DELIVERABLE 1.2

Knowledge exchange on future-oriented local climate adaptation scenario development in replicating regions

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Knowledge exchange on future-oriented local climate adaptation scenario development in replicating regions

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Abbreviations

CIC	Climate Impact Chains
CRA	Climate risk assessment
DEL	Deliverable
DEN	Design Entrepreneurship Institute
EU	European Union
FRR	Front-runner region
IPCC	International Panel on Climate Change
LAND4CLIMATE	Utilization of private land for mainstreaming nature-based solution in the systemic transformation towards a climate-resilient Europe
NbS	Nature-based solution
RCP	Representative Concentration Pathways
RR	Replicating region
RWTH Aachen	RWTH Aachen University
SSP	Shared Socioeconomic Pathways
TUDO	Technical University Dortmund
WP	Work Package

Executive Summary

This deliverable presents the material prepared for the knowledge exchange workshops on future-oriented local climate adaptation scenario development between the front-runner and replicating regions. The workshops were held between November and February 2024/2025 and aimed promote the exchange of knowledge on local climate adaptation scenarios. It provides a report on which topics were discussed and what knowledge was shared with the replicating regions. The replicating regions were presented an overview of the different scenarios in the context on climate adaptation, why they are used and how they can be used. How a scenario-based approach was incorporated into the climate risk assessment in LAND4CLIMATE and which steps can be undertaken to conduct a climate risk assessment that incorporates a scenario-based approach were also discussed.

Keywords

Stakeholder workshop, knowledge exchange, adaptation scenarios

1. Introduction

Climate change is causing global temperatures to rise, which is expected to increase the frequency of extreme hydrometeorological events in the future. These events include heatwaves, droughts, heavy rainfall, and flooding. To address these climate risks, it is crucial to strengthen climate resilience. Nature-based solutions (NbS) offer effective adaptation strategies, providing a range of benefits. The Land4Climate project aims to boost climate resilience across Europe by implementing NbS on private land within the continental biogeographical region. As part of this initiative, various NbS measures are being carried out on private land in six front-running regions (FRR) across Germany, Romania, Austria, Italy, Slovakia, and the Czech Republic. Each FRR is paired with a replicating region (RR) where the project's results are to be replicated and scaled up, with the ultimate goal of expanding these outcomes throughout Europe.

The experiences and insights gathered from the FRR will be shared with their respective RR to facilitate successful replication and upscaling of the project outcomes. To support this effort, several knowledge exchange events are planned within the project framework. The knowledge exchange workshops on future-oriented local climate adaptation scenario development were held between November and February 2024/2025, facilitating interactions between each front-running region and its respective replicating region.

The main focus of the workshops was to promote the exchange of knowledge on local climate adaptation scenarios. It was determined that the workshops should aim to provide the RRs with an overview on what scenarios are in the context of climate adaptation, why they are used and how they can be used. Since in LAND4CLIMATE scenarios were mainly used in the climate risk assessment (CRA) it was decided to demonstrate how a scenario-based approach was incorporated into the climate risk assessment. Additionally, the results of the front-runner regions climate risk assessments were used to show the comparison between the different modelled climate risk scenarios.

In this deliverable, the material prepared for the knowledge exchange workshops on future-oriented local climate adaptation scenario development between the front-runner and replicating regions is presented. Chapter two gives an overview of the scheduled workshops in work package (WP) one as well as the process of creating the workshop materials. Afterwards, chapter three gives a detailed insight into the input that was prepared. The report ends with conclusions summarizing the workshop results.

2. Workshop schedule and material

In WP one, five knowledge exchange workshops were programmed based on the Grand Agreement between the FRR and their RR. The five knowledge exchange workshops originally planned were combined into two workshops. The decision to combine the workshops was driven by several considerations. For one, the initial plan to hold five separate workshops placed an undue strain on the available capacity of the FRRs, who were already dealing with multiple concurrent demands. By combining the workshops, the risk of overburdening these resources was minimized, ensuring that the FRRs could better manage their responsibilities and maintain high-quality engagement. Moreover, there was a risk of fatigue among the RRs by demanding their participation in five workshops. The high number of workshops could have resulted in diminishing returns, with participants losing interest or becoming disengaged. By reducing the number of workshops, we helped to maintain a high level of participation and collaboration. In addition to that the implementation timeline of NbS required a more streamlined approach. Hosting fewer workshops allowed for better alignment with the broader project schedule, ensuring that critical phases were not delayed and that the necessary work could proceed without disruption. The first workshop addressed the CRA and the second NbS related topics. Figure 1 gives an overview of the two workshops and the associated DELs that describe the workshop results and highlights the assignment of DEL 1.2.

Climate Risk Assessment	**DEL 1.2** – Knowledge exchange on future-oriented local climate adaption scenario development for replicating regions
	DEL 1.4 – Knowledge exchange workshop on climate risk analysis for replicating regions
Nature-based Solutions	**DEL 1.6** – Knowledge exchange workshop on cause-effect relations and systemic effects for replicating regions
	DEL 1.8 – Knowledge exchange on stakeholder analysis in regard to cause-effect relations and potential systemic effects in replicating regions
	DEL 1.10 – Knowledge exchange workshop on stakeholder-led no-regret NbS measures identification and evaluation for replicating regions

Figure 1: Assignment of deliverables and knowledge exchange workshops in WP1 (own illustration)

Prior to the workshops, conference calls took place between TU Dortmund, RWTH Aachen, DEN, and the FRRs. During these calls, the objectives, content, and structure of the workshops were discussed. Consideration was given to various factors, including the type of organizations involved, the type of stakeholders present (including ratio of men and women), and the existing knowledge in the RRs. Following the preparation calls, TU Dortmund developed workshop material for the CRA workshop which was tailored based on feedback from the FRRs. In order to address the topic of Del 1.2, a Power Point presentation slide deck introducing a simplified step-by-step guid to conducting a CRA with a focus on the role of the scenario-based approach was created. Throughout the workshop preparation, if needed, partners from DEN supported the FRRs.

3. Knowledge exchange workshop – Input on scenario-based approaches

In order to inform the RRs about the use of scenarios in CRAs, a step-by-step guide on how to conduct a quantitative CRA was prepared. The guide was created based on the ISO 14091:2021 publication from 2021 that was also used for direction in conducting the climate risk assessments for LAND4CLIMATE. It offers a guideline on what to consider when conducting a CRA, including the selection of risks to assess, choosing indicators, gathering data, aggregating risk components, and interpreting the analysis results (see figure 2). Two principles that should be considered before starting a climate risk assessment are reproducibility and practical feasibility of the analysis. Reproducibility refers to the ability to obtain consistent results when using the same methodology and indicators across different studies or analyses. For example, if a hazard indicator like average heat wave days is calculated with the same satellite data and methods in multiple studies, and consistently yields similar results, it demonstrates strong reproducibility. A strong reproducibility in turn builds confidence in the results and their application for decision-making. Another important criterion that should be taken into account is practical feasibility. The practical feasibility concerns the viability of conducting the analysis, considering factors such as cost, time, capability and available resources at the institution due to carry out the CRA (ISO 14091:2021 2021).

Figure 2: Key steps in the creation of a CRA (own illustration)

Once the scope of application as well as objectives of the analysis have been discussed, the first step of a CRA is the decision of which risks the analysis should encompass. A good starting point are Climate Impact Chains (CIC), which serve as an analytical starting point for assessing overall risks in a region. CICs are structured to focus on the risks arising from a specific hazard (e.g., high temperatures leading to heat), while the exposure identifies the sector affected by that risk (e.g., human health, agriculture). Intermediate impacts typically involve biophysical elements, which are primarily linked to the hazard itself, and eventually contribute to the final human-related risk. Vulnerability factors capture non-climatic aspects that either amplify or reduce the risk for the exposed sector (Fritzsche et al. 2014; Zebisch et al. 2017). An example of a climate impact chain for the impact of heat on human health can be seen in figure 3.

Combined with local knowledge (e.g., problems with drought in agriculture have led to specific crop failures in the past in these areas; problems with heat in cities have led to specific types of health issues and fatalities in these local areas), climate impact chains can help to identify relevant hazards, exposures and vulnerabilities for a CRA. CIC can also be used for communication with different stakeholders since they illustrate clearly the connection between the hazard, exposure and vulnerability elements. Therefore, climate impact chains are a useful tool not only in the climate risk assessment phase, but on multiple occasions in the process of the development and implementation of nature-based solutions.

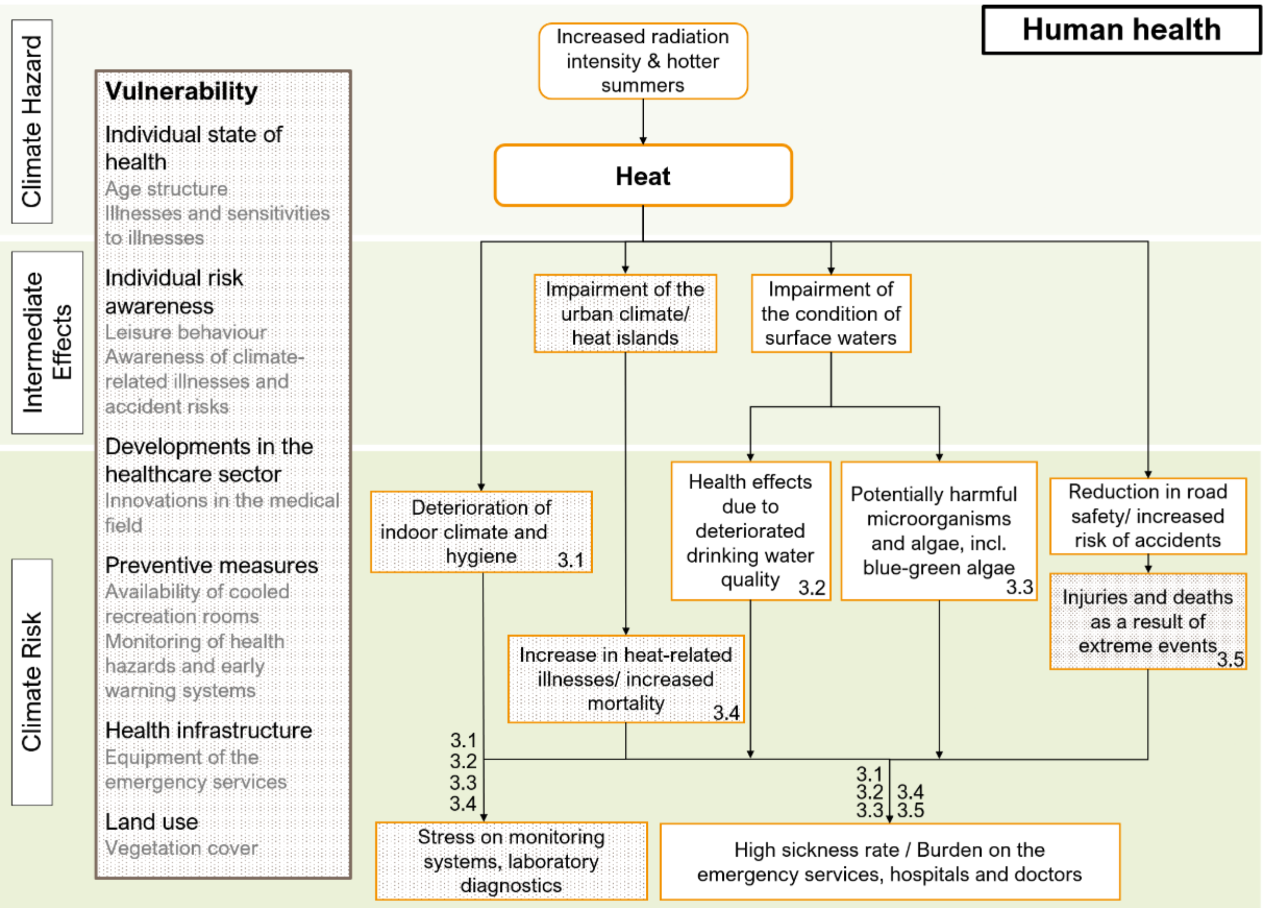

Figure 3: Example of a climate impact chain (own illustration)

3.1 Indicators and scenarios

After the relevant hazards, exposures and vulnerabilities are identified, indicators have to be found to make the different elements measurable. An indicator can be described as a variable that is quantitative, qualitative, or binary, which can be measured or described to offer an assessment on a specific component such as a hazard. To make the subject of indicators more tangible, table 1 shows exemplary indicators that can be used in a climate risk assessment. Criteria that should be considered in the process of choosing the right or most appropriate indicators are representativeness and temporal coverage (ISO 14091:2021 2021).

Representativeness refers to how well an indicator reflects the broader population or phenomenon it is intended to measure. For example, an indicator that measures the number of days when the temperature exceeds 40°C during the summer months would be representative because it reflects the actual heat exposure that residents experience, and it could be used to assess the associated health risks. However, if a heat hazard indicator only looks at average summer temperatures without accounting for extreme heat events, it might not fully represent the risk to vulnerable populations, such as the elderly or those with pre-existing health conditions. Indicators in risk assessments must be selected carefully to ensure they are reflective of the risk factors they are meant to measure, while also being accurate, clear, and relevant to the specific context.

Table 1: Examples for climate risk assessment indicators as shown in ISO 14091:2021

Risk component	Example for risk factor	Example for indicator
Hazard	Heat	Number of tropical nights or hot days
	Heavy rain	Percentage of flooded area with a water depth exceeding 10/50/100 cm
Exposure	Location of infrastructure	Distribution of transportation infrastructure in flood-prone areas
Vulnerability	Vulnerable population group	Percentage of the vulnerable population (e.g., young or elderly individuals)

The second criterion, temporal coverage, refers to the time period over which an indicator is measured or collected. It can help determine trends, patterns, and changes over time (e.g., climate dataset from 1950 - 2020). Since there is no certainty about future developments, neither in the forecasts of climate hazards nor in the forecasts relating to the level of exposure and vulnerability of a system, it is sensible to work with different scenarios in order to be able to map a range of possible future conditions. One way of doing so is to use the parallel modelling approach. It models possible future outcomes in a defined time frame, taking into account demographic and socio-economic changes and climate changes to project future impacts of climate change on society (see figure 4). The approach helps recipients of the modelling results to understand uncertainties associated with climate risks (Greiving et al. 2018).

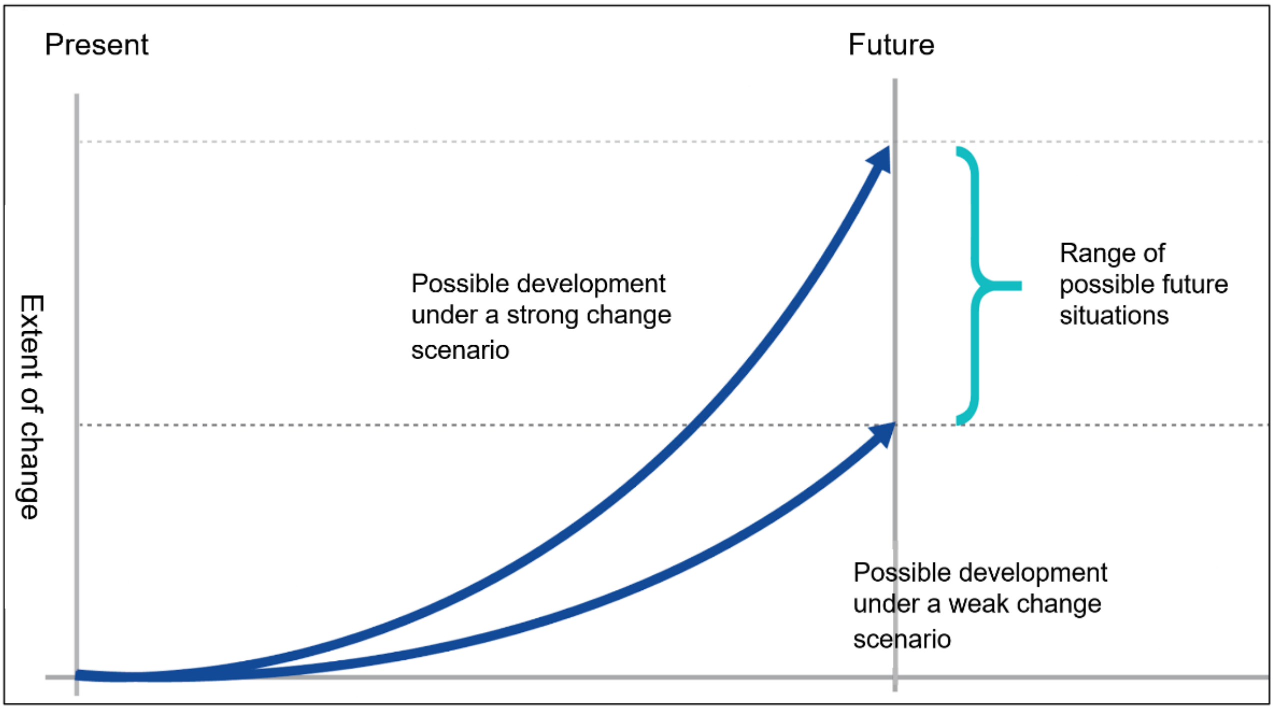

Figure 4: Parallel modelling approach (own illustration)

To give an example of what the application of the parallel modelling approach can look like, the indicators and scenarios considered in the LAND4CLIMATE climate risk assessment are presented in table 2. For the hazard of heavy rain, the scenarios of a rare event and an extreme event were chosen. To model a rare heavy rain event, it is common to use a 100a event which means a rainfall event, which is based on statistical analysis of historical rainfall data to determine a representative heavy rainfall event with a return period of 100 years. This rainfall event is then modelled for a period of time e.g., 60 minutes. For the extreme event the commonly used amount of rainfall that is modelled depends on the region. In parts of Germany, including the German front-runner region, the county of Euskirchen, a rainfall event with 90mm rainfall is commonly modelled for a duration of 60 minutes (LANUV 2023; s. DEL 1.3 Climate risk analysis - FRR).

Table 2: Indicators and their modelled scenarios in LAND4CLIMATE (own illustration)

	Scenario A	Scenario B	Scenario C
Heavy Rain *Indicator:* *Flooding Depth & Velocity*	**Rare event:** Heavy rainfall-runoff modelling 100a / 60min	**Extreme event:** Heavy rainfall-runoff modelling 90mm / 60min	-
Floods *Indicator:* *Flooding Depth & Velocity*	**Event with mean probability of occurrence:** Flood hazard map HQ100	**Event with low probability of occurrence:** Flood hazard map HQ500	-
Heat *Indicator:* *Number of hot days & tropical nights*	**Current situation:** Monitoring data 1991 - 2020	**Mid-21 Century - Moderate climate change:** RCP Scenario 4.5 - 2050	**Mid-21 Century - Strong climate change:** RCP Scenario 8.5 - 2050
Drought *Indicator:* *Standardized Precipitation Index (SPI)*	**Current situation:** Monitoring data 1991 - 2020	**Mid-21 Century - Moderate climate change:** RCP Scenario 4.5 - 2050	**Mid-21 Century - Strong climate change:** RCP Scenario 8.5 - 2050

In order to model the hazard of river flooding, events with a mean probability and a rare probability are commonly used scenarios. For an event with a mean probability, a HQ100, describing a river flooding event which is based on statistical analysis of historical river discharge data to determine a representative flooding event with a return period of 100 years, is commonly used. An event with a mean probability can be model with a HQ500 which means a river flooding event that is based on statistical analysis of historical river discharge data to determine a representative flooding event with a return period of 500 years (see DEL 1.1 Future-oriented local climate adaptation scenarios – FRR).

The hazards of heat and drought are commonly modelled with the help of RCP (Representative Concentration Pathways) or SSP (Shared Socioeconomic Pathways) scenarios. These scenarios are calculated by the IPCC and are used to model future scenarios. RCP scenarios are a set of greenhouse gas concentration trajectories that serve to explore potential climate futures. The current situation regarding heat and drought can be represented by monitoring data. The RCP 4.5 which assumes a moderate level of climate change mitigation efforts and some increase in global temperatures but stabilization of emissions by mid-century can be used as a possible future scenario. Another possible future scenario is the RCP 8.5 which is the high-emissions scenario representing a "business-as-usual" pathway where emissions continue to rise throughout the century. It is often referred to as the worst-case scenario and is associated with significant climate impacts. The socio-economic justifications for the RCP scenarios were presented in the 6th IPCC report, under the label of SSP scenarios. For this purpose, five main scenarios (SSP1 to SSP5) were developed and linked to existing or newly created RCP scenarios (IPCC 2023).

3.2 Collection of data and aggregation of indicators and risk components

Based on the selected indicators, data to model the chosen scenarios needs to be collected. Data availability can vary greatly between countries and regions and also depends on the available resources of the institution conducting the analysis. During the process of data collection three criteria should be considered. Firstly, the spatial coverage, which means the geographic area encompassed by a dataset or study such as a county, region etc. has to be considered. The second criterion is the spatial resolution which describes the smallest distinguishable unit in a dataset, e.g., 100m x 100m (ISO 14091:2021 2021). Depending on the aim of the analysis (e.g., identifying regional or municipal hotspots of climate risk) the data resolution has to be high enough to reach that aim while still being within the limitations of available resources. If the data is too high-resolution, meaning it's overly detailed (e.g., 1m x 1m resolution), it could become difficult to process.

After processing the data for each indicator, the evaluation of the results of each indicator should be discussed. Determining a precise threshold at which an indicator becomes critical is challenging. As a result, a broad evaluation is often the only way to make comparative assessments. Even when climate impacts can be modelled or estimated with proxy indicators, applying uniform quantitative standards, such as monetization, to all climate impacts is difficult. This is connected to the challenge of combining the various indicators into risk values. To gain an assessment for each hazard/vulnerability, the individual indicators can be aggregated. The aggregation can be achieved in different ways for example by normalising the indicator values which was done in the LAND4CLIMATE CRA (see DEL 1.1). Normalization of values means that values measured on different scales are adjusted to an abstract common scale. If, for example, for the hazard of heavy rain, the indicators flood depth and flow velocity are considered, the two values have to be combined into one total value for the heavy rain hazard (see figure 5). For this purpose, the values of the two indicators can be normalized on a dimensionless scale between 0 and 1. Value 1 corresponds to the maximum value of an indicator e.g., 4m flooding depth, value 0 is usually assigned to the value range 0, meaning in this case 0m flooding depth. Accordingly, a comparative rather than an absolute statement is made regarding the extent of hazard / vulnerability (Buth et al. 2017).

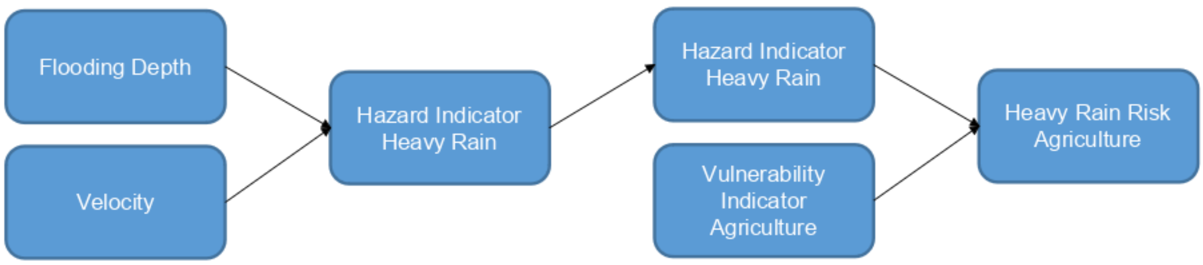

Figure 5: Example for the aggregation of risk components (own illustration)

By combining the overall assessments of climate hazards and vulnerabilities the climate risks for the different exposures/sectors can be determined. To achieve this, the normalized values of both hazards and vulnerabilities can be multiplied. This multiplication ensures that climate risks are only identified in areas where vulnerable assets are exposed to hazards. The resulting climate risk values can then be subjected to another min-max normalization to highlight spatial hotspots within the study area. However, the actual risk in these hotspot areas can still be moderate since the analysis makes a comparative rather than an absolute statement. Because of that the underlying values of the indicators before normalization should be preserved and displayed next to the normalized ones.

3.3 Interpretation and evaluation of findings

The results of a risk assessment should always be validated by local stakeholders. In the case of LAND4CLIMATE the results of the climate risk assessment were validated during a workshop, where partners from the front-runner regions reviewed and discussed the findings (see DEL 1.7 Report stakeholder workshops on cause-effect relations and potential systemic effects - FRR). They were tasked with noting and discussing any results that diverged from their expectations or experiences. Afterwards their findings were discussed with the partners that conducted the CRA and reasons for discrepancies were explored.

An important aspect that has to be considered when evaluating and interpreting the results of a CRA are existing climate adaptation and mitigation measures. The amount and effectiveness of existing or planned adaptation and mitigation strategies and measures can significantly reduce the risk or alter the severity of potential impacts. Through validating the results of the analysis with local stakeholders it can be investigated if results diverge from the stakeholders' expectations/ experiences because of existing measures/ strategies or other reasons.

A further aspect to take into consideration when interpreting the analysis results of a CRA is uncertainty. Climate models often include uncertainties, such as assumptions about future emissions scenarios or socio-economic factors. These uncertainties should be acknowledged and communicated, as they influence the robustness of the risk assessment. To reduce the uncertainty connected to the analysis, different future scenarios can be modelled (see chapter 3.1). However, it is ultimately impossible to eliminate all uncertainties when assessing the risks of climate change (ISO 14091: 2021 2021).

Another aspect worth reflection are interconnections. Climate risks are rarely isolated. Impacts on one sector (e.g., agriculture) can cascade to others (e.g., food security, health). A comprehensive understanding of these interconnections is essential for evaluating risks holistically. The climate impact chains presented in chapter two can help grasp these interconnections and thereby interpret the findings of the analysis.

To continue the work with the analysis results the identified climate risk hotspots should be discussed and prioritised to determine at which locations which adaptation measures should be strived for. Prioritisation should be undertaken by relevant decision-makers or by the project team in collaboration with decision-makers and should include consideration of potential adaptation actions and responsibilities. In LAND4CLIMATE this process took place in a workshop which was documentted in the associate deliverable 1.7 "Report stakeholder workshops on cause-effect relations and potential systemic effects - FR".

4. Conclusions

The knowledge exchange workshops on future-oriented local climate adaptation scenario development were successfully held in the six LAND4CLIMATE partner regions. The aim of the workshop, to presented an overview of the different scenarios in the context on climate adaptation, why they are used and how they can be used to the RRs, was fulfilled. It was demonstrated how a scenario-based approach was incorporated into the climate risk assessment in LAND4CLIMATE and which steps can be undertaken to conduct a climate risk assessment that incorporates a scenario-based approach.

The step-by-step guide for conducting quantitative CRA was created based on ISO 14091:2021, used in the LAND4CLIMATE project. The guide covers selecting risks, indicators, collecting data, and interpreting results, emphasizing reproducibility and practical feasibility. The process begins with selecting risks to assess, using climate impact chains to identify hazards, their impacts on sectors, and relevant vulnerabilities. Once hazards and vulnerabilities are identified, suitable indicators are chosen. Criteria for selecting indicators include representativeness and temporal coverage. To model future conditions, the parallel modelling approach is presented, incorporating various scenarios like the 100-year rainfall event, RCP scenarios (for heat and drought), and HQ100/HQ500 flood events, addressing uncertainty in projections. The data collection considers spatial coverage, spatial resolution and available resources. After processing, results are evaluated, with normalization used to aggregate indicator values on a common scale. The results are then combined to assess climate risks in exposed areas. Stakeholder validation is crucial to ensure results align with local expectations, helping identify discrepancies, including those due to existing adaptation or mitigation measures. Uncertainty in climate models should be acknowledged, as well as the interconnections between sectors, using CICs to capture these relationships. Finally, identified climate risk hotspots should be discussed and prioritized for adaptation actions, involving decision-makers in the process, as demonstrated in the LAND4CLIMATE project.

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