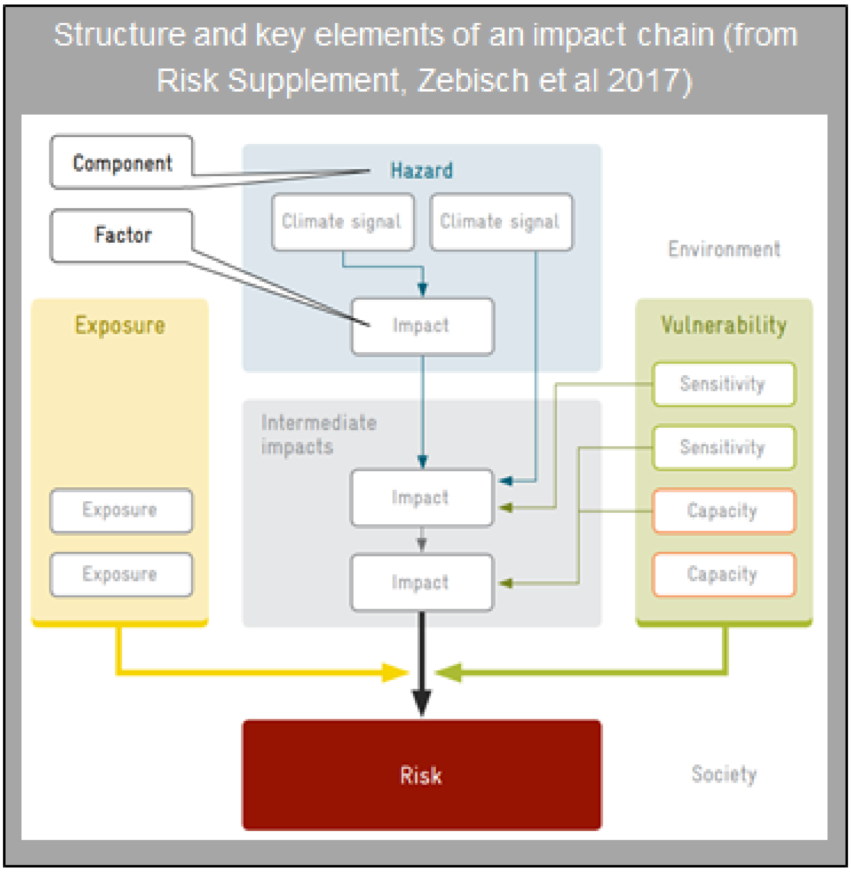
Introduction

The UNCHAIN project is basically about refining and expanding on current frameworks and approaches for understanding, analysing, and addressing climate risks in the context of climate change. Thus, the concept of 'climate risk' is one core of the reference point for the UNCHAIN project. The second core reference point, chosen in the application stage, is the current version of the Impact Chain framework. In principle, the outcome of the case-studies can come up with suggestions on alternating or expanding on both concepts. However, the UNCHAIN project is set up first of all to develop propositions on how to improve the way to analyse climate risks – by using the current understanding of the Impact Chain framework as a starting point – rather than altering the understanding of what climate risk is.

The concept of climate risk

The UNCHAIN project applies the definition of climate risks provided in the IPCC Fifth Assessment Report (AR5), where risk is described as the interaction between vulnerability, exposure and hazard (cf. figure below).

Figure 1: *The IPCC AR5 WG2 Risk Concept to be applied in the case studies of the UNCHAIN project*



The IPCC AR5 defines the four key concepts in the figure above in the following way[1]:

- **Hazard**: "The potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources".
- **Exposure**: "The presence of people, livelihoods, species or ecosystems, environmental services and resources, infrastructure, or economic, social, or cultural assets in places that could be adversely affected".
- **Vulnerability**: "The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts including sensitivity or susceptibility to harm and lack of capacity to cope and adapt".
- **Risk**: "Risk results from the interaction of vulnerability (of the affected system), its exposure over time (to the hazard), as well as the (climate-related) hazard and the likelihood of its occurrence".

It is also important to note that the IPCC limit the concept of risk to negative (adverse) impacts; thus 'positive' impacts (e.g. increased production of hydro-energy due to increased precipitation) is treated as opportunities – not as (positive) risks.

Impact Chains are foremost a conceptual model for a specific climate risk, composed of risk components according to the IPCC AR5 concept (hazard, exposure, vulnerability) and underlying factors for each of these components (see sub-chapter below). The structure of the impact chain represents the main cause effect chains: a climate signal (e.g. a heavy rain event) may lead to a sequence of intermediate impacts (e.g. erosion upstream that contributes to flooding downstream), which in interaction with the vulnerability of exposed elements of the social-ecological system finally lead to a risk (or multiple risks). For an operational risk assessment, impact chains serve as a basis for the selection of appropriate indicators as well as a backbone for the aggregation of indicators to composite risk indicators. Operational assessments based on impact chains can combine data and model driven approaches with expert-based approaches. Participatory methods (to be conducted in f. ex workshops) are implemented at all steps, to validate the results and ensure ownership and sustainability.

The Impact Chain framework

Impact chains (ICs) is framework developed to understand, systemise and prioritise the factors that drive climate impact related risks in a specific system of concern and serve as a backbone for an operational climate risk assessment. The framework was developed by EURAC Research for studies on climate vulnerability in the Alps (Schneiderbauer et al, 2013) and further developed for the national climate vulnerability assessment for Germany (Buth et al, 2017) and the GIZ Vulnerability Sourcebook on climate vulnerability assessment in the context of international cooperation (Fritzsche et al, 2014). In 2017, the framework was adapted to the new IPCC AR5 concept of climate risk (Zebisch et al, 2017) and recommended for climate risk assessments in the context of Ecosystem Based Adaptation (Hagenlocher et al, 2018). ICs have since then been more and more widely used as

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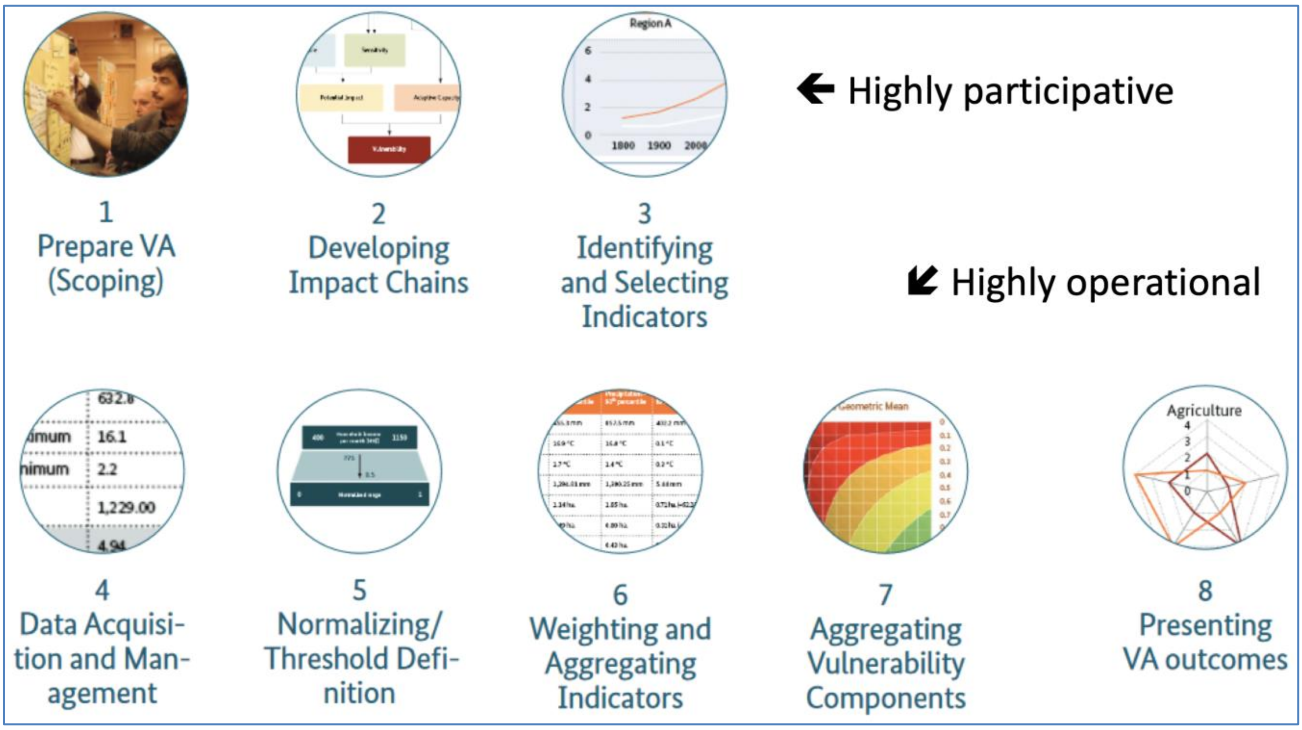
[1] https://www.ipcc-data.org/guidelines/pages/glossary/glossary_e.html

a climate risk assessment method. The method is perceived as a useful tool for analysis as well as for communication of complex cause-effect relationships in climate change impacts and risks.

The GIZ Vulnerability Sourcebook separates doing an impact chain analysis into eight main stages or modules (see Figure 2).

Figure 2: *Main stages of Impact Chain assessment according to Vulnerability Sourcebook and Risk Supplements Guidelines for national to sub-national Climate Risk Assessment (GIZ – Deutsche Gesellschaft für Internationale Zusammenarbeit)*



1. Scoping

The understanding of the context the climate risk assessment is primordial: what are the objectives; what are the beneficiaries/end-users of the provided results, what are the main climate-related risks; the major non-climatic drivers influence… This reflection is made to define the purpose of the study, i.e., to understand what it is being carried out for. In fact, risk studies are often commissioned in response to a lack of information, sometimes linked to an area with high climatic stakes. Finally, the scoping phase will also help find out what resources or means are available for carrying out the study.

2. Developing impact chains

An impact chain is an analytical tool that helps to better understand, systematize and prioritize the factors underlying the risk being studied. The construction of an impact chain is based on the identification of the factors involved in the different components of the risk. The first step consists in identifying the main climate risks the system is facing or will face in the future. This step is followed by the determination of the related hazard and intermediate impacts factors, in order to then define the exposure and vulnerability of the system/features at risk. This entire process should be based on a collective reflection (brainstorming), involving key experts and stakeholders in order to reflect as much as possible the realities of the territorial/local context.

For creating Impact Chain **diagrams**, case studies may use

- General purpose graphics tools;
- Mind-mapping tools; or
- Special purpose tools, like the RESIN Impact Chain Editor ICE[2].

3. Identifying and selecting indicators

After identifying the factors that constitute the impact chain, the next step is to define and select indicators to assess or measure these factors. In practice, indicator selection is an iterative process by which a list of final indicators must be established (depending on their availability and quality). The identification and selection of the indicators is made with the help of the stakeholders to replace the theoretical components of the risk with available indicators.

4. Data acquisition and management

The first step is data collection. It is therefore necessary to consider the type of data required: who can provide this data, what are the alternatives if data are missing? A frequent pitfall in the indicator selection process is underestimating the question of data availability. To minimize such issues, it is important to consider international databases to complete regional and national available datasets.

Then, the quality of the data must be studied (desired format, corresponding geographical area, missing values...). At this stage, it is necessary to think more deeply about how data is collected before finalizing the list of indicators. Once the data have been collected and special attention has been paid to their quality, processing can begin.

5. Normalizing indicators

In the literature (e.g. OECD 2008), the term "normalization" refers to the transformation of indicator values measured on different scales and using different units of measurement into unitless values on a common scale. The goal of normalization is to convert numbers into a meaning by evaluating the criticalness of an indicator value. Following standardization, the indicators will range on a scale from 0 to 1, that can be, for instance, respectively defined as the "optimal" situation and the "critical" situation. Different approaches can be used to complete this task of indicators normalization, that can be more or less statistical or participatory.

6. Weighting and 7. Aggregating indicators and components

The objective of weighting and aggregating indicators and then components is to build a composite indicator for the risk, combining all underlying indicators of hazard, exposure and vulnerability components. The weighting process allows the consideration of factors that have a greater influence on the different components and sub-components of risk. At the end of this step, you will obtain a risk score ranging from 0 to 1 for the systems/features studied. Different methodologies can be used for this step. A participatory approach can also be implemented through consultation with experts to gather their judgments.

For **quantitative assessments**, those steps may be supported by:

[2] https://resin.iais.fraunhofer.de/ICE

- General purpose statistics tools; and
- Special purpose tools, like software that uses Principle Component Analysis for automatically creating weight coefficients.

8. Presenting VA outcomes

The outcomes format and visualisation should be discussed in concertation at the very start of the risk assessment exercise. In addition, end-users' involvement throughout the risk assessment process is crucial to ensure results' appropriation and usefulness to end-users. The outcomes can take different formats: provision of maps, charts, etc.

For presenting **outcomes** of risk assessments, case studies may employ

- Standardized reports;
- Narratives;
- Risk scorecards (like the UNDRR disaster risk scorecard, see United Nations office for Disaster Risk Reduction (2017));
- Risk matrices according to ISO/IEC 31010 (2009);
- Geographical Information System (GIS) for creating maps showing georeferenced risk categories;
- Maps;
- Radar charts (or spider web diagrams); and
- Presentation slides.

For further guidance, the Vulnerability Sourcebook (BMZ (2014a)) and related publications (GIZ et al. (2018), Rome et al. (2017)) contains detailed recommendations.

The case studies

This section gives an overview of the case studies to be implemented and the research innovations they address.

#	Case	Description	Region	Country	Sector	Research Innovations
1	*Potential risk of loss of tourism comfort and destination attractiveness due to climate change*	Investigating how the reduction of beach availability and increased temperatures will have an impact on the attractiveness of the Balearic Islands as a tourist destination. The objective is to establish an estimate of relevant indicators acceptable to stakeholders, and to incorporate uncertainties to risk assessment	The Balearic Islands	Spain	Tourism	1,2,3
2a	*Economic effects of adapting critical infrastructure*	The case study will look at potential CC threats to infrastructure using the environmental-economic Model PANTA RHEI to simulate potential damages to infrastructure and the economic effects thereof. Further, adaptation strategies will be defined and simulated with the modelling framework. Generalization will be produced from case 2b examples and include scale effects.	Mannheim, hamburg	Germany	Infrastructure	1,3

2b	*Economic effects of adapting critical infrastructure*	The case study will focus on the port of Hamburg and the port of Mannheim, and actors using the ports. In addition to handling goods, the Port of Hamburg is site for industrial production and raw material processing, and is currently the largest inner-city urban development project in Europe. The port of Mannheim is one of the most important and largest inland ports in Europe, and is home to numerous large companies in sectors such as energy, chemicals and pharmaceuticals.	Mannheim, Hamburg	Germany	Harbor management/ infrastructure	1,2,3,4
3	*Improving climate change impact assessments of open economies by beyond state-of-the-art economic modelling approaches. A case study on the implied transborder climate change risks of international supply chains.*	Quantified estimates of future developments for basic socio-economic indicators such as population size, GDP and consumer spending at national and global level are (among other things) already available for the five SSP scenarios documented in O'Neill et al. (2014). These datasets can be freely accessed on servers of the International Institute for Applied Systems Analysis (IIASA). However, conventional climate models apply these data only as input for projections of associated climate effects.	Cross-border	Germany	Ports/ infrastructures	1,4

4	*Drought in Alpine regions*	The aim of the case is to develop impact chains, stakeholder dialogues and workshops, system dynamic approaches, quantitative assessment, focusing on co-development of drivers of agricultural drought and derivation of adaptation approaches; application of causal loop diagrams as well as integration of systems modelling approaches; application of regionalisation approach which is independent from admin boundaries	Salzburg-Umgebung	Austria	Agriculture, water management, insurance	1,2,3
5	*Adapting to Multiple Water Hazards in Sweden*	This case will focus on multiple water hazards that occur simultaneously, cascadingly, or cumulatively over time. There is a need to consider the consequences of these hazards combined, and by adopting the impact chain approach we will in this study address climate risks and drivers of multiple water hazards at the local and regional level, including both hydrological and coastal hazards and the implications for society in terms of vulnerability and adaptive capacity.	Southern coastal regions	Sweden	Municipalities, insurance sector, national authorities, regional cooperative initiatives	1,2,3

6	*Securing sustainable food production in Northern Norway under the auspices of climatic changes*	The case will provide downscaled data of the potential for future food security less dependent on large-scale centralized food production and on the increasingly fragile supply chains upon which they depend. The Unchain methodology will be implemented focusing both on food security issues for the region and the business resilience for individual actors, seeking to understand the way their place and contribution in the production chain influences sustainability.	Nordland County	Norway	Aquaculture industry, fodder import sector, freight sector, municipalities	1,2,3,4
8 and 9	*Climate change impacts on financial investment portfolios/ Risks and impacts of climate change on railway infrastructure*	Expected likelihood of increase of flood and prolonged periods of drought presents a unique challenge to financial institutions and railway sector in the Netherlands, representing both physical and economic risks. The cases will focus on real estate companies and railway companies seeking to understand how excessive heat and changes in future storms will affect their operations.		The Netherlands	Finance, railway infrastructure	1,2,3,4

10	*Sensibilities and vulnerabilities of small and medium enterprises in the Upper Rhine Region*	The case study focusses on the Rhine as a "river infrastructure", and how the consequences of climate change pose new risks to river transport such as drought, diminishing the water level. Threats include increased costs for shippers and carriers and the use of land-based transport, which is more expensive (increased costs) and less environmentally sustainable. As the Rhine is an international region, the arenas form for discussion and decision-making are cross-border.	Upper Rhine; Strasbourg, Karsruhe, Kehl, Basel	Germany, France	Ports, shippers, transport operators, infrastructure managers	1,2,3,4
11	*Global climate change impacts on French cocoa supply chain*	This case study will focus on the French cocoa market, including its origins in the Ivory Coast and Ghana. The effects of climate change, which includes declining farm productivity and the aging of producer populations, are fuelling the spectre of a sudden and imminent decline in world production. Drought threatens the fragile cocoa trees, not least due to the swollen shoot virus (transmitted by floury mealybug, an insect that likes dry air). In addition, the industry is vulnerable due to the fact that primary processing is an operation which brings little added value to the product, thus price sensitive.		France, Ivory Coast, Ghana	Cocoa producers, importers, chocolate producers	1,2,3,4

12	*Regional knowledge base for local climate change adaptation*	Based on previous work with the Rogaland county in doing a limited version of Impact Chain analysis, this case will assist the county in promoting the Impact Chain framework for doing climate change risk assessments at the local level by conducting a pilot-project with one selected municipality (Sokndal). Experiences from this will be used by the county when working with the remaining muncipalities in the county.	Rogaland	Norway	Municipalities, Counties	1,2,3,4

The following chapters will – based on perspectives carved out in the initial knowledge review report – present a more detailed presentation on how to conduct the cases with a focus on the following aspects of the five research innovations:

- Needs for further developing the Impact Chain framework identified in the knowledge review report
- How to better estimate uncertainties in Impact Chain approach and further in adaptation decision-making processes?
- How to secure and further develop the aspects of user interface and stakeholder involvement
- How to implement socio-economic scenarios and societal exposure to climate change in analysis of climate risks
- How to analyse transborder Climate Change Risks

Furthermore, the generic issue of data flows within and between the cases will also be covered. Also, the final list of cases to be conducted will be presented at the end of the case study protocol, including a provisional characterisation of the cases according to (1) which (one or more) research innovations each case addresses; (2) which part – i.e. stage(es) and/or cross-stage element – of the current understanding of the Impact Chain approach each case addresses; and (3) the societal context of the cases, such as level of government/governance and societal/economic sector each case addresses.

Research innovation relating to Impact Chain method

Introduction

This chapter relates to the following **research innovation** of the UNCHAIN project:

- to improve the existing methodological approach of IC model for better integration of quantitative/qualitative/dynamical aspects and for assessment of uncertainties and data reliability.

This section describes the case study protocol for addressing improvements to the Impact Chain based risk analysis method. Since the five innovation areas of UNCHAIN are not completely disjunct, we will define the scope of the research protocol for the Impact Chain framework explicitly.

For providing guidance to the persons in charge of the case studies, the research questions and sub-questions related to improving the Impact Chain approach are mapped to the eight modules (process steps) of the Vulnerability Sourcebook (**VSB**) method as described in BMZ (2014a) and GIZ et al. (2018). Depending on the extent of the Impact Chain based assessment (like qualitative / quantitative) and the related process steps (modules) applied in a case study, research questions and sub-questions may be addressed or not. In case research questions are being addressed, innovation-related research results and observations need to be documented and reported back for evaluation.

Guidance for implementation

In the following, the five research questions and their sub-questions concerning the further development of the impact chain concept are listed and linked to steps of how and when to address these in a case study. Since some of the case studies were already performed, some questions might not be directly realizable in these case studies anymore. For those, the case study conductors should try to explain in best possible way on how they would have dealt with the questions.

For all other case studies that start from scratch, we strongly recommend to consider and identify those research questions – related to the Impact Chain Framework – to be dealt with already before the case study commences. That is, the research questions should be part of the *research* design.

Those who apply the Impact Chain based analysis of climate change related risk from scratch need to decide whether they want to perform a qualitative analysis (VSB modules M1–M3 and M8) the full qualitative and quantitative analysis (VSB modules M1–M8) or the full analysis plus additional approaches of other innovation areas (shared socio-economic pathways (SSP, see page 52), transborder climate change risk analysis (TCCR, see page 62), consideration of uncertainties (see page 32). For a qualitative analysis using the VSB method, research questions 1 and 5 would be potentially relevant (see). For the full risk assessment (RA) VSB method, all research questions would be potentially relevant. Case studies need not address all research questions, but all case study reports[3] should specify which of the research questions and sub-questions have been addressed, what the criteria for their selection was, and what the degree of achieved innovation is. That essential research

[3] Report template for case studies is provided by WP3.

information will form the basis for the evaluation and consolidation work in UNCHAIN's work package 5.

Table 1 also points to other UNCHAIN innovation areas that could be considered for a research question or sub-question.

For each research question, there is a **detail table** providing specific guidance: partly addressing the **innovation aspect** (table cells with **blue** background) and partly addressing the **case study design** (table cells with **white** background). The latter ones contain guidance similar to the VSB but enriched with specific recommendations originating from concrete experiences in past case studies.

And finally, Table 2 maps the four stages of the VSB method and the corresponding VSB modules to research questions. This table can be used in the following way. If a case study shall perform, say, an ex-post qualitative analysis – consisting of modules M2 and M3, i.e. no preparation (module M1), no quantitative analysis (M4–M7) and no result presentation (module M8) need to be conducted –, the case study owner can quickly look up in the table that up to six research questions and sub-questions could be addressed.

***Table 1.** Related research questions and sub-questions for case studies addressing innovation of the Impact Chain framework*

Research (sub-)questions	VSB Modules	Link to other innovation areas
1. How to identify the relevant system elements and their interrelations when doing impact chain analysis?	M1-M7	User interface & stakeholder
1.1. How to better support identification of system elements / include knowledge from all relevant impact fields?	M1	User interface & stakeholder TCCR SSP
1.2. How to identify and consider interdependencies between climate change risks?	M1-M3 M4-M7 M8	User interface & stakeholder
1.3. How to draw clear causal links between climate signal and impact / actual risk to the investigated asset?	M2	TCCR SSP
1.4. How to support methods for result evaluation?	M2, M7, M8	User interface & stakeholder
1.5. How to combine a multitude of (sector-specific) information and still present them in a clear and concise manner?	M8	User interface & stakeholder
1.6. How to identify potentially beneficial vs. potentially problematic interdependencies?	M2 M6–M7 M8	User interface & stakeholder
2. How to better integrate quantitative, semi-quantitative, qualitative and narrative approaches?	M6–M8	Uncertainties
3. How to integrate in the impact chain framework knowledge from other approaches already existing in literature on the normalization and aggregation phases and the definition of critical thresholds?	M1 M5, M6, M7	TCCR SSP Uncertainties
3.1. How to make assessments and results comparable?	M4–M8	User interface & stakeholder
4. How to address limitations in the availability of reliable data? (heterogeneity, spatial / temporal resolution, mismatch between resolutions)	M3, M4, M8	User interface & stakeholder Uncertainties
5. How to forward the impact chain approach from a 'linear' representation of risk components towards more system dynamics-oriented models?	M1–M8	TCCR SSP Uncertainties

Research question	RA Stage / VSB Modules	Methodology design, Approach, Procedures (how)
RQ 1 How to identify the relevant (social-ecological) system elements and their interrelations when doing impact chain assessment?	**M1** Preparing the RA	**1) Check** available public International/European/National/Local data sources for a) relevant hazards for the to-be-assessed area; b) past impacts; and c) relevant non-climatic drivers (e.g. SSPs) **2) Identify and check / talk** with local experts about a) what the most relevant hazards are; b) what past impacts occurred; and c) what non-climatic factors drive the impacts **3) Document resulting information** (e.g. where did information come from; rank hazards; link impacts to hazards; etc.)
	M2-M3 Qualitative RA	**1)** Before developing Impact Chains: a) **Pre-identify** potentially relevant thematic area(s) and related (local) experts b) **Be aware of potentially opposing goals and different backgrounds** of participating (local) experts that might prevent them to share all relevant information, depending on the group setting (e.g. not willing to share all information if "the boss" is in the room) **2)** During Impact Chain development: a) **Invite** (local) experts for relevant thematic area(s) to workshops, taking potential power dynamics into account b) **Ensure** that a critical number of (local) experts attends the workshops c) **Ask / interview** (local) experts about interrelations of thematic area(s); this can also be gathered as "information by-catch" from discussions during the workshop d) If critical (local) experts cannot attend, consider approaching them after the workshop to discuss the resulting impact chain; if necessary, hold further workshops **3) Document information** a) Which thematic area(s) were identified? b) Which experts were identified / invited for which thematic area(s)? c) Which experts did participate at the workshops? What was the critical number of experts defined at the outset? d) Which interrelations where identified?

	M4-M7 Quantitative RA	**1) Check for statistical correlations between indicators**. These can indicate (un)known interrelations between system elements 2) **Document** if additional (statistical) interrelations between indicators / system elements were found and how they were handled (e.g. if Impact Chain was changed or not and how)
RQ 1.1 How to better support identification of system elements / include knowledge from all relevant impact fields?	**M1** Preparing the RA	**1) Check** available public International/European/National/Local data sources for information about a) relevant (historic and future) hazards for the to-be-assessed area; b) past impacts and consequences; and c) relevant non-climatic drivers (e.g. SSPs) If feasible / available, use sources that **visualize data** and allow to **explore** the to-be-assessed area. **2) Consider compiling information** from available data sources in a visual and/or easily digestible format. If using local data sources, consider complementing these with other relevant National/European/International data sources **3) Identify and talk** with local experts about a) what the most relevant hazards are; b) what past impacts occurred (and what the consequences of these were); c) what non-climatic factors drive the impacts; and d) which other experts to contact / include. **Consider using questionnaires** (analog & digital) to elicit information from local experts. **4) Document** resulting information a) Where did information come from? b) Which local experts were included? c) Why was something (hazard, impact, etc.) included or not? d) Ranked list of hazards e) Impacts / consequences linked to hazards

RQ 1.2 How to identify and consider interdependencies between climate change risks?	**M1** Preparing the RA	**1) Check** available data sources for information about a) Interrelations between relevant (historic and future) hazard or the to-be-assessed area b) Past cascading impacts and consequences on the to-be-assessed area If feasible, **2) Develop separate impact chains** and **check any possible interrelations** and connections between these, by following steps: a) Develop raw drafts of separate impact chains, each focusing on a different climate change risk (e.g. different hazards) b) Identify all relevant attributes and indicators for each impact chain c) Find common attributes and indicators of the different impact chains d) Identify links and similarities between the impact chains e) Fuse the different impact chains into one impact chain and mark the interdependencies **3) Verify interdependencies with (local) experts**
	M2 / M3 Qualitative RA	**1) Ask / Interview (local) experts**, that have broad knowledge about different climate change issues and the area.
	M4–M7 Quantitative RA	**1) Check for any datasets** that incorporate / describe interdependencies between climate change risks **2) Check for any correlations between indicators.** These can indicate interrelations between risks **3) Document** if additional (statistical) interrelations between indicators were found, how they were found and described (e.g. if Impact Chain was changed, what kind of connections between impacts chains were found)
	M8 Presenting RA results	**1)** Any interdependencies between climate change risks that have a significant influence on the result of the risk assessment should be explained in the result presentation

RQ 1.3 How to draw clear causal links between climate signal and impact / actual risk to the investigated asset?	**M2** Qualitative RA	**1)** As a supplement to the Impact Chain diagram, create narratives that describe the causal links between climate signal and impact / actual risk to the exposure **2)** Let climate and asset experts validate the narratives
RQ 1.4 How to support methods for result evaluation?	**M2** Qualitative RA	**1)** Assess and document how comprehensive the considered elements of the investigated social-ecological system are **2)** Assess and document the number, quality and importance of the considered interrelations of system elements
	M7 Quantitative RA	**1)** If available, check previous RA results for the same asset / climate risk combination and assess the differences to the current RA **2)** Document the quality of the used data, the applied methods for aggregation, weighting, and risk assessment, and the confidence of the results of the RA
	M8 Presenting RA results	**1)** Describe what facilitates or complicates evaluating the result of your RA **2)** In case your RA results shall be compared with results of other RA in the same domain, governance district or adaptation framework, make sure you use the same type of result presentation (tables, diagrams, indicators, templates, reports)
RQ 1.5 How to combine a multitude of (sector-specific) information and still present them in a clear and concise manner?	**M8** Presenting RA results	**1)** Categorize the information **2)** Use tools like collapsible tree diagrams for presenting the information in a hierarchical manner on several levels of aggregation **3)** Use tools like spider web diagrams for displaying quantitative information **4)** Supply narratives for explaining more complex sector-specific information
RQ 1.6	**M2** Qualitative RA	**1)** Ask local experts to assess if interdependencies are beneficial or problematic and let them justify their assessments

How to identify potentially beneficial vs. potentially problematic interdependencies?	**M5–M7** Quantitative RA	**1)** **Check** for statistical correlations between indicators. These can indicate (un)known interrelations between system elements **2)** **Document** if (statistical) interrelations between indicators / system elements were found and how they were handled (e.g. if Impact Chain was changed or not and how)
	M8 Presenting RA results	**1)** Wherever beneficial or problematic interdependencies may affect adaptation measures, **explain the influence of the interdependencies** and identify those adaptation measures. Lay the grounds for considering the interdependencies in adaptation planning
RQ 2 How to better integrate quantitative, semi-quantitative, qualitative and narrative approaches?	**M3** Qualitative RA	**1)** **Link** the different indicators and approaches, check if there are any relations **2)** **Check and confirm** with external lists/glossaries/example studies **3)** **Try to find** quantitative, semi-quantitative, qualitative and narrative approaches per indicator
	M6 / M7 Quantitative RA	**1)** The use of quantitative and semi-quantitative methods may depend on factors like availability of data, human resources for performing the assessment, and time demand. A mixture of quantitative methods and semi-quantitative methods can be quite common. **a)** **Document and motivate the use of mixed methods** **b)** **Assess any influence of mixed methods** on the confidence of your assessment
	M8 Presenting RA results	**1)** For presenting results of **quantitative RA, combine them with narratives** **2)** For presenting results of **qualitative RA, combine them with narratives** and **motivate the use** of semi-quantitative methods, for instance when data for quantitative RA where lacking or resource demand of full quantitative RA was prohibitive
RQ 3 How to integrate in the impact chain framework knowledge from other approaches already existing in literature on the normalization and aggregation phases and the definition of critical thresholds?	**M1** Preparing the RA	**1)** The assumption here is that the decision for performing a quantitative RA will be made in the preparation phase **2)** Decide whether you will use local expertise in statistics or whether you need additional support from academia and appoint those experts **3)** Check if you have the resources for experimenting with different methods on normalisation and aggregation **4)** If yes, identify and select the normalisation and aggregation methods that you want to explore in your RA
	M5, M6, M7	**1)** **Screen** available approaches for normalization, aggregation, and threshold definition for a) suitability for inclusion in case study

	Quantitative RA	b) suitability for combining with each other **2)** **Test, verify, and validate** different potentially suitable combinations systematically (i.e. change one parameter/approach then examine result) 3) **Document results**
RQ 3.1 How to make assessments and results comparable?	**M4–M7** Quantitative RA	**1)** **Be consistent** and always **make use of the same methods / definitions** for normalisation and weighting within the risk assessment, meaning always use a) the same indicators b) the same categories for risk, vulnerability, sensitivity, capacity classification c) the same spatial/temporal resolution d) common min/max values (if using min-max normalisation) e) the same approach for result presentation (e.g. same color scheme for risk classes) **2)** **Document all these relevant methods and definitions** that you use by keeping them in an up-to-date list **3)** **Document all assumptions** you have made in your assessment **4)** **Document underlying data on climate signals** (age, model type, spatial resolution etc.) and investigated assets
	M8 Presenting RA results	**1)** In case your RA results shall be compared with results of other RA in the same domain, governance district or adaptation framework, make sure you **use the same type of result presentation** (tables, diagrams, indicators, templates, reports)
RQ4 How to address limitations in the availability of reliable data? (heterogeneity, spatial / temporal resolution, mismatch between resolutions)	**M3** Qualitative RA	**1)** **Pre-check availability of data** for indicator candidates a) from International/European/National/Local open data repositories; b) from "private" data repositories, e.g. infrastructure providers, different departments of a municipality, etc.; and c) from local experts, i.e. experts who can provide knowledge and experiences to substitute for "hard data" **2)** **Include owners of critical data and knowledge** as stakeholders in the assessment 3) **Decide (and document!) how to proceed** if data for a suitable indicator is not available or usable
	M4 Quantitative RA	**1)** Check if available data can be **transformed** into consistent spatial / temporal resolution **2)** Consider if gaps in data can be **filled**, e.g. by employing Machine Learning methods based on proxy indicators that are correlated to the actual indicator **3)** **Assess the influence** of missing data on the confidence of the RA

	M8 Presenting RA results	**1) Consider how to communicate data limitations** (and a potentially resulting lack in confidence of the results) a) Where possible, **clearly communicate effects of missing / unreliable data**. This is not only related to results but also to the approach taken for the assessment (e.g. conducting a non-probabilistic RA for only a specific hazard scenario, if not enough data for calculating hazard probabilities are available) b) **Explain how to deal with data limitations** when selecting adaptation measures
RQ5 How to forward the impact chain approach from a 'linear' representation of risk components towards more system dynamics-oriented models?	**M1** Preparing the RA	**1) Determine if – and to what extend –** a System Dynamics approach is suitable and feasible for the context of the RA a) Should/will the System Dynamics model be developed together with (local) experts? Should/will it be used to communicate cause-effect relationships to stakeholders? If so, is this understandable for stakeholders? If not, how will the System Dynamics model be linked to the "communication model" used/developed with stakeholders and (local) experts? b) What kind of System Dynamic model can/should be used? Qualitative (e.g. to identify feedback loops)? Quantitative (e.g. to model deeper cause-effect relationships)? **2) Screen** for applicability / adaptability: a) Qualitative System Dynamics approaches (e.g. Cognitive Maps / Mental Maps) b) Quantitative System Dynamics tools (e.g. AnyLogic) **3) Document** a) The purpose of the System Dynamics model b) How it is intended to be used with stakeholders and local experts (if at all) c) Which approaches and tools are planned to be used

	M2 / M3 Qualitative RA	**1)** During Impact Chain development: a) **Elicit** information from local experts on potential interrelations between attributes b) **Document** identified interrelations, either directly in the Impact Chain or in a separate document (if using the System Dynamics approach only for internal purposes) **2)** During/After indicator identification a) If using quantitative System Dynamics tools, **map** employed tools/models to indicators b) **Document** how toll/model was used (and for which indicators)
	M4-M7 Quantitative RA	**1)** Consider **checking statistical correlations** between indicators to identify interrelations that might be modelled using System Dynamics **2)** Consider employing (System Dynamics) tools that allow **sensitivity analyses**, e.g. for easily shifting between different weighting or normalization methods **3)** Consider **comparing results** from non-System Dynamics approaches and System Dynamics approaches (using otherwise the same methods for weighting and normalization) **4)** **Document** results
	M8 Presenting RA results	**1)** **Determine if – and to what extend –** a System Dynamics approach is suitable for result presentation **a)** Is the model understandable for the target audience? Does it clearly communicate the relevant issues? **b)** Can a simplified model achieve the same communication result? What are the benefits of the System Dynamics model in result presentation / communication?

Table 2. *Mapping VSB modules to UNCHAIN research questions for deciding which innovation of the Impact Chain based assessment method is relevant in a given assessment process stage or module.*

	Module	**RQ1**	**RQ1.1**	**RQ1.2**	**RQ1.3**	**RQ1.4**	**RQ1.5**	**RQ1.6**	**RQ2**	**RQ3**	**RQ3.1**	**RQ4**	**RQ5**
Preparing the RA	**M1**	x	x	x						x			x
Qualitative RA	**M2**	x		x	x	x		x					x
	M3	x		x								x	x
Quantitative RA	**M4**	x		x							x	x	x
	M5	x		x						x	x		x
	M6	x		x				x	x	x	x		x
	M7	x		x		x		x	x	x	x		x
Presenting RA outcomes	**M8**			x		x	x	x	x		x	x	x

Research innovation relating to uncertainties

Introduction

This chapter relates to the following **research innovation** of the UNCHAIN project:

- to improve the existing methodological approach of IC model for better integration of quantitative/qualitative/dynamical aspects and for assessment of uncertainties and data reliability.

The way we conceptualize and assess uncertainty is central in the debate on climate change. On the one hand, it is important to be clear about the uncertainties associated with climate change. At the same time, the way and extent climate change uncertainties are presented may lead to doubt and legitimate scepticism among people without basic scientific knowledge, a situation that can be easily misused by sceptics seeking to amplify uncertainty in order to generate inaction and delay in climate change policymaking, and discredit climate change research (Oreskes and Conway 2010). Notions of uncertainty can also add to other cognitive, affective and behavioural barriers to people's engagement with the issue of climate change (Lorenzoni et al. 2007). Because **decisions** about climate change mitigation and adaptation will always have to be made under **uncertainty**, it is thus **critical** that we find ways to **guide such processes** (Willows and Connell 2003).

Moss (2007) argues that uncertainty analyses should be **decision focused**, instead of being presented in what he denotes as 'a vacuum'. Ha-Duong et al. (2007) make a case for a **multi-dimensional** approach to uncertainty communication, whereas Lempert et al. (2004) and Dessai and Hulme (2004) **criticize the extensive use of probability-based** estimates of risks, and advocate putting more effort in presenting approaches to **decision-making under conditions of uncertainty**.

Schneider and Kuntz-Duriseti (2002:54) presents two alternatives in addressing climate uncertainties.

> *The first option is to reduce the uncertainty through data collection, research, modeling, simulation, and so forth. This effort is characteristic of normal scientific study….*

However, the daunting uncertainty surrounding global environmental change and the need to make decisions before the uncertainty is resolved make the first option difficult to achieve. Thus, they point out the following (Op cit):

> *That leaves policymakers an alternative: to manage uncertainty rather than master it. Thus, the second option is to integrate uncertainty into policymaking.*

In the following we differ between addressing the uncertainties involved in **conducting an impact chain analysis**, and uncertainties involved in **local decision-making** on climate change adaptation based on the information present in a given impact chain analysis. The former is about **quantifying uncertainty** in the knowledge basis for adaptation decisions, whereas the latter is about **making decisions under uncertainty**. But before we proceed on this, a short summary of the way IPCC addresses uncertainties is presented.

How are climate uncertainties addressed by the IPCC?

Manifold critiques have been raised concerning how uncertainties are handled in the climate debate. A good way to capture these critiques is to investigate the discussions relating the works of the Intergovernmental Panel on Climate Change (IPCC), and in particular the works of the **main assessment reports (AR)** – the fifth (AR5) being the last so far.

The uncertainty quest of the IPCC has been formulated in the following way (Moss, 2007:5):

> *to assess the state of our understanding and to judge the confidence with which we can make projections of climate change, its impacts and costs and efficacy of mitigation options*

Early **critiques** of AR1 (1990/92) and AR2 (1995) can be summarized in the following way (Moss, 2007:5):

> *In the first and second IPCC assessments, little attention was given to systematizing the process of reaching collective judgments about uncertainties and levels of confidence, or standardizing the terms used to convey uncertainties and levels of confidence to decision-maker audience*

Responses to these critiques have been as follows:

- The development of a chapter on uncertainties in the general guidance note prior to the AR3 (Moss and Schneider, 2000)
- A separate guidance note on uncertainty prior to AR4 (IPCC, 2005)

The current IPCC approach to address climate uncertainties rely much on a set of **typologies**, that can be summarized in the following way (all of which from IPCC, 2005):

- **Categories** of uncertainties:

Table 1. A simple typology of uncertainties

Type	Indicative examples of sources	Typical approaches or considerations
Unpredictability	Projections of human behaviour not easily amenable to prediction (e.g. evolution of political systems). Chaotic components of complex systems.	Use of scenarios spanning a plausible range, clearly stating assumptions, limits considered, and subjective judgments. Ranges from ensembles of model runs.
Structural uncertainty	Inadequate models, incomplete or competing conceptual frameworks, lack of agreement on model structure, ambiguous system boundaries or definitions, significant processes or relationships wrongly specified or not considered.	Specify assumptions and system definitions clearly, compare models with observations for a range of conditions, assess maturity of the underlying science and degree to which understanding is based on fundamental concepts tested in other areas.
Value uncertainty	Missing, inaccurate or non-representative data, inappropriate spatial or temporal resolution, poorly known or changing model parameters.	Analysis of statistical properties of sets of values (observations, model ensemble results, etc); bootstrap and hierarchical statistical tests; comparison of models with observations.

- Levels of **understanding**

Level of agreement or consensus →			
	High agreement limited evidence	…	*High agreement much evidence*
	…	…	…
	Low agreement limited evidence	…	*Low agreement much evidence*
	Amount of evidence (theory, observations, models) →		

- **Confidence**

Terminology	Degree of confidence in being correct
Very High confidence	At least 9 out of 10 chance of being correct
High confidence	About 8 out of 10 chance
Medium confidence	About 5 out of 10 chance
Low confidence	About 2 out of 10 chance
Very low confidence	Less than 1 out of 10 chance

- **Probabilities**

Table 4. Likelihood Scale.

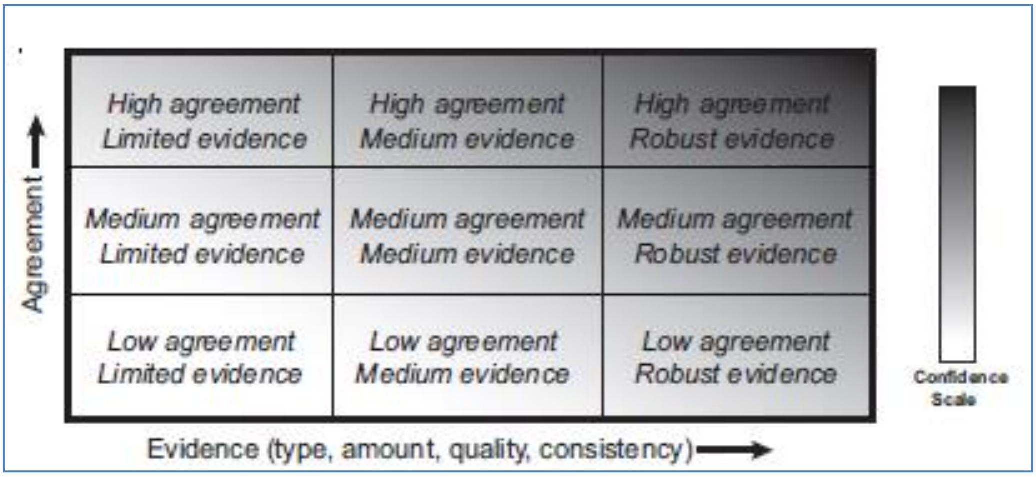
Terminology	Likelihood of the occurrence/ outcome
Virtually certain	> 99% probability of occurrence
Very likely	> 90% probability
Likely	> 66% probability
About as likely as not	33 to 66% probability
Unlikely	< 33% probability
Very unlikely	< 10% probability
Exceptionally unlikely	< 1% probability

These typologies are mostly about how to describe uncertainty and mostly applied on ecological uncertainties and is to a very limited extent about how decision-makers can relate to climate uncertainties in climate policymaking.

Curry (2011) has summed up the debate on IPCC and climate change uncertainties prior to the fifth assessment report by stating that the IPCC has oversimplified the issue of uncertainty, which could give rise to a misleading overconfidence. In response, she suggests that the IPCC should (Op. cit: 723):

identify better ways of framing the climate change problem, explore and characterize uncertainty, reason about uncertainty in the context of evidence-based logical hierarchies, and eliminate bias from the consensus building process itself

As a response to these critiques, a separate guidance note on consistent treatment of uncertainties was develop for lead authors of the AR5 – providing guidance in **communicating the degree of certainty** (Mastrandrea et al, 2010):



Van der Sluijs and colleagues find the IPCC consensus strategy underexposes scientific uncertainties and dissent, making the chosen policy vulnerable to scientific error and limiting the political playing field (Van der Sluijs and Rinie van Est 2010). Thus, Ekwurzel and colleagues argue that the IPPC should "more effectively characterize and communicate the role of uncertainty in human actions as distinct from other sources of uncertainty across the range of possible climate futures" (Ekwurzel et al. 2011, p. 791). Terje Aven (2014) continues a critique along the same line, by stating that the IPCC approach is too strongly associated with statistically expected values, and that the risk characterizations fail to integrate probabilities and judgments of the strength of the knowledge supporting these.

The ongoing work on the **sixth assessment report** still relies – at least partly - on the 10-year-old guidance note, also referred to in the annexes of the IPCC special report "Global Warming of 1,5 ºC" (IPCC, 2018). However, a recent **shift** in – or rather the introduction of - the conceptualization of '**climate risks'** that took place between the fourth (AR4) and fifth (AR5) assessment report, also has consequences for the conceptualization of uncertainty. This shift is also an important reference-point for the UNCHAIN project.

The core definition of climate risk is as already pointed out "the potential for adverse consequences", and the link between 'risk' and 'uncertainty' relates to the word '**potential'**, which makes it clear that uncertainty, or more broadly, incomplete knowledge (as defined in IPCC), is a key element of the concept of climate risk (Kunreuther et al, 2014). It is important to note that uncertainty applies also to '**exposure'** and '**vulnerability**, not merely to the magnitude and frequency of hazards.

An important point here is that as from now on – after the introduction of the new risk concept - risk (and thus uncertainty assessments) is applied to both impacts of and **responses** to climate change. According to Reisinger et al (2019: 3) this is a significant evolution and clarification compared with earlier assessments, which have tended to be dominated by risk related to climate change impacts. Adverse consequences relating to responses to climate change – covering both **mitigation** and

adaptation efforts - can arise from such responses failing to achieve its intended outcome, or creating **unintended adverse effects**; thus being closely related to the concepts of **malmitigation** (Kongsager et al, 2015) and **maladaptation** (Barnett et al, 2010). In practice, it means that in the impact chain framework uncertainties have to be considered for all the elements of the chain, including the adaptation/mitigation actions considered under the umbrella of "Vulnerability".

Addressing uncertainties when conducting an impact chain analysis

In the impact chain approach, there are three main sources of uncertainties that can cause imprecise or badly-funded decision making. **First**, existing **datasets** are **uncertain** leading to uncertain indicators. **Second**, the **relative importance of each element** of the impact chain has a profound impact on the final risk, whatever the weighting and normalization strategy is applied. However, that is usually defined based on subjective expert knowledge, which is inherently subject to uncertainties. And **third**, some **key elements** of the actual **chain of impacts** may **not** be **included** in the **theoretical** impact chain. This would lead to a biased estimate of the final risk, so the problem must be bounded.

This section explains the types and impacts of uncertainties within the Impact Chain framework when being used for local decision-making in climate change adaptation and gives guidance on how to address these. The final goal is to be able to **produce a measure of the uncertainty associated to the risk assessment**. An additional outcome is that through this process, it will be possible to **assess the relative importance of each element of the Impact Chain** and to identify the **main sources of uncertainty**.

The basic elements

For clarity purposes we first recall some key concepts of the Impact Chain approach. The **risk assessment** can be defined as:

$$R = W_{H\to R}\sum w_k H_k + W_{E\to R}\sum w_j E_j + W_{V\to R}\sum w_l V_l$$

Where **H**, **E** and **V** are the indicators that describe the **hazard**, **exposure** and **vulnerability** respectively, and the **W**'s refer to the **Weight/Normalization** factor applied to transfer Hazard, Exposure or Vulnerability to Risk.

So, the **Risk** can be expressed as a linear combination of Hazard, Exposure and Vulnerability components:

$$R = \sum \alpha I\,, \quad with\, I \in H_k, E_j, V_l$$

Therefore, the main goal is to substitute each α and I by $\alpha \pm \varepsilon_\alpha$ and $I \pm \varepsilon_I$, so we can obtain $R \pm \varepsilon_R$, where ε represents the associated uncertainty to each element.

The three main sources of uncertainty

In this section we review **the three main sources** of uncertainty associated to the impact chain procedure and then we present a proposal for dealing with them.

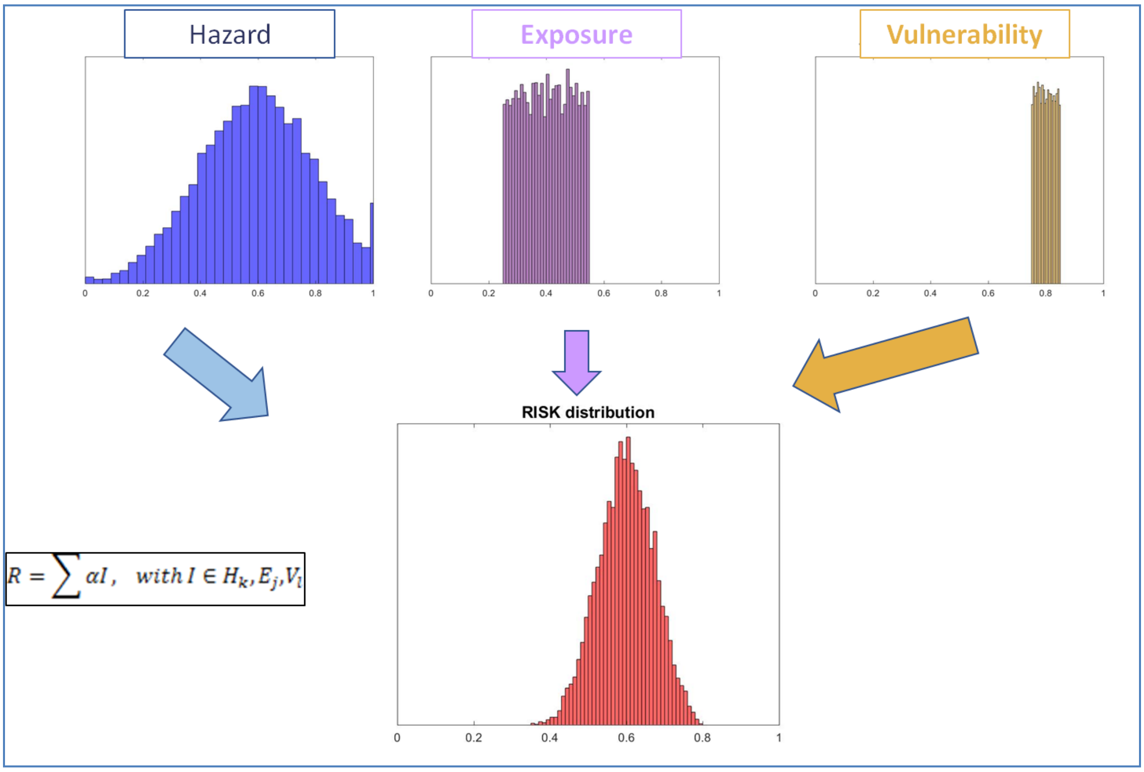
Firstly, the **datasets** used to define the different indicators are uncertain. For instance, climate models projecting the evolution of certain hazards are not perfect. Uncertainties associated to model numerics, model representativity or uncertain forcings will translate into uncertainties in the derived indicators. This is even clearer for indicators related to exposure or vulnerability where the available datasets are often limited or incomplete.

The **second** main source of uncertainties appear due to the **nature of local decision-making processes** on the topic of climate change adaptation itself. What is the **relative weight** of each indicator with respect to the final risk can often not be objectified, so one has to rely on the expert's opinions? This in turn depends on the choice of the group of experts or on biases in their view of the particular problem. Thus, unavoidably, any kind of tuning based on expert judgement has associated a certain degree of uncertainty. In practice, this means that the definition of weights in the impact chain should not be addressed as an absolute truth but allow some degree of variability.

The **third** source of uncertainty is the **lack of key components** on the actual Impact Chain. Limited knowledge of the problem at stake, or the lack of data may lead to the definition of an incomplete Impact Chain That is, some indicators that may have a key impact on the final risk may be missing. Therefore, some strategies should be defined to, at least, try to bound this problem.

Our proposal is to use a classical **Monte-Carlo technique** to propagate the uncertainties associated to each component of the impact chain. A graphical example is presented in the next figure. Each indicator is transformed from a single value to a range of values, represented by a probability density function. Then, a large number of combinations is produced to create a probability density function for the final risk.

Figure 3: *Monte Carlo technique-based analysis of risk*



IEO will assist in the computations for each case study. However, the key element is to have a measure of the uncertainty related to each component of the impact chain. Therefore, each group conducting a case study should ensure that they are sampling the uncertainty properly. In practice, this can be done differently for each element of the impact chain.

Uncertainties in the indicators

This refers to both **qualitative** and **quantitative** indicators. For instance, projections from climate models are commonly used for hazards (e.g. for the intensity of heat waves). In this case, uncertainty in the climate projections comes from inaccuracies in the climate models, the representativity of the climate model outputs due to the internal climate variability and/or the GHG emission scenario. The common approach (e.g. by IPCC) is to use the spread of a large number of climate models as a measure of the associated uncertainties for a given projection.

For **qualitative** indicators (e.g. sensitivity of tourists to heat stress), the common strategy is to rely on the **experts' opinions**. They can be categorized in discrete values (e.g. low, medium, high), which in turn can be transformed to a numerical value (e.g. 2,5,7) to be included in the impact chain. The important point here will be to keep the individual choices of each expert, so a certain range of uncertainty can be associated to each particular indicator.

Uncertainties on the weighting/normalization

In the UNCHAIN project different strategies for the definition of the weights and normalization will be investigated, including objective estimates based on historical data. However, in most cases the definition will be based on subjective criteria. Thus, here we assume that **the weights will be set by the experts** following a certain procedure like the **analytical hierarchical protocol**, or by means of any other **participatory processes**. Here again, it is important to store each individual choice so the whole range of values can be introduced in the Monte-Carlo procedure.

Uncertainties in the Impact Chain construction

It is possible that some elements that are considered to play an actual role in a chain of impacts cannot be quantified, and thus they are excluded from the Impact Chain at the time of computing the risk. Or, that some elements were not included from the beginning because a lack of appropriate expertise, for instance. A proposal to have an estimate of the relevance of the missed elements in the Impact Chain is to assess the sensitivity of the final risk with respect to variations of the hazards, exposure and vulnerability indicators. This could be done asking the experts what do they think should be the final risk given a set of extreme situations for the indicators. In other words, what should be the risk if **we modify from the minimum to the maximum the hazard**, **vulnerability and exposure**. Theoretically, as we are in a linear framework, those variations should imply a variation of the risk from the minimum to the maximum. If that does not happen, mean that something is missed in the impact chain.

A final warning is about the **danger of biases** in the different elements of the impact chain. The linear framework typically used in the ICs (linear combination of weights and indicators), is very sensitive to biases, either in the indicators or the weights. For instance, if the climate models selected are systematically producing higher temperatures than they should, then the uncertainty estimate will not be able to take this into account and will underestimate the errors in the final risk. The same applies if the group of experts selected to provide estimates for the weights is biased towards a certain belief. Then, the spread in the values assigned to the weights will not reflect the actual uncertainty in the weights, leading again to an **underestimation of the uncertainty**.

Addressing uncertainties in climate change adaptation decision-making

Mastering or managing climate change uncertainties?

Tangney (2019) criticizes the newly adopted IPPC risk-based approach described above for perpetuating the ideals of objective risk – as well as uncertainty - calculations, and he cautions against prescriptions for the rational application of objective risk assessment to policymaking. Schneider and Kuntz-Duriseti (2002) has outlined two main modus operandi on how to relate to climate change uncertainties:

- Society must reduce climate change uncertainties to a level that allows for accurate selection of policy measures.
- Society must implement climate policy measures even in situations with high climate change uncertainties.

The former is in the literature termed at the '**predict-then-act'** modus operandi (Lampert et al, 2013), whereas the latter – which is more about developing rules on how to deal with uncertainties rather than how to reduce them - could be termed as '**reflect-then-act'**.

Even though many alternatives to the 'predict-then-act' approach have been put forward, the climate community has so far not been able to agree on the 'best' of these alternatives (Jones and Preston 2011). Thus, the predict-then-act approach still seems to remain the prevailing approach in both climate change science and policymaking (Workman et al, 2020). The fact that the IPCC still is relying on a methodology for addressing climate change uncertainties that dates to 2010 (Mastrandrea et al, 2010) illustrates this point.

A proposed theoretical basis for developing a comprehensive alternative to 'predict-then-act'

Workman and colleagues have in a recent work critically analysed climate policy decision making and what they denote as the philosophy underlying the use of integrated assessment modelling to inform climate policy (Workman et al, 2020). They criticize current climate policy-making processes for being **naïve** with respect to how they view **model outputs** as '**objective facts'** and use the outputs directly to '**program'** policies. From this observation, they conclude that there is a need for an **alternative approach** on how to **inform climate policymakers** about climate change uncertainties. They refer to the '**robust-decision-making'** framework as a good starting point for doing so, and sums up their thoughts about an alternative approach in the following way (Op. cit:77):

> *an … approach that explicitly embraces uncertainty, multiple values and diversity among stakeholders and viewpoints, and in which modelling exists in an iterative exchange with policy development rather than separate from it*

Below is a proposed outline for the requested alternative approach, based on the works of Warren Walker and colleagues (2003) on how to handle situations of large and complex uncertainties, and of Lyla Metha and colleagues (2001) which looked into the uncertainties that are typical for the management of natural resources.

A proposed practical framework for analysing the uncertainty situation

The idea is first to get an **overview** of the **uncertainty situation** – typically after an impact chain analysis has been conducted - prior to entering the stake of making the adaptation decisions.

Below is a proposed two-axis framework for doing such assessments (Aall and Groven, 2020):

- **Location** of uncertainties
    - **Climate**: Covering climate change scenarios and downscaling of this
    - **Ecology**: Covering impacts of climate change (anticipated manifestation of sea level rise, flooding, avalanches etc)
    - **Society**: Covering exposure to impacts of climate change (exposure to sea level rise, flooding, avalanches etc)
- **Nature** of uncertainties
    - **Basic**: We are neither familiar with the basic cause and effect relationships, nor whether these are exclusively governed by coincidence
    - **Model**: We have basic insight into cause and effect but have not succeeded in developing models that are good enough to take these relationships into account in a satisfactory way – e.g. in producing scenarios
    - **Scale**: We have basic insight into cause and effect, and have managed to model these relationships, but when trying to downscale the findings from these models, we arrive at a wide variety of projections
    - **Data**: We have basic insight into cause and effect, and have managed to model these relationships, but lack of input data does not allow our models to produce reliable results

In the table below are two examples from Norway of how such an assessment could look like, for the case of sea level rise and for flooding – both about risks relating to road transportation.

Table 3. *Examples of applying the proposed framework for analysing the risk situation (Aall and Groven, 2020)*

Flooding and roads

Nature of uncertainties	**Location** of uncertainties		
	"Climate"	"Nature"	"Society"
Total or recognized ignorance	Not relevant	Not relevant	Not relevant
Model uncertainty	Inclusion of other-than-water-monitoring-data in the flooding models	Not relevant	Not relevant
Scale uncertainty	The east-west distribution of extreme precipitation	How do steep rivers in the western part of Norway respond to extreme precipitation	Not relevant
Data uncertainty	Not relevant	Which small and steep rivers are most exposed to flooding	Administrative capacity in the municipalities

Sea level rise and roads

Nature of uncertainties	**Location** of uncertainties		
	"Climate"	"Nature"	"Society"
Total or recognized ignorance	Not relevant	Not relevant	Not relevant
Model uncertainty	The effect of climate change on heavy wind intensity and frequency	How does sea level rise affect the ground underneath the road surface	Not relevant
Scale uncertainty	The downscaling of changes in heavy wind intensity and frequency	How do steep rivers in the western part of Norway respond to extreme precipitation	Not relevant
Data uncertainty	Not relevant	Which small and steep rivers are most exposed to flooding	Administrative capacity in municipalities

Moving from risk analysis to adaptation

After analysing the uncertainty situation – in the context of the UNCHAIN project when the impact chain analysis is finished – we must answer the question "**then what**". The figure below illustrates a way to proceed.

On the one hand we could decide to dig further into the uncertainties embedded in the risk analysis, trying to **reduce** them **even more**. The analysis of the uncertainty situation may then guide us on where to put our effort.

However, if the answer is '**no'** to the question whether to continue the effort in reducing uncertainties, the next question to ask is whether to **wait and see** or to enter '**real adaptation'**.

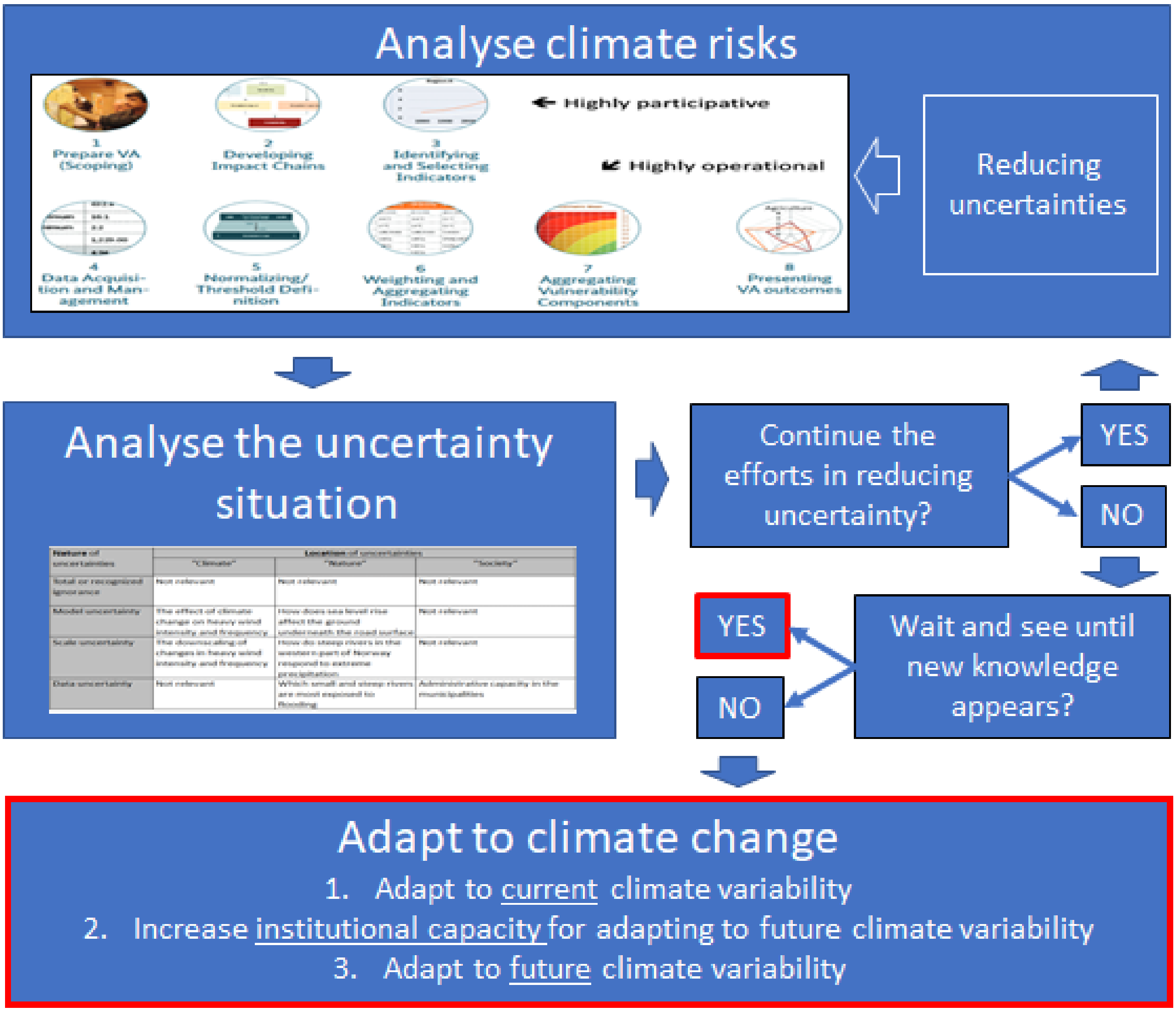
The alternative '**wait and see**' can be a **sensible** alternative in situations with very large uncertainties (cf. the category 'recognized uncertainty') and/or if new knowledge is on the way to being produced.

If the answer is to enter '**real adaptation'**, there are two options that still take into account the existence of large climate uncertainties and still 'act': The **first** option is to **adapt** to **current climate variability**. In many situations, we will find that society is still not well adapted to risks relating to current climate variability (flooding, drought etc). Adapting to current risks may therefore be a 'no-regret' measure, i.e. even if it should turn out that the measures were wasted towards future risks, they were at last positive towards current risks. The **second** option is to **increase institutional capacity** for adapting to **future** climate variability. The chances of 'wasted effort' in economic terms might be a little higher than the alternative 'adapt to current climate variability', but will in most cases be **far less** than the fore active final option: 'real' adaptation to future climate variability – and by 'real' we mean measures that go beyond strengthening institutional capacity. Such measures would in most cases involve **implementation** of or **prohibition** of **physical measures** or specific **activities**.

If **uncertainties** are considered to be '**low'** or in any other respect '**acceptable'**, the consideration of whether to do '**real adaptation**' will face the usual challenges involved in policy decision and -implementation – such as availability of technology and/or economic resources.

However, if uncertainties are considered to be **too large** for one to normally be able to justify implementing adaptation measures, applying the **precautionary principle** can be helpful. This principle states that (1) in situations with **justified major uncertainties and (2)** a justified probability of **irreversible damage** to nature and society if measures are not implemented, it can be justified to carry out measures. It is important to note two things here: First, that both preconditions must apply, and secondly that the precautionary principle does not imply what kind of measures to be implemented - it merely supports that 'something' should be done.

***Figure 4:** A proposed framework for bridging climate risk analysis, uncertainty analysis and adaptation options*



Research innovation relating to co-production of knowledge

Introduction

This chapter relates to the following **research innovation** of the UNCHAIN project:

- To refine a structured method of co-production of knowledge and integrate this into impact modelling to better account for different views on desirable and equitable climate resilient futures.

It is increasingly recognized that effective climate risk, vulnerability and adaptation assessments benefit from well-crafted processes of knowledge co-production involving key stakeholders and scientists. To support the co-production of actionable knowledge on climate change, a careful design and planning process are often called for to ensure that relevant perspectives are integrated, to promote shared understandings and joint ownership of the research process. This chapter aims to guide UNCHAIN case studies in their planning and implementation of stakeholder engagement activities in the context of climate risk assessment and adaptation. The methodological underpinnings are based on insights from the WP1 knowledge review (Leander et al. 2020) and SEI's previous research on co-designed and co-produced climate services and more broadly on science-stakeholder collaborations (e.g. André et al. 2020; Daniels et al. 2020; Gerger Swartling et al. 2019; Järnberg et al. 2020; Jönsson and Gerger Swartling 2014).

To advance the Impact chain frameworkology, specifically in relation to UNCHAIN's Innovation 2 (user interface and stakeholder involvement) we build on the existing Impact Chain approach (Fritzsche et al. 2014) by applying a related framework for co-designed transdisciplinary knowledge integration processes, called Tandem (Daniels et al. 2020). The Tandem framework is a process-centric framework for participatory climate services that has been developed inductively in recent years (André et al. 2020; Butterfield and Osano 2020; Daniels et al. 2019; Santos and Gerger Swartling 2020). By expanding the empirical scope to UNCHAIN case study contexts we will further test and refine the methodology and document the results in UNCHAIN outputs (notably in D3.2).[4]

Definitions used in the proceeding text:

- **Co-production:** "Iterative and collaborative processes involving diverse types of expertise, knowledge and actors to produce context-specific knowledge and pathways towards a sustainable future." (Norström et al. 2020, p.2):
- **Co-design:** "providers, intermediaries and users work together to design a climate service based on a shared understanding of decision-making needs and complexities, and individual and institutional capacities." (Daniels et al. 2019, p.5)
- **Co-exploration:** "a participatory process that explores different knowledge types to develop a shared understanding of concerns and needs (e.g. from scientists, decision-makers, planners, researchers and adaptation and learning specialists)." (Daniels et al. 2019, p.5).

[4] **Lessons learned from the co-production of knowledge (SEI, WNRI,** all**)**: *One journal article* that will present the methodological framework and the lessons learned from the development and application in case studies.

- **Intermediaries:** "actors who "translate" between providers and users. Examples include adaptation and learning specialists, project managers, consultants and researchers" (Daniels et al. 2019, p.5)
- **Decision-making context:** An important part of a climate change risk assessment and resulting adaptation action is to understand the decision-making context of each case study. Yet decision-makers often tend to under-utilize climate information in their decisions, and their political agendas include many other (often interlinked and interacting) issues and priorities. The decision-making context refers to how decisions are being made, and the relationship to other decisions previously made or anticipated or on the agenda. Part of the analysis is identifying the constraints within which the decision is made.

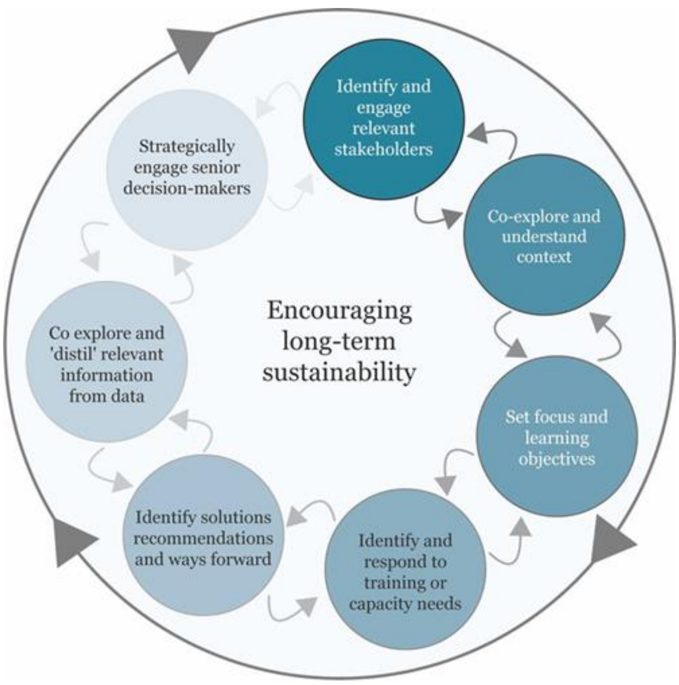
The Tandem framework

Tandem aims to guide interaction of stakeholders who need to be part of effective decision-making processes on adaptation and ultimately build climate resilience. As such it emphasises *the collaborative process* rather than specific products. In previous research we have observed that products are often presumed to be a singular end product, and usually delivered and tailored by scientists who do not always fully appreciate the potential decision context, needs, goals or capacities of the people they seek to support. As a result, there are few examples of structured guidance to support complex, real-world decision-making (Daniels et al. 2020).

In brief, the Tandem framework constitutes of seven iterative elements (see Figure 5). How these elements and associated guiding questions could be related to the Impact Chain modules and stages is further outlined in Table 4 below.

Figure 5 *Constituent elements of the Tandem framework.*

Source: Daniels et al. (Daniels et al. 2020, p.11 see also https://www.weadapt.org/tandem/home)



The central premise of the Tandem approach is that expertise central to climate-informed assessments and decision-making processes comes not only from science, but also from on-the-ground politics and practice, hence the most effective decisions emerge from incorporating diverse perspectives and disciplines. Such collaborative, knowledge integration processes bring together insights from people with experience in government, the private sector, civil society, and climate science. The processes themselves focus on building human capacity and establishing trustful relationships that can help communities make effective decisions to address the challenges they face. Apart from supporting adaptation decision-making and climate action, inclusive planning processes that span diverse areas of expertise can help build capacities, common understanding, promote learning, commitment, local ownership and create networks and partnerships that are essential components of science-informed decision making for climate adaptation and beyond (see e.g. André et al. 2020; Daniels et al. 2020; Daniels et al. 2019; Järnberg et al. 2020; Jönsson and Gerger Swartling 2014; Rodela and Gerger Swartling 2019).

By highlighting the value of highly collaborative and iterative knowledge integration processes, Tandem thus offers a *complementary perspective* to the Impact Chain approach (Fritzsche et al. 2014) that takes its starting point in the climate science and vulnerability assessment domains. As shown in Table 4, some of the aspects that are addressed within Tandem are reflected also in the modules and stages outlined in the GIZ Vulnerability Sourcebook (Fritzsche et al. 2014). However, Tandem captures additional dimensions that appear useful to consider in the stakeholder engagement process and puts the institutional and decision-making landscape and capacity building at the core. In brief we conclude that the Impact Chain *approach offers a more expert-driven approach to stakeholder-informed climate risk assessment for reduced climate vulnerability while Tandem advocates a truly transdisciplinary knowledge integration approach towards climate resilient decision-making and action*.

User interface and stakeholder involvement in the case studies

Through UNCHAIN's initial knowledge review (Leander et al. 2020) we explored the role of knowledge co-production in climate risk assessments to better inform decision-making and adaptation action. We also identified challenges to and opportunities for knowledge co-production processes. One of the most critical gaps concerned a lack of reflection and transparency as regards stakeholder roles and format and degree of involvement in the process. Another key finding was that few studies had systematically evaluated or assessed the (long-term) outcomes of the knowledge co-production process. This means that it was difficult to identify clear evidence on the potential to inform climate action although there are several studies signalling positive impacts, for example for awareness raising and agenda setting.

With a starting point in these findings from the knowledge review and SEI's previous research on co-produced climate services and science-stakeholder processes (see above), we have identified four overall research questions to be addressed through UNCHAIN case studies:

1. How can knowledge co-production in climate change risk assessments better inform decision-making and adaptation action?
2. What are the critical factors concerning how knowledge co-production processes may lead to improvements in adaptation action?

3. What outputs and outcomes were generated from the knowledge co-production processes in case studies? How was the relevance of these processes/outputs/outcomes assessed by stakeholders?
4. What characterizes an integrated method combining knowledge co-production and impact modelling that enable more action- and user-oriented climate change risk assessments?

In the following section we describe how the research questions can be operationalized with support from the Tandem framework and the Impact Chain approach.

Table 4. *General outline of the Tandem Framework and how it relates to the Impact Chain approach. Note that references to the Impact Chain modules should be seen as tentative and needs to be considered in the context of each case study*[5]*.*

Tandem Guidance: Elements and guiding questions Source: https://www.weadapt.org/tandem/home, see also (Daniels et al. 2020) *NB: not all guiding questions are included in the table and some questions are slightly modified. Some of the questions are content-oriented whereas several questions are process-related focusing on the "how".*	**Impact chain approach: Modules and steps** (Fritzsche et al. 2014)
Identify and engage relevant stakeholder • What local organizations are working on climate resilience-related issues with relevant sectoral expertise and experience? • What institutional actors are critical to engage in the process? • Can champions or change agents be identified in these organizations? • Which groups are impacted on the ground and can provide representative voice(s)? How: • How can early engagements be designed to build trust and a safe learning space between a diverse mix of participants? • Can a local organizing team be established to support the logistics and facilitation, and maintain relationships in between face-to-face engagements? • What engagements might work best to bring other stakeholders into the process as needed? • How can information developed in the process be shared on a regular basis with participants?	*Module 1 (Preparing the vulnerability assessment**)**, Step 1: Understand the context of the vulnerability assessment* • Which institutions and resources can and should be involved in your vulnerability assessment? *Module 1 (Preparing the vulnerability assessment), Step 4: Prepare an implementation plan* • Vulnerability assessment team: Who are the people and institutions involved? • Tasks and responsibilities: Who does what?

[5] Also, for full information about Tandem elements and corresponding guiding questions see Tandem online guidance.

• How can venues and the length of engagements create a conducive atmosphere for learning away from day-to-day distractions?	
Co-explore and understand the context • What adaptation issue(s) are being experienced? • In the policy, planning and implementation landscape, what plans, projects and policies are in place or in the pipeline? • What existing weather or climate information is available from local providers? • What institutions have responsibilities or mandates for the issues being discussed and for data production and sharing? How: • How can engagements be designed to co-explore: the drivers of these issues (climate and non-climate); the complexity of multi-sector system-wide issues; and different perspectives and priorities? • Can site visits, first-hand accounts and examples from other contexts help to spur discussion, learning and unpacking of adaptation issues and solutions? • How can activities (e.g. the use of graphics, maps, narratives, models) be designed to communicate to and engage participants on various approaches to climate risk assessment, global climate modelling and projections and downscaling of data? • How can activities and discussions be designed to drill down and co-explore decision making? • How can discussions be designed to co-explore the agreement or uncertainties around institutional mandates and responsibilities, and institutional capacity strengths and weaknesses?	*Module 1 (Preparing the vulnerability assessment),* *E.g. Step 1: Understand the context of the vulnerability assessment and Step 3: Determine the scope of the vulnerability assessment* *Module 2 (developing impact chains), step 1: Identify potential impacts:* • Which direct and indirect impacts are relevant for the vulnerability assessment? *Module 2 (developing impact chains), step 2: Determine exposure:* • To which changing climate signals is your system exposed? *Module 2 (developing impact chains), step 3: Determine sensitivity* • What characteristics make your system susceptible to changing climate conditions? *Module 2 (developing impact chains), step 4: Determine adaptive capacity* • Which adaptive capacities allow you system to handle adverse climate change impacts?

Set focus and learning objectives • Can learning objective(s) be agreed for the process or for specific engagements? • Can indicators be developed to measure impact particularly where outcomes are intangible? How: • How can reviews and reflections provide feedback and learning for the process? • How can a culture of learning and reflection be encouraged between all participants? • Can the processes be anchored through developing tangible outputs or projects?	*Module 1 (Preparing the vulnerability assessment), Step 2: Identify the objectives and expected outcomes* • What do you and key stakeholders wish to learn from the assessment? *Module 3 (Identifying and selecting indicators), step 1: Selecting indicators for exposure and sensitivity* • How do I assess the exposure and sensitivity components of the impact chain? *Module 3 (Identifying and selecting indicators), step 2: Selecting indicators for adaptive capacity* • How do I assess the adaptive capacity components of the impact chain? *Module 3 (Identifying and selecting indicators), step 3: Check if your indicator is specific enough* • Are my indicators sufficiently specific? **Comment**: The indicators developed in Impact Chain measures project impact, whereas tandem focuses on evaluating the outcome.
Identify and respond to training or capacity needs • Have specific capacity needs emerged from the co-exploration 'phase'? • How can these be addressed to achieve most impact? e.g. training of trainers, senior decision-makers, politicians, technical planners etc.	**Comment**: Not addressed in Impact Chain approach.
Identify solutions, recommendations and ways forward • What scale-appropriate solutions and recommendations (temporal, spatial) can be identified? • Can examples from other contexts help to identify possible adaptation measures? • How can solutions build on "windows of opportunity" e.g. existing efforts and initiatives or leveraging existing partnerships? • Which structures or actors are needed to deliver and to contribute or support the delivery of these solutions? • Which decisions are critical to unpack further? Which need further support with climate – and other – information	*Module 2 (developing impact chains), step* 5: *Brainstorm adaptation measures (optional)* • What measures could help increase adaptive capacity and decrease sensitivity in the system? **Comment:** Tandem moves beyond brainstorming by assessing the enabling environment and institutional context.

Co-explore and "distil" relevant information from data • Can specific information needs at relevant time and spatial scales now be articulated for particular decision-making processes or development of plans, processes or tools? How: • How can activities and engagements be designed to co-explore these information needs and the process, assumptions and trade-offs of distilling key messages from data? • How can sessions be designed to be accessible to the varying levels of technical capacity and knowledge of participants? • How are data and information being communicated, shared and disseminated?	*Module 4 Data acquisition and management* *Module 5: Normalization of indicator data* *Module 6: Weighting and aggregating of indicators* *Module 7: Aggregating vulnerability components to vulnerability*
Strategically engage senior decision-makers • What key messages and new information emerging from the process need to be communicated to key influencers and senior decision-makers?	*Module 8: Presenting the outcomes of your vulnerability assessment:* **Comment**: Tandem presents the outcomes continuously throughout the project
Encourage long-term sustainability • What is needed to maintain networks, partnerships and action after the process? How can these be put in place as the process is ongoing? • Can a strategy or ideas for continued conversations and longer-term research and engagement be developed?	**Comment**: Not addressed in Impact Chain approach.

Guidance for implementation

One of the main differences between the Impact chain frameworkology and the Tandem framework is that the former proposes a step by step approach whereas the latter emphasizes the iterative nature of a truly collaborative process. This means that the elements of Tandem can be addressed throughout the various Impact Chain modules and steps. It may therefore be appropriate to revisit some of these elements at different stages of the case study research. As shown in Table 4, there are some overlaps between Tandem and Impact Chain in terms of addressing similar guiding questions throughout the assessment and collaboration process. Furthermore, it is likely that some proposed questions will not be directly applicable to each UNCHAIN case study. However, we recommend that Tandem is used nonetheless due to its stakeholder-oriented, decision-driven approach to adaptation decision-making and action, and responds to several of the issues identified in the literature review.

As a minimum requirement and to allow for comparison between case studies, we propose that the following critical aspects are captured and documented systematically:

- Degree of stakeholder engagement (e.g. justification and description of at what stages of the process and how stakeholders are engaged in the process)

- Stakeholder knowledges and perspectives relevant for the concerned climate risk assessment / adaptation appraisal
- Stakeholder representation and diversity
- Frequency and means of stakeholder interaction
- Stakeholder information needs and expectations of the process and its results and outcomes (e.g. how will they use the results and how does it relate to ongoing planning processes, decision-making etc.)
- Learning objectives and developing indicators (monitoring, evaluation and learning, MEL) need to be embedded throughout the process. This could be done by co-developing indicators of effectiveness and appropriate feedback mechanisms with stakeholders.

To provide further, practical guidance to UNCHAIN case studies, we suggest that the following ten recommendations (Table 1) are considered. They are targeting primarily researchers, consultants and facilitators of co-design processes and have been empirically developed based on inspiration from the Tandem framework.

Table 5 *Ten ways to support climate change adaptation planning and decision-making (Järnberg et al. 2020)*

	Key recommendations
Process	**1.** Help practitioners articulate their needs, and challenge predefined solutions.
	2. Thoroughly assess the planning and decision-making contexts.
	3. Discuss outputs and time horizons early in the process.
	4. Involve facilitators in the co-design process.
Forma	**5.** Adjust communication to the target audience.
	6. Combine different formats, including visualizations, to present the information.
	7. Align the climate service with existing planning tools and processes.
Conte	**8.** Discuss resolution of data.
	9. Address uncertainty.
	10. Ensure transparency and traceability.

Finally, regular meetings with case study researchers will support the planning and facilitation of stakeholder workshops and the overall process in each case study. These meetings also serve as a learning opportunity and sharing of experiences between case studies. Other resources to consult are for example Seeds for Change[6] that provides practical tips and tricks for facilitators of stakeholder workshops and meetings. Also, embedded in the Tandem framework's online guidance are some method-oriented questions that are applicable throughout the process.

[6] https://www.seedsforchange.org.uk/shortfacilitation and https://www.seedsforchange.org.uk/facilitationmeeting.pdf.

Tools for analysis and evaluation

Evaluation is an important component of the method development conducted in UNCHAIN. Our WP1 knowledge review found that monitoring, learning and evaluation from science-stakeholder processes are often poorly conducted or absent. To analyse and evaluate the outcomes of UNCHAIN case studies we propose to start from a set of indicators for evaluating co-produced climate science put forward by Wall et al (2017 see further Table 6). Similar to our WP1 knowledge review findings, Wall et al. suggest six components (input, process, output, outcomes, impacts and external factors) for the evaluation capturing both internal and external factors related to knowledge co-production processes, as well as short-term outputs and long-term outcomes and impacts.

Table 6. *Indicators for evaluation of co-production processes (Wall et al. 2017, pp.102–3)*

Components	Indicators
Inputs	I.1. Necessary scientific disciplines are included on research team (research capacity maps to research question). I.2. Significant research time is devoted to project (% of FTE yr^{-1} allocated to the project) I.3. Research team works collaboratively among themselves. I.4. Target agency indicated commitment through contribution of services, funds, time, and a specific point person. I.5. Target agency representatives on the project can articulate a need for this research (i.e., they have a problem they want to solve through this research project). I.6. Target agency representative perceives a path to use/application of the research findings (i.e., does manager see barriers to implementation?) I.7. Proposal includes a clear plan for communication, engagement, and/or collaboration between research and management team I.8. Total funding for project compared to total amount allocated for engagement/collaboration activities (if discernable). I.9. Research team has training or experience in collaborative research approaches. I.10. Research team's motivations for participating in the project (i.e., their goal is actionable science). I.11. Research team and agency representative have preexisting working relationship.
Process	P.1. Point at which host/target agency enters or participated in the project: vision, problem definition, research question articulation, research design, data collection, data analysis, knowledge/meaning making, testing results, dissemination of knowledge, evaluation of project. P.2. Frequency and medium of communication between research and management teams. P.3. Participants perceive they had equitable opportunities to participate in project meetings, workshops, etc. (observe interactions when possible). P.4. Target agency representative is satisfied with the level of engagement. P.5. Researchers are satisfied with the level of engagement. P.6. Challenges within project are resolved in mutually agreeable ways. P.7. Researchers are aware of whether/how information was used or not used by agency.
Outputs	OP.1. Number of peer-reviewed articles. OP.2. Number of technical reports/gray literature. OP.3. Workshops or meetings to disseminate findings. OP.4. Final report is delivered directly to agency representative(s) or made easily accessible via another format. OP.5. Findings are delivered in a timely manner (meet agency's decision calendar or timeline). OP.6. Other outputs (media reports, websites, other products created by the project).
Outcomes	OC.1. Project goals have been achieved (both objective assessment by evaluator and researcher and agency representative perceptions with regard to completion of goals). OC.2. Participants perceive science as credible. OC.3. Findings/outputs meet the standard the agency applies to "usable" information for action. OC.4. Agency participants perceive the science as salient to their needs/problems. OC.5. Participants perceive that the process of producing the science was legitimate (i.e., all participants had opportunities to contribute). OC.6. Mutual interest in longer-term collaboration (i.e., both teams express interest in working together again).
Impacts	IM.1. "Enlightenment" use of information (agency representative perceives self to be better informed about an issue). IM.2. "Problem Understanding" use of information (more specific than Enlightenment, better comprehension of particular problems). IM.3. "Instrumental" use of information (agency representative finds out what to do and how to do something; gained new skills). IM.4. "Factual" use of information (provision of precise data, for example). IM.5. "Confirmational" use of information (previous information was verified). IM.6. "Projective" use of information (agency gained better understanding of possible future scenarios). IM.7. "Motivational" use of information (encouraged someone to keep going (or not) on search for information). IM.8. "Personal or Political" use of information (helped a person gain control of a situation or avoid a bad situation). IM.9. Findings from study are explicitly used in agency planning, resource allocation, or policy decision. IM.10. Findings contribute to successful climate change adaptation action.
External factors	E.1. Turnover in agency staff. E.2. In-house (agency) technical capacity to manage new information. E.3. Political will for action/change within agency. E.4. Financial capability for change/action within agency. E.5. Catalyzing event affected perceived need/lack or need for information.

Research innovation relating to societal change and socio-economic consequences

Introduction

This chapter relates to the following **research innovation** of the UNCHAIN project:

- To develop and test an applicable framework for analysing how societal change can affect local climate change vulnerabilities, how to conduct an integrated assessment of the combined effect of potential climate and societal changes, and how to better understand the socio-economic consequences involved in local climate change adaptation.

This research innovation aims at adding insights from socio-economic scenarios, economic analysis, and socio-economic climate change adaptation modelling with the impact chain approach. It acknowledges that impact chains with their focus on today's vulnerability, exposure and hazard assessment might miss the socio-economic dynamic development of the world and that this may lead to an over- or under-estimation of the risk. The vulnerability sourcebook (Fritzsche et al., 2014) states to this regard: "In some cases there may be a need to consider vulnerability to future climate as well, e.g. for long-lived infrastructure. This will, however, require an understanding of how the climate will change for a given location, i.e. sufficiently reliable climate projections, or at least plausible scenarios will be needed as an input. Reference periods typically cover 30 years (e.g. 2021-2050). When considering future climate, you should ideally "*also have scenarios for socio-economic developments*, such as population growth or anthropogenic land-use change." (Fritzsche et al., 2014, own emphasize by italics) Impact chain concept applications such as (include examples, maybe from chapter 2 or intro) mostly focus on the derivation of a risk estimate from today's situation. They describe exposure as the presence of people, livelihoods, environmental function etc. and vulnerability as the propensity or predisposition to be adversely affected, as it has been outlined in the IPPC's AR5 WG2 risk concept (SREX 2012). The SREX report explicitly points out "Exposure and vulnerability are dynamic, varying across temporal and spatial scales, and depend on economic, social, geographic, demographic, cultural, institutional, governance, and environmental factors (high confidence). Individuals and communities are differentially exposed and vulnerable based on inequalities expressed through levels of wealth and education, disability, and health status, as well as gender, age, class, and other social and cultural characteristics."

The scope of research innovation 3 tries to cover this dynamic changing nature of exposure and vulnerability using scenarios. In more detail, the following research questions are addressed:

- How to include future vulnerability conditions based on socio-economic scenarios to better depict future critical conditions?
- How to gain a better understanding of socioeconomic consequences involved in climate change adaptation?
- What are the most relevant economic indicators to include in impact chain assessments?

However, this case study protocol acknowledges that socio-economic scenarios have not been part and parcel of the planning and design of the case studies. Therefore, the next section will share key definitions before a subsequent section will help case studies to put themselves into one out of four categories to address socio-economic scenarios.

Shared Socio-Economic Pathways (SSP)

Riahi et al., 2016, describe the Shared Socio-Economic Pathways (SSP) in their seminal paper as "part of a new scenario framework, established by the climate change research community in order to facilitate the integrated analysis of future climate impacts, vulnerabilities, adaptation, and mitigation." They aim at providing major global developments causing different future challenges for mitigation and adaptation. The SSPs include five narratives of alternative socio-economic developments, such as sustainable development, regional rivalry, inequality, fossil-fuelled development, and a middle-of-the-road development.

Table 7: *Summary of SSP Narratives(Source: Riahi et al, 2014, own compilation).*

SSP1 **Sustainability – Taking the Green Road** *Shift to a more sustainable path with more inclusive development respecting nature boundaries. Better management of the global commons, faster educational and health investments and economic growth leads to more human well-being. Lower inequality both across and within countries. Low material growth and lower resource and energy intensity from consumption.*
SSP2 **Middle of the Road** *Continuation of past structures and patterns. Development proceeds somewhat, progress towards SDGs is slow. Environmental degradation continues, but material and energy efficiency grow. Global population grows moderately, income inequality continues.*
SSP3 **Regional Rivalry – A Rocky Road** *Nationalism, competitiveness, security concerns, and regional conflicts dominate this development, leading to low investments in education and technological development. Slow growth, material intensive consumption and low concern for the environment characterize this scenario.*
SSP4 **Inequality – A Road Divided** *Very unequal investments in human capital, lead to very unequal developments of countries which are well-connected and thrive and fragmented groups of lower-income low-tech economies. Low social cohesion, high risk of conflict and unrest. High technology development in some parts, also towards low carbon. Few international environmental treaties, more local/regional.*
SSP5 **Fossil-fueled Development – Taking the Highway** *The classic growth scenario with competition, innovation, technological progress, and education. Improvement of human and social capital, but exploitation of any fossil fuel source. Overall resource intensive lifestyles. Environmental problems are solved by technology.*

Challenges to adaptation and mitigation

Different pathways present different challenges to adaptation and mitigation (

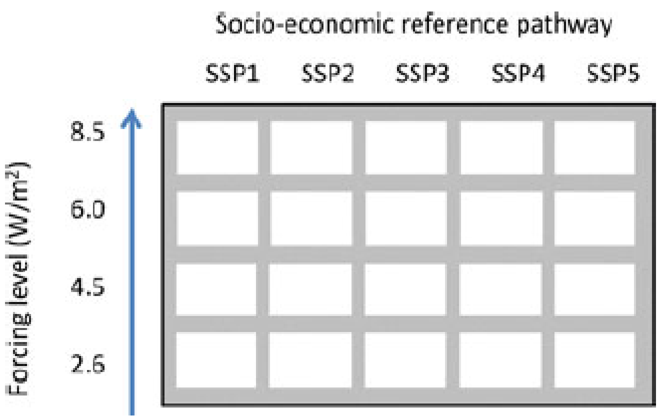
Figure 6). Challenges to mitigation are driven by high uses of fossil fuels (SSP5) or low concern for environmental issues (SSP3); challenges to adaptation are mainly driven by low investment, poverty (SSP3) and inequality (SSP4).

Figure 6: *Classification of the SSPs according to their socioeconomic challenges for mitigation and adaptation (Source: O'Neill et al. 2017).*

RCP/SSP matrix – connecting radiative forcing and socioeconomics

The different strands of research around climate change mitigation, adaptation and damages have developed a joint scenario framework which serves as a backdrop to the more elaborate individual country or sector specific scenarios. The set of scenarios characterized by a certain amount of radiative forcing (the representative concentration pathways RCP) and a certain development narrative, can be arranged as a matrix (Van Vuuren et al. 2013).

Figure 7: *The scenario matrix architecture (Source: Van Vuuren 2013).*

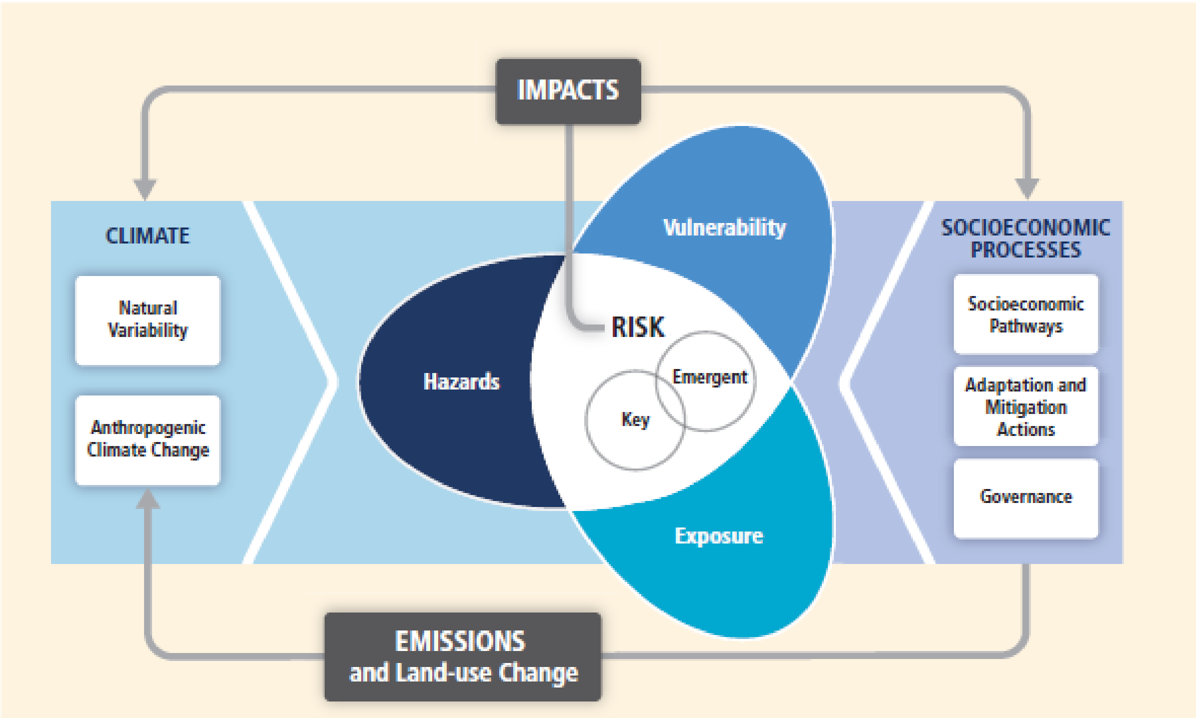


Following the authors, we suggest using this matrix to allocate the socio-economic background of the respective case study and thus attach it to the scenario framework it represents.

Connecting scenarios with the Impact Chain approach

Socio-economic developments as outlined in the respective scenarios can enhance or mitigate the risk from climate change, because socio-economic development will affect exposure and vulnerability negatively or positively. The AR5 report on vulnerability shifted the terminology from a focus on vulnerability (AR4) to risk as the central concept. For a comparison of the frameworks and the implications of this shift see Das et al. 2020 with an example of impact assessment in the Indian Bengal Delta.

***Figure 8**: Components of Risk Assesment according to AR5 (Adapted from IPCC AR5, 2014, P.1046)*



Exposure is the presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected. Megacities comprise higher exposure in terms of population than deserts, but deserts may comprise cultural heritage, ecosystem services and other functions, which can be adversely affected, too.

Regional population density, infrastructure, built environment, cultural assets change under different scenarios. Under the SSP framework outlined above, different pathways for population, investment and therefore state of infrastructure etc. can be selected. Exposure is reduced if the population in a region, a country, a coastal area decreases under the respective scenario. This would lead to a lower risk, all other things unchanged. The AR5 defines risk as "the potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. It is often represented as the probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur". A similar logic applies to **vulnerability,** which is the propensity or predisposition to be adversely affected. As outlined in D1.1, vulnerability contains a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt. All aspects will change for better or worse under different socio-economic scenarios. The physical attributes of systems, such as building materials, as well as the social, economic and cultural aspects such as age structure, or income structure will contribute in a scenario typical way to the sensitivity and will differ between scenarios, as the brief narratives in table 1 illustrate. The main differences can be expected regarding the capacity to adapt. In thriving economies with plenty of wealth to spend this will be strengthened.

Future hazard on today's structures and future hazard on future structures will lead to different risks. Modelers in the economic adaptation modelling community have pointed at the relevance of future socio-economic scenarios for a meaningful risk assessment (see Schwarze 2015 and Steininger et al. 2016), as has been pointed out in D1.1. For the case studies and the UNCHAIN project detailed insight into the scenario sets and the wide set of socio-economic modelling results might not be necessary. However, we suggest treating this scenario set as map and we deem it important that case studies indicate, where they are located on this map.

Socio-economic aspects in the case studies

How relevant are socio-economic scenarios for the respective case study? Case study should be able to classify themselves as a case study, where

- I: socio-economic scenarios pertain and are a relevant input to the case (front seat).
- II: socio-economic scenarios matter as relevant background information and reference to the literature (back seat)
- III: socio-economic quantities matter but have not yet been considered as changing and/or relevant (no seat).

The protocol aims mainly at case studies with socio-economic scenarios in the back seat and invites class III case studies to maybe give a thought or reference to economic development, too. We assume in the following, that the case studies focusing on scenarios and socio-economic modelling do not need much guidance from this case protocol. However, the following guidance may be useful for all case studies.

Guidance for implementation

The protocol can be implemented following the procedure outlined in the following tables. The tables are organized by sub-research question, as described in the literature review in D1.1. The core challenge for case studies where socio-economic scenarios have not been addressed yet is awareness that these scenarios matter and that any case study takes place against the background of some assumed socio-economic development. This shall be acknowledged and briefly described.

Table 8 provides first suggestions for this. We assume that this table will be refined during the case studies and the project as such, adding experiences and answering to questions and difficulties which have been encountered by the case studies.

Table 8. *Implementation of the socio-economic scenario protocol*

Sub-research question 1: How to include future vulnerability conditions based on socio-economic scenarios to better depict future critical conditions?		
Purpose (what)	**Methodology design, Approach, Procedures (how)**	**Timeframe (when during the risk assessment cycle)**
Identify the relevance of socio-economic pathways (front seat or back seat?)	Review the case study at the suggested milestones and assess the role of socio-economic scenarios.	@beginning (minimum requirement: socio-economic baseline) @end (estimate role of scenario during the case study. This can be done by answering the following questions: • Which SSP(s) was/were included • Which SSP indicators were used • (Feedback from end-users on how (un)helpful the inclusion of SSPs was?))
Separate assumptions on socio-economic development, independently from the climate change assumptions	A similar matrix as developed by Van Vuuren et al 2013 can be applied More regional assumptions might be necessary, it will be helpful if they are reported in a similar framework. Clearly distinguish climate change, socioeconomic assumptions, and adaptation policies now and in the future.	Develop matrix @beginning and double-check after first results.
Sub-research question 2: How to gain a better understanding of socio-economic consequences involved in climate change adaptation?		
Include the future impact on vulnerability Identify most dynamics to understand under which socio-economic assumptions risks are obtained	Acknowledge and identify the socio-economic background scenario. Most countries have a socio-economic projection included in their adaptation strategy. Make reference to this.	@beginning for "new" case studies to determine the complete scope of the case study, including the socio-economic scope. @end for case studies revisited to better understand how they are placed on the SSP map.

Identify economic indicators which matter to the case	If needed, one can resort to the indicators listed in the SSP literature reviewed in the literature review.	@beginning: report if and how this is used
Sub-research question 3: How do we ensure that local/context-specific 'first experiences' with impact chain frameworkology and framework are fed back into the improvement of the framework?		
Ensure exchange, consideration with/of other case study results, and literature	Connect with CS Connect with IRG	@end (towards)

A tool to understand the content of the SSPs under different radiative forcing and to understand the results of the different integrated assessment models is provided by IIASA under the following link https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=40. It requires registration free of cost and provides tutorials, links to the literature and a wealth of information. The main indicators are connected with tables and graphs. The results are given as values or growth rates, globally or per region.

Research innovation relating to transborder climate change risks

Introduction

This chapter relates to the first part of the following **research innovation** of the UNCHAIN project:

- To explore the possibility of expanding the logic of impact chains along two dimensions: '**time & space**' (i.e. including the indirect or trans-border impacts of climate change) and '**scope'** (linking mitigation and adaptation).

Based on the knowledge review report from WP1 and inputs from the international reference group we propose the following **research questions** to be guiding the UNCHAIN cases that relate to TCCR:

1. What transborder climate change risks can be identified within the case-study system?
2. What is the nature and character of the transborder climate change risks identified?
3. How significant are the identified transborder climate change risks?
4. Who are the risk 'owners'?
5. To what extent (and why) are current risk assessment and adaptation planning processes limiting or enabling the identification and management of TCCR?
6. What measures and actions might reduce or manage such transborder climate change risks?

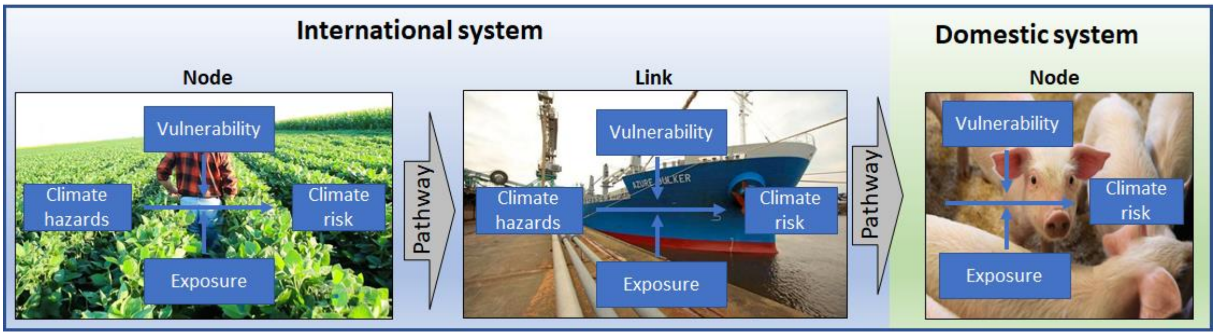
Depending on the specific context and framing of the cases, all or some of the aspects presented above could be included; and **additional sub-research questions** could also be formulated. This is all up to the research institutions responsible for each case.

Case-study managers are advised to progress through the stages of this framework in a linear fashion: first identifying where their case study sits within the typology proposed, before progressing to the tasks outlined in the scoping phase, and subsequently the assessment, appraisal, ownership and management stages (as appropriate). A summary can be found towards the end of the protocol. However, before presenting the proposed way of conducting the TCCR cases, we present the basic concept of transborder climate change risks (**TCCR**) and how TCCR differ from the traditional climate risks.

What is transborder climate change risk?

We may characterise **TCCR** as a cascading outcome or consequence of a climate-related hazard, climate-induced change or adaptation action that crosses one or more national borders and has an impact on others beyond the jurisdiction of the risk's source. The definition of TCCR slightly differs from the general definition of climate risks as presented in the IPCC Fifth Assessment Report (AR5), in the sense that the interactions between vulnerability, exposure and hazard differ along the cause-effect chain from risk source (international) to risk-owner (domestic): in the domestic end-point of this chain, the hazard-element is per definition taken out of the equation (see Figure 9).

Figure 9: *Proposed adaptation of the original risk-framework when analysing TCCRs*



The hazards and accompanying exposures and vulnerabilities need to be analysed at two different "location" categories, described as nodes and links. **'Nodes'** are typically a location for producing or processing input factors imported for domestic production (e.g. soy from Brazil for fodder production in Norway) – but could also relate to production of domestic services (e.g. domestic tourism fed by inbound tourists). **'Links'** are the means of connecting the nodes to the domestic country in question (e.g. shipping of soy to Norway).

It is important to note that nodes and links in a network might not be physical or fixed entities. In coupled socio-ecological systems, flow of money (for example) is often defined as a link, although it has no tangible geography. Thus, systems can be complex and interconnected (with multiple 'receiving' and 'sending' systems).

Hedlund et al. (2018) categorize TCCRs into different transmission 'pathways' or 'links': trade, biophysical, people and finance. UNCHAIN case studies may wish to focus on TCCR transmitted through any of these pathways, although trade and finance could be considered preferential over the two others (flows of people or biophysical resources) given the potential risks and sensitivities associated with the former and the wealth of existing research and evidence on the latter – particularly for transboundary rivers and water basins.

Example: Climate risks relating to **import and export of food** is often referred to as a prominent example of TCCRs. A study on the food-interdependencies between Senegal and Thailand can serve as an example here. Senegal is dependent on rice imports for its food security. The effects of climate change impacts on rice yields in countries like Thailand, Vietnam and India – currently key exporters of rice to Senegal – therefore determine Senegal's climate risk exposure. Furthermore, policy measures taken by rice exporting countries (such as export bans), as well as by fellow rice importing countries (such as hoarding rice stocks), determine how global prices react to poor harvests as a result of extreme or unusual weather. Given that domestic consumption patterns do not change in accordance, Senegal's vulnerability is a product of measures taken by countries thousands of miles away (Benzie et al. 2018).

Conducting cases about transborder climate change risks

In the following, we proceed to present a case-study protocol to reveal and assess TCCRs, divided into the following stages:

- Stage 1: Categorisation of cases
- Stage 2: Defining system boundaries
- Stage 3: Scoping - in 'reverse order'
- Stage 4: Identifying data sources
- Stage 5: Assessing vulnerabilities
- Stage 6: Assessing climate risks
- Stage 7: Identifying risk ownership
- Stage 8: Adaptation recommendations

Stage 1: Categorisation of cases

The aim of this stage is to identify and classify where in the 'case study matrix' your impact-chain analysis sits. The approach advised to assess and analyse TCCR – including the extent to which it is considered feasible to evaluate ownership and management of TCCR – will be influenced to a great degree by two factors relating to the process of selecting which climate risks to address in the case, and the outcome of this process.

- Process: Identify when in the process of case-study design and development the decision is taken to incorporate a TCCR assessment. The decision should be made in dialogue between the researchers and relevant stakeholders, and it can be done prior to the actual case-process, or it can be a possible outcome of the case-process (and if so, most probably as part of the initial stage of the case-work – e.g. the scoping stage as described in the Impact Chain framework)
- Content: The output of (1); i.e. to identify whether TCCR are the only risks to be explored or one of several. A few of the cases have so far been identified to be of the former, but we should leave open the possibility that cases could include TCCRs in addition to traditional 'local' climate risks.

This case-study protocol advises different approaches at each stage of the process depending on the answers to these questions.

Table 9. *Four categories of TCCR cases*

	TCCR the only risk to be addressed	TCCR one of several risks to be addressed
Decision on including TCCR made before the case study started	(A) Pre-defined proprietary TCCR case	(C) Pre-defined embedded TCCR case
Decision on including TCCR **made** during the case study	(B) Emerging proprietary TCCR case	(D) Emerging embedded TCCR case

In the application, only two of the 12 cases were listed as full-scale TCCR cases – case "Improving climate change impact assessments of international supply chains" and case "Tourism mobility and climate change" – i.e. category A in the table above. However, by opening up to also include cases that inclusively address TCCRs, and cases that during the case study end up focusing on TCCRs (solely – cf. category B– or inclusively – cf. category D), we can hopefully expand the empiric basis in UNCHAIN for addressing research innovation #5.

Key outcome of stage 1: To have identified your case study as type A, B, C or D

Stage 2: Defining system boundaries

Defining the system boundaries of your case is crucial, i.e. to answer the question "what is (really) the case?" Below is a list of questions that can help you to do this.

- What is the **operational administrative level** involved in the case (e.g. country, county, municipality, company)?
- Who are the **main actors**, i.e. the stakeholders / organisations / institutions etc. that you will relate to in the case study?
- What is the **lowest unit of risk analysis** (e.g. one or more private companies, or one or more commodities)?

Key outcome of stage 2: To have a clear description of the system boundaries of the case.

Stage 3: Scoping and the 'system-first-approach'

While a '**hazard-first'** approach is dominant in most climate risk assessments – i.e. to start by first describing the possible climate change hazards and then move on to identify and describe the exposures and vulnerabilities – a '**systems-first'** approach might be the best way to start in the case of TCCRs.. The below listed questions may help you when conducting this stage.

- What are the main inputs to, outputs from, and drivers of, the case-study system?[7]
- Which of these inputs or drivers originate from beyond the case-study location (i.e. internationally)?[8]
- What are the key nodes and links domestically and internationally that connect the case-study scale to other scales (and the case-study system to other systems)?
- What are the exposures – i.e. the 'values at stake' – for each of the nodes and links that are selected?[9]
- Based on the answers to the above, do you expect the system to be significantly affected by TCCRs?
- If so, can you anticipate which TCCRs could be most significant? If you identify lots of potential TCCR, it is advisable to choose between 1-3 nodes or links to explore (to take forward to the assessment phase), to manage scope/scale.

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[7] Inputs might be flows of materials, finances, or ecosystem services. Outputs might be end-products or services. Drivers could be external conditions such as market dynamics, supply and demand forces, policy enablers/constraints, and so forth.

[8] Outputs will per definition be located domestically at the geographical location of the case in question.

[9] Exposures may very well vary. Say that you analyse domestic food production, then 'exposure' could be 'reliable import of fodder'. The most important foreign node could then be the production-site of soy, in e.g. Brazil, in which 'exposure' then might be 'reliable production of soy'.

The focus and design of the study will depend not only on the system itself, but also on the focus of the case study/research questions, availability of data, stakeholder engagement as well as context and barriers. Therefore, and to ensure relevance, feasibility and value-add, it is advisable to approach the questions below within the scoping phase:

- Scope: how far do you want to go? Given that a TCCR assessment could go infinitely into system dynamics, how far (geographically) do you want to go? Which elements of the system will be assessed? This depends on focus and typology and data and methods can be influenced by stakeholder preferences and the policy scope of the case study.
- Focus and typology: is there greater value (academic or other) in a narrow focus (typology A and B) or a broad focus (C and D)?
- Data availability and methodological innovation: what is the availability of data and methods to study the TCCR? Is there a need for methods innovation?
- Stakeholder engagement: Who should be involved in the stakeholder process for the chosen case study and what approach do you have?
- Are there other context-specific traits or barriers that could inform the case study design?

Answering the questions listed above will most often have to be done by interviewing the main actors identified in stage 2 - in particular those which are involved in /responsible for imports of the input-factors in question if the TCCR being analysed are trade-related.

Key outcome of stage 3: To have identified the critical nodes and links domestically and internationally, and to have defined the scope and focus of the case study as well as its value and feasibility.

Stage 4: Identifying data sources

For each of the selected nodes and links, accessible data will have to be identified for describing exposure (to the extent that data is needed for this), hazards and vulnerabilities.

When identifying relevant and accessible data sources for the links and nodes internationally, you may go back to the traditional 'hazards-first' approach – since the international analysis shall include hazards as opposed to the domestic analysis. Thus, the order of actions described below can be changed when moving from a domestic to international focus.

Data on '**hazards'** located internationally can in some cases be difficult to get hold of – at least at a detailed level on the impacts of climate change (flooding etc.) – depending on the geographical location of the nodes and links in question. National (or even international) climate service centres are a natural place to start.

As already pointed out, describing '**exposure'** is primarily about identifying the 'values' or functionalities that can be at stake due to negative impacts from climate change (the 'hazards'). And, also as previously pointed out, exposure can differ from one node or link in the impact chain analysis to another. Identifying exposures will have to be done through a dialogue with the user representatives.

Vulnerabilities can be many different things and selecting which of all possible categories of vulnerabilities to focus on is a crucial issue to discuss through stakeholder engagement in the case studies. An integral part of this is to select the vulnerabilities that can be assessed, which may again depend on data accessibility.

Data can be assessed through literature review, while data from downscaling of climate scenarios for the relevant international locations could also be of relevance. However, assessments of the potential impacts of, exposure to and vulnerabilities of climate change hazards must in most cases be based on the expertise of local stakeholders and cannot be expected to be covered fully by the expertise of the UNCHAIN researchers responsible.

Key outcome of stage 4: To have identified available sources of data for hazards and vulnerabilities (and, if needed, also for exposures) for all identified nodes and links that are to be included in the impact chain analysis.

Stage 5: Assessing vulnerabilities

In line with recommendation above (stage 3) to apply a 'systems-first' approach, assessing the **vulnerabilities** involved in the different nodes and links is of **key importance** in order to arrive at any meaningful assessment of transborder climate change risks.

The knowledge review report from WP1 points at different versions of '**theories of social risk**' as relevant **theoretical frameworks** for analysing TCCRs, and precisely the social part of the climate risk nexus: vulnerability. The works of Charles Perrow appear to be particularly relevant. Perrow (2007) describes two key interaction **concepts of connections: complexity** (linear versus complex) and **coupling** (loose versus tight). Perrow suggests that the systems with the largest catastrophe potential are those that combine complex with tight couplings; tight couplings allow for rapid propagation and complex connections allow for unexpected, cascading effects of an initial shock or impact (cf. table below).

Table 10 *System characteristics for analysing catastrophic potential (Perrow, 2007)*

		Complexity	
		Linear	Complex
Coupling	Loose	Lowest potential	Medium potential
	Tight	Medium potential	Largest potential

The next figure may serve as an inspiration for adapting the analytical framework of Perrow to the situation of climate risks and the specific context of TCCRs. In the figure we have tried to operationalise and specify how a shift from linear to complex complexity, and from loose to tight coupling, may manifest itself with relevance for assessing vulnerabilities in relation to transborder climate change risks.

***Figure 10** Proposed framework for assessing climate change vulnerabilities relating to TCCRs*

LOW ← Climate change vulnerability → HIGH

Linear («assembly line in a factory»)	Complex («current global economy»
Linear relationships between system elements	Non-linear relationships between system elements
Loose spaced and unique elements, implying that one component fault will not spread easily to different parts of the system	Tight spaced and common-mode elements serving several functions, implying that one component fault may spread easily to different parts of the system
Stabile system with respect to size and number of elements and functions	Growing system with respect to size and number of elements and functions
Interactions in an expected sequence, low risk of unintended feedback loops	Interactions in an unexpected sequence, increased risk of unintended feedback loops

LOW ← Climate change vulnerability → HIGH

Loose couplings	Tight couplings (ideal of "lean production")
Processing delays possible	Delays in processing not possible
Slack in resources possible	Little slack possible in supplies, equipment, personnel
Buffers and redundancies fortuitously available	Buffers and redundancies are limited and designed-in
Substitutions fortuitously available	Substitutions of supplies, equipment, personnel limited and designed-in

Key outcome of stage 5: Description and assessment of relevant vulnerabilities to climate change linked to the different nodes and links.

Stage 6: Assessing climate risks

The original impact chain framework stipulates how the assessment of climate risks can be done, putting much weight on quantifications and the construction of indicators weighting these into one (or a few) indexes. This level of quantification might not be attainable or desirable when dealing with TCCRs, depending of the outcome of the scoping phase (stage 3). Rather than calculating a final risk, the outcome of the TCCR assessment could be a description of a variety of risks, their impacts and dynamics in the system studied.

In this stage you should, for each unit of risk analysis and the accompanying input-node(s) and link(s) identified previously, intimate the following:

- What are the most important climate hazards, exposures, and vulnerabilities?

- Are any of the international nodes or links likely to be *highly* exposed or vulnerable to climate-related hazards, or could climate risks be *prevalent* throughout the system being explored?
- Are there any current warning signs that climate change could be impacting the system? Or are there changing conditions that indicate/forecast new or emerging risks?
- How do the nodes and links relate to each other and interact – are there key dependencies?
- Can you forecast second- or third-order impacts of particular climate-related risks on economic, social, political or environmental systems? Are there consequences for trade flows, financial agreements, business prospects, movements of people, security and diplomatic interests, levels of human well-being or natural resources and ecosystems?

Key outcome of stage 6: Identify the location, type and (as far as possible) category of risks along the impact chain.

Stage 7: Identifying risk ownership

Before entering the discussion on 'what to do' (adaptation options), we should ask the question 'who can or should do it'? Thus, the concept of **risk ownership** has been applied. This concept is an analytical device for identifying the different rights, roles and responsibilities of state and non-state actors in governing risk and assessing the division-of-labour between them. When we say a risk is 'owned' then an attributable person or entity is accountable or responsible for managing its effects; an unowned risk has no such oversight. The concept has been advanced and applied to natural hazard risk management in Australia by Young et al. (2015). The 'map' of nodes and links with the accompanying risks is the place to start when looking at risk owners.

In order to descripe risk ownership, Young et al (2015) propose to address two core questions:

1) Who is **paying** for the risk?
    - Who plays a role in the provision of funding or finance to mitigate or manage the TCCR? And if unclear, consider the financial repercussions of the risk being realised – who would bear the cost?
2) Who is **responsible** and **accountable** for the risk?
    - Who has a remit/mandate to lead tasks, actions or processes to mitigate or manage the TCCR, and who is 'ultimately answerable', according to relevant policy and legal instruments? If unclear, consider the political and instutional repercussions of the risk being realised – who would be held to account?

For each question, case-study authors could consider the institutional stakeholders, funding mechanisms and policy/legal instruments:

- At relevant governance scales and administrative levels (international, regional, national, sub-national), including arrangements that connect them (bilateral agreements or transnational agencies and partnerships etc.)
- Across relevant jurisictions (at the source or origin, point of impact, along the pathway or indeed beyond)
- Associated with studied systems components and risks in the impact chain
- Across institutions (public, private, civil society etc.), domains (political, social, economic, environmental etc.) and sectors and policy departments (trade, agriculture, finance, defence, health, security, foreign affairs, climate, development etc.)

Case-study authors could also consider whether their answers to the above questions change depending on key factors, such as:

- The stage/task in the risk management process (are the owners accountable for reducing a future risk distinct from those responsible from managing the risk once realised, or recovering from its effects? What about those strengthening resilience? Drafting relevant plans and strategies? Leading response efforts? Communicating about the risk/response?)
- From whose perspective allocation of risk ownership is being assessed (how do those held as accountable or responsible shift according to different stakeholder perceptions and/or the creators of the legislative frameworks, regulations and policies under review?)
- The type of hazard that triggers the risk (does ownership change depending on whether it is a drought or a flood that impacts the case-study system, for instance?)
- The level or threshold of the risk (actual or perceived) and assumed coping capacity (does a 'higher power' take over mitgation or management of the risk if the impacts go beyond a certain scale or the implementing measures cross a certain value?)

Key outcome of stage 7: Identify the owners of risk relating to the different nodes and links.

Stage 8: Adaptation recommendations

In a final stage, case-study authors are invited to reflect not just on whether and how transborder climate change risks are known and managed currently (cf. previous stage), but also provide their **normative recommendations** for how they might be better known and managed in the future. Some prompt questions in this regard:

- Are there practices set up to support the identification and/or management of similar TCCRs in the future?
- To what extent are current risk assessment and adaptation planning processes limiting or enabling the identification and management of TCCR? Why? How might such processes be enhanced? How can we encourage risk assessment/management approaches that reflect the interdependencies of our systems?
- What do transborder risk assessments and adaptation plans look like? What sorts of new/differentiated capabilities might cross-border approaches to adaptation demand to enable action across sectors and scales? How does the scope and nature of adaptation change through a transborder perspective? How can we draw out best practices and downscale these to the local level?
- What are the barriers/constraints or enablers/prospects either limiting or advancing the capabilities and motivations of policymakers/planners to account for TCCR and the opportunities they can harness?

The recommendations should be aimed at the previously identified risk owners and related to their potential roles in reducing or managing TCCRs.

Key outcome of stage 8: To have assessed current practices to manage the risk and evaluated their efficacy (as applicable), and to have generated normative recommendations for how they might be better known and managed in the future.

Eight-stage summary

Stage	Tasks
1. Categorisation of cases	• Identify your case study as type A, B, C or D (cf. table 1)
2. Defining system boundaries	Explore and answer: • What is the operational administrative level involved in the case? • Who are the main actors? • What is the lowest unit of risk analysis?
3. Scoping	Explore and answer: • What are the main inputs to, outputs from, and drivers of, the case-study system? • Which of these inputs or drivers originate from beyond the case-study location (i.e. internationally)? • What are the key nodes and links domestically and internationally that connect the case-study scale to other scales (and the case-study system to other systems)? • What are the exposures – i.e. the 'values at stake' – for each of the nodes and links that are selected? • Based on the answers to the above, do you expect the system to be significantly affected by TCCR? • If so, can you anticipate which TCCRs could be most significant? If you identify lots of potential TCCR, it is advisable to choose between 1-3 nodes or links to explore (to take forward to the assessment phase), to manage scope/scale.
4. Identifying data sources	Identify data sources for each node and each link: • Hazards (beyond the case-study jurisdiction) • Vulnerabilities • Exposures
5. Assessing vulnerabilities	• Characterization of systems vulnerability/cascading propensity/"catastrophic potential": level of complexity and tight versus loose coupling.
6. Assessing climate risks	• Locate risks in relation to the nodes and links • Assess the type and (if possible) level of risk (qualitative or quantitative)
7. Identifying risk ownership	Explore and answer: • Who is paying for the risk? • Who is responsible and accountable for the risk?
8. Adaptation recommendations	Draft normative recommendations: • For each location of climate change risks • Related to the identified risk owners

Data flows

Introduction

Various research innovations of the UNCHAIN project are directly linked to specific data needs. This ranges from the data driven modeling in "Advancing climate change impact assessments (socio-economic aspects, framings across scale and sectors)" to the development of risk indicators in the vulnerability source book/impact chain modeling approach which is contributed to by all case studies.

The nature and type of data produced, and the respective management is described in the data management plan for each case study. Apart from that, the case study protocol here focuses on more content related issues which need to be addressed by the case studies. Taking the literature review from D1.1. as a basis, data challenges have already been identified for the thematic fields of socio-economic scenarios and transborder risk assessments. The successful involvement of stakeholders in individual cases will need, generate, and use data, too.

The data flow research protocol leads to the possibility of supervising and evaluating data flows from individual case studies to the joint improvement of the Impact chain frameworkology. It complements the data management plan, which deals with data availability and the FAIR principles of data management in research projects. In the data management plan, a template for the description of *data sets* has been developed and filled by few case studies.

In this research protocol, a first draft of a template to collect and share information regarding *data flows* is suggested. Several aspects are considered:

- Data as input: systematic identification of relevant data gaps and identification of potential synergies across case studies.
- Data as input and/or output: identification of the role of scale, mismatch between scientific, political, administrative system borders.
- Data flow to Impact Chain analysis: weighting, normalization, identification.
- Relevance of specific indicators for decision support.

Note, however, that data flows are not only part of this phase of developing research protocols, but will be covered well into the overall workflow.

Data as input: systematic identification of relevant data gaps and potential synergies across case studies

The part of the data flow analysis is intended to identify joint data sets across the case studies and to connect case studies which possess data sources or produce indicators which are also relevant in other cases to the respective cases.

It also will identify joint methods, or procedures, to close data gaps. If several case studies are facing comparable challenges harmonized procedures may be developed by the respective participants.

Basic question in this regard are:

a. What indicators are needed for a successful implementation of these case studies?
b. For which of the necessary are project-external parameterizations already available?

c. For indicators that were not previously parameterized, - can supplementary methods or models be applied for individual case-specific parameterizations?

The lead of the data flow work package will try to facilitate the exchange between case studies. Filling in a template regarding data should be mandatory for each case study.

Data as input and/or output: identification of the role of scale, mismatch between scientific, political, administrative system borders

While the availability of socio-economic indicators at national and international level can be regarded as relatively good, impact chain assessments can also be implemented at regional or local level. As already mentioned in the literature review, in these cases the required regional or local indicators usually must be derived from available national information (downscaling). Under this point, we first ask case studies whether administrative borders and climate change related impact system borders match. If the administrative borders cover smaller regions compared to the region directly impacted by the original climate effect (for example in case of river catchments), climate change data may need to be downscaled.

If the data templates identify several case studies which downscale using different methods, a harmonized approach can be discussed. This can improve the transferability and comparability of results. However, the decision on any calculation in the case studies obviously remains with the case studies.

Data flow to Impact Chain analysis: weighting, normalization, identification

The main challenge will be to improve the Impact chain framework with the results of the case studies. Although the main strength of the Impact chain framework is its flexibility regarding qualitative and quantitative data, in the end it yields a quantitative result. The data flow work package tries to support the process from the case studies' results to the Impact Chain with templates and tools and create a platform for the discussion of the respective approaches.

Relevance of specific indicators for decision support

Here, we consider the effect that the success of co-production approaches can (among other things) be significantly promoted by adequately considering individual stakeholder-specific information needs. [10] In order to record the respective stakeholder needs on a case-by-case basis, we first ask the people working on the identified case studies to survey the stakeholders participating in the respective cases. We then systematically compile the relevant feedback to compile an overview of the specific indicators considered relevant by the stakeholders based on these findings. Finally, we methodically comment on this overview regarding the possibilities of providing appropriate indicators using dynamic input-output modelling.

[10] While representatives of a local administration, for example, may not be interested in the details of the macroeconomic developments assumed in an individual assessment, they will usually take note of selected details of socio-economic scenario elements (e.g. on projected developments of key industries of the municipality they represent) with specific interests. See also the separate thematic chapter "user interface and stakeholder involvement" in Aall (eds., 2020) for further relevant comments.

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Appendix: Data flows template

Step 1: Extracting an overview	**Lead question 1: Is this aspect of the data flow of relevance?**			
	Data as input: systematic identification of relevant data gaps and potential synergies across case studies	*Data as input and/or output: identification of the role of scale, mismatch between scientific, political, administrative system borders*	*Data flow to Impact Chain analysis: weighting, normalization, identification*	*Relevance of specific indicators for decision support*
Name of case study	Please explain	Please explain	Please explain	Please explain
	Lead question 2: Are you aware of data sets in other case studies which might be of use to you?			
Name of case study	Please explain			