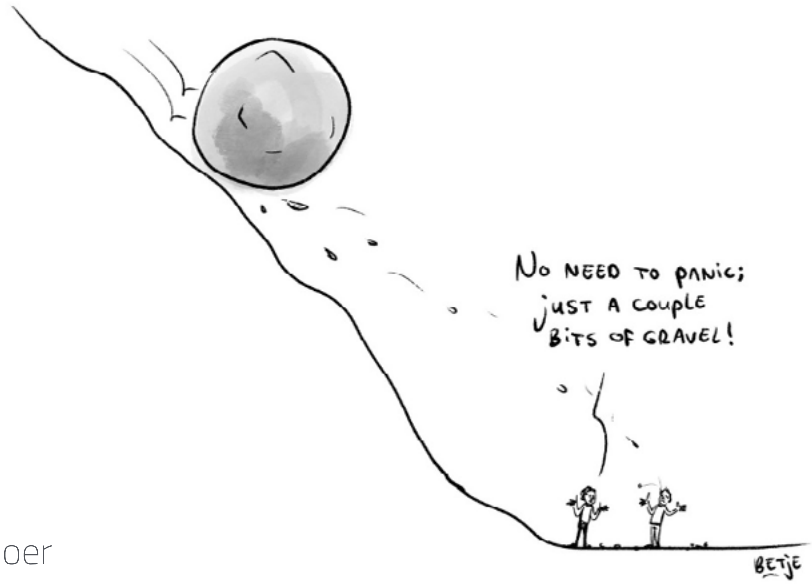
# Stress-testing systems

## A guide to the assessment of compound and cascading risk

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# Table of contents


## INTRODUCTION 4

1.1 Overview 4
Why did we write this guide? 5
What does this guide do? 5
How to use this guide 6
1.2 Why stress testing? 8

## APPROACH AND METHODOLOGY 11

2.1 Framing the problem and defining the system 11
2.2 Defining the stressors 15
2.3 Stress testing 18
2.4 Exploring solutions 21
2.5 Reflection and sense-making 24

## CONCLUSIONS 26

## Annex 1 – Examples: How stress testing has been used in PARATUS 27

## Annex 2 – Further reading and resources 29

## BIBLIOGRAPHY 30


# INTRODUCTION

## 1.1 Overview

Stress tests are a useful method for measuring a system's exposure to multiple threats. In stress tests, scenarios are crucial, however the ones frequently utilised usually fail to consider inner, more contextual and social elements. Consequently, adaptation opportunities may be lost and hazards may be underestimated. Stress testing reveals the vulnerabilities of specific systems (projects, plans, etc.) to different risk scenarios, both climatic and non-climatic. It helps connect risk information with scenario planning and adaptation options by examining a wide range of scenarios, which helps us deal with uncertainty in projections for various stressors (climate, environment, socioeconomic, etc.). As a result, the information leveraged by projects from the humanitarian and development sectors can strengthen this approach by identifying weak points in projects and the design of activities.


Stress testing has played a pivotal role in maintaining the resilience and stability of banking financial systems by assessing the impacts of 'what if' events on key financial measures. Its success has made it a valuable tool for creating policies that can withstand the shocks and challenges of the present day and years to come[1]. Used in the fields of engineering, banking, social protection and various other sectors, we now aim to translate stress testing principles into disaster risk management and humanitarian contexts.

> *"Stress testing is a process for assessing the ability of a system to maintain a certain level of functionality under unfavourable conditions, and understanding the consequences if this functionality is not maintained"[2] (CIWEM, 2023)*

1 European Parliament. Directorate General for Parliamentary Research Services., *Stress Testing to Promote the Resilience of EU Policies.*

2 Chartered Institution of Water and Environmental Management, 'Climate Change Stress Testing - Guidance'.

## Why did we write this guide?

PARATUS is a Horizon Europe-funded project that aims at increasing the preparedness of first and second responders in the face of multi-hazard events; and to reduce the risks related to impacts on various sectors that result from complex disasters. To achieve these objectives, the project will perform in-depth assessments of complex interactions between hazards and their resulting impacts in various sectors, as well as analyse the current risk situation and study how alternative future scenarios could change multi-hazard impact chains. In this context, stress testing approaches can support a more robust analysis of complex systems.

## What does this guide do?

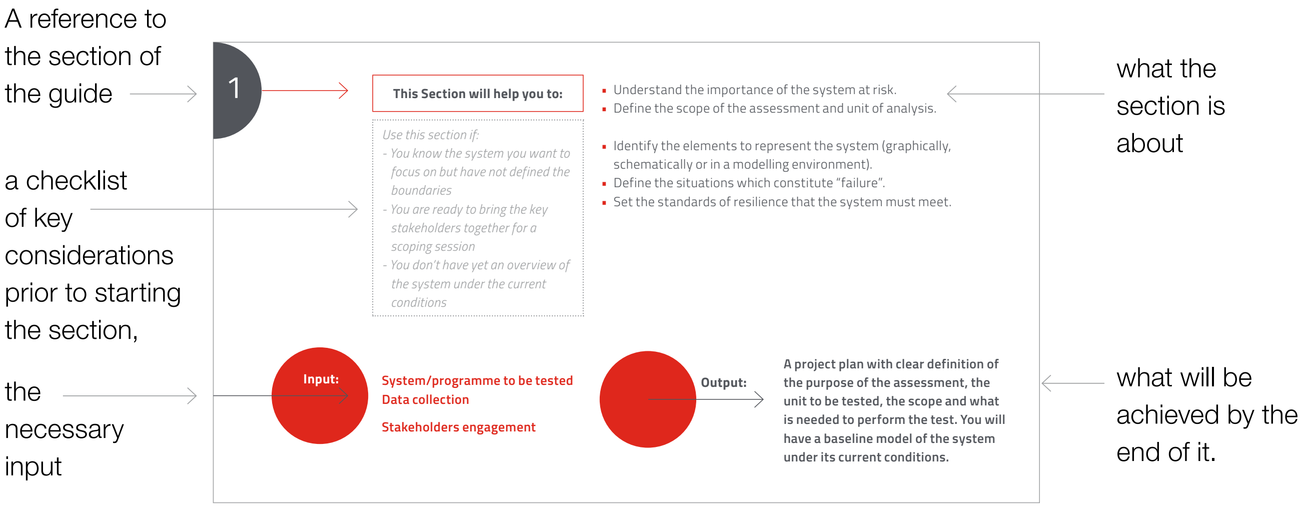
This stress testing guide is a collaborative exploration to define where and how potential impacts may put excessive stress on a system. In some cases, it can also be used to test adaptation options. This guide is intended as a bottom-up exploratory approach to identifying the vulnerabilities of specific systems to various possible stressors and scenarios. It is envisioned as a flexible and generally applicable guidance document. Hence, it is not prescriptive.

As a flexible tool, the implementation and format of the test can vary depending on the system or unit of analysis being tested (e.g. size, type and core functions of a system), what stressors are taken into consideration (e.g. climate, urbanisation, economic, shocks, etc.), whether adaptation options should be included, and what type of information and other resources are available. For example, in a data/resource-scarce context, the approach may explore basic scenarios (more rainfall, hotter temperatures), while in other contexts, much more advanced projections and historical impact information may be available to include in the test. The approach is based on available science on system shocks and stresses, aiming to support decision-makers in assessing where and how these might impact the system (outcome) and what could be feasible and acceptable actions to address these risks. This document provides non-technical guidance for a wide range of organisations and sectors that could benefit from stress testing, recognising multiple hazards in rural and urban settings.

# How to use this guide

The guide is divided into five parts. Depending on the level of development of the system's analysis, it can be picked up at any point in the different phases.

The boxes at the beginning of each section contain information on:

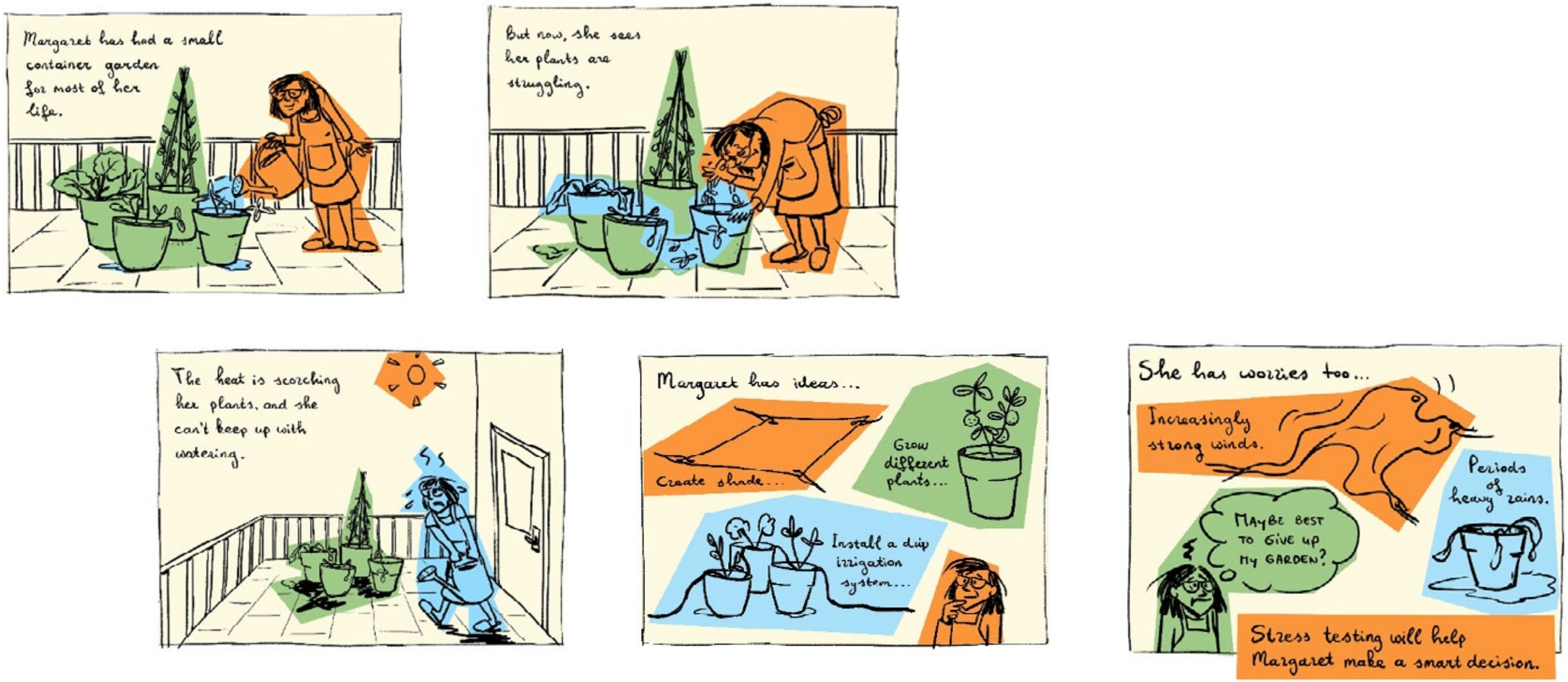



- Part One - focuses on framing the problem, bringing all the relevant stakeholders together and determining the scope and unit of analysis by developing an overview of the system under current conditions.
- Part Two - involves identifying the key stressors and developing a range of future scenarios.
- Part Three - uses the scenarios developed to evaluate the system's baseline against them to identify the stress points.
- Part Four - entails the development of adaptation solutions or resilience strategies and their assessment under stressed conditions.
- Part Five - is about validating the solutions, summarising and interpreting results, and socialising them in forms that can be useful for a range of stakeholders.

After conducting a stress test for a system, the user will gain critical insights into the system's resilience and capacity to withstand extreme and unexpected conditions. The iterative nature of the process will help reveal vulnerabilities that might not be apparent under normal operating conditions, allowing the user to identify potential points of failure and assess the overall stability of the system. By understanding how the system performs under stress, the user can make informed decisions about necessary improvements or contingency plans. Ultimately, stress testing equips the user with the knowledge to enhance the system's robustness, ensuring it can maintain functionality and recover quickly in the face of adverse events, thereby reducing the risk of significant disruptions.

**Robustness:** is the ability of a system to continue to operate correctly across a wide range of operational conditions in an uncertain or changing environment.[3]

**Resilience:** the capacity to prepare for, respond to, and recover from the impacts of hazardous climatic events while incurring minimal damage to societal wellbeing, the economy and the environment.[4] While there is no standard definition of resilience, it is an agenda shared by actors concerned with threats to development, whether financial, political, disaster, conflict or climate related.[5]




Comic by Betje

3 Moazami et al., 'Towards Climate Robust Buildings'.
4 Mehryar, 'What Is the Difference between Climate Change Adaptation and Resilience?'
5 Sturgess, 'What Is Resilience?'

## 1.2 Why stress testing?

Although increasingly unprecedented and uncertain, extreme events do not necessarily have to be unforeseen. Climate change is modifying the variability, frequency, intensity, and duration of extreme and unprecedented events (e.g. droughts, floods, heatwaves, etc.). Given that extremes are dynamic and interact directly and indirectly with other types of hazards and vulnerabilities in the system, a comprehensive understanding of potential cascading risks is necessary. Analysing these complex compounding and cascading risks is challenging and involves, in many cases, additional uncertainties. These include, for example, the validity and availability of data (especially in fragile contexts with limited infrastructure), subjectivity in assessing and quantifying different areas of risks, and uncertainties in how these different areas interact locally. Furthermore, as precise estimates hold significant uncertainty, the accurate likely future of these extremes is exceedingly varied.

Considering the intricate structure of the climate system, even slight variations can have a profound effect, making any small inaccuracy in climate models highly consequential. Additionally, as our knowledge of the climate system is still incomplete, models represent a simplified version of what we know and are, therefore, unrealistic to certain degrees.

Climate change affects multiple interconnected economic, social, environmental, and technological systems. Stress testing these interconnected systems can account for cascading effects and reveal feedback loops, which are otherwise difficult to visualise. By using stress testing, we can see how sensitive a system is to hypothetical adverse climate or environmental scenarios and measure its ability to cope. In this complex and uncertain context, there isn't a one-size-fits-all solution for dealing with the impacts. The best strategies will vary significantly depending on the future scenarios of a region. Stress testing helps by offering a flexible, bottom-up approach to identifying weaknesses in specific systems under various potential conditions.


Taking this into account, each stress test will depart from a different starting point, whether it's data collection or adaptation planning. Also, the availability of resources and capacities, as well as the unit of analysis, will inform the level of ambition to be adopted.

Stress testing can represent how components interact and their direct and/or indirect impacts on the systems vulnerability and/or robustness. It can help (urban) planners, policymakers, and stakeholders identify weaknesses in current systems and set out more robust long-term policies or operations so vulnerable populations and/or systems can absorb or become less exposed to shocks and hazards.

## *Compound and cascading risk*

Compound risk has been referred to as the risk associated with multiple hazard events that can occur simultaneously or successively. It can be combined with background conditions that amplify the overall impact or can result from the combination of average events.[6] It refers to the environmental domain or the co-occurrence of natural events, that may eventually be linked to different patterns of extreme impacts caused by climate change.

*"Compound risk is the interaction of simultaneous or successive multiple hazards or events that combine to produce extreme disasters capable of generating widespread losses." (IPCC, 2012)*

Cascading risk is associated mainly with the anthropogenic domain and the vulnerability component of risk. It points to a process of disaster escalation. As such, it is primarily concerned with the management of infrastructure and social networks. Compound and interacting dynamics can affect the amplitude of cascades[7]. For example, cascading effects among critical infrastructures can happen rapidly and over large areas due to the interdependent nature of risk. Such failures could cascade and cause a breakdown in multiple infrastructures with potentially catastrophic consequences.[8]

*"Cascading effects increase in progression over time and generate unexpected secondary events of strong impact. These tend to be as serious as the original event and contribute significantly to the overall duration of the disaster's effects. In cascading disasters, one or more secondary events can be identified and distinguished from the original source of disaster." (Pescaroli, Alexander, 2015)*


6 N Office for Disaster Risk Reduction, 'Scoping Study On Compound, Cascading And Systemic Risks In The Asia Pacific'.

7 Pescaroli and Alexander, 'Understanding Compound, Interconnected, Interacting and Cascading Risks: A Holistic Framework'.

8 Sulfikkar Ahamed et al., 'Unpacking Systemic, Cascading, and Compound Risks'.

| | Objective | Input: What is needed to do this activity? | Components | Output: What comes out of this? |
|---|---|---|---|---|
| 1 | Framing the problem and defining the system | Stakeholder engagement<br>System to be tested | ▪ Setting the scope and the boundaries of the system<br>▪ Understanding the importance of the system at risk<br>▪ Identifying the expertise needed to achieve results<br>▪ Representing the system in a model | A project plan<br>Baseline model/overview of the system under current conditions |
| 2 | Identifying the stressors | Baseline model | ▪ Identifying critical hazards<br>▪ Mapping historical stressors<br>▪ Constructing a range of future scenarios<br>▪ Selecting the scenarios to be used for the test<br>▪ Documenting how the scenarios were constructed | Scenarios with key shocks and stressors for the test |
| 3 | Stress testing | Scenarios to be used | ▪ Running future scenarios in the system model<br>▪ Identifying vulnerabilities and exposure<br>▪ Evaluating the frailties of the system: stress points<br>▪ Evaluating the scope of for change in the system<br>▪ Fisrt ideas of possible adaptation solutions | Baseline system's robustness: stress-points |
| 4 | Exporing solutions | Frailties of the unit analysis | ▪ Developing adaptation solutions<br>▪ Integrating the solutions into the model<br>▪ Assessing the resilience and potential outcomes under the stressed conditions<br>▪ Determining which solutions/strategies are more robust/resilient | Adaptation solutions/ resilience strategies<br>Adjustment and refinement of the model<br>Similar to step 3. Re-running the test as many times as necessary with various potential solutions |
| 5 | Reflection and sense-making | Adaptations solutions | ▪ Interpreting results<br>▪ Presenting to stakeholders<br>▪ Translating outputs into a form the is useable for decision-making processes<br>▪ Summarizing and communicating next-steps | Conclusion and recommendations |

*This is an exploratory exercise to identify where and how potential impacts may put excessive stress on a system. It is envisioned as a flexible and generally applicable guidance tool; you can select where to begin the process and choose the methodologies that best adapt to your context. By understanding how the system performs under stress, the user can make informed decisions about necessary improvements, enhancements, or contingency plans. Ultimately, stress testing equips the user with the knowledge to enhance the system's robustness, ensuring it can maintain functionality and recover quickly in the face of adverse events, thereby reducing the risk of significant disruptions.*

# APPROACH AND METHODOLOGY

## 2.1 Framing the problem and defining the system

PART 2 is divided into two steps. The first aims to define the scope of the system that will be stress tested, and its critical functions. The second seeks to identify the system's components and how they interact with risk to determine what constitutes failure.


1

**This Section will help you to:**

*Use this section if:*
*- You know the system you want to focus on but have not defined the boundaries*
*- You are ready to bring the key stakeholders together for a scoping session*
*- You don't have yet an overview of the system under the current conditions*

- Understand the importance of the system at risk.
- Define the scope of the assessment and unit of analysis.
- Identify the elements to represent the system (graphically, schematically or in a modelling environment).
- Define the situations which constitute "failure".
- Set the standards of resilience that the system must meet.

**Input:**

System/programme to be tested
Data collection
Stakeholders engagement

**Output:**

A project plan with clear definition of the purpose of the assessment, the unit to be tested, the scope and what is needed to perform the test. You will have a baseline model of the system under its current conditions.

## Framing the problem

The initial problem framing phase is critical in laying the foundation for a comprehensive analysis. This stage involves clearly defining the core problem, identifying the key challenges, and establishing the context in which these challenges exist. By framing the problem accurately, stakeholders can align their understanding and focus on the most relevant issues. This phase ensures that subsequent analysis is grounded in a thorough understanding of the problem and is aligned with realistic scenarios, setting the stage for informed decision-making.

**Input:**

**Framing the problem can start by bringing the key stakeholders together to define the critical functions and outcomes of the system of interest, along with its components and boundaries. Systems can be anything from a small project to more complex networks of actors responsible for delivering a particular service.**

*Keep in mind: even if you already have a defined unit of analysis and identified the importance of the system at risk. You can still use this section to have a clear Theory of Change (ToC). You can start by defining the long-term goal and then working backwards to map the steps needed to achieve it.*

*This section should frame the problem in terms of what needs to change, allowing for a structured approach to identifying the causes and solutions for the problem.*

The following questions can serve as a guide to develop this section:

- *Why is this test relevant to your work? How is it going to be used, or what will it inform?*
- *What is the importance of the system at risk? What is at stake, and what are the critical consequences of the unit of analysis failing?*
- *What are the boundaries of the unit under analysis (system, project, activity, etc.)? Are they physical, jurisdictional?*
- *Will the system be tested under a relevant time frame? For example, during the rainy season. What is the lifecycle of the system?*
- *Who is involved, and what is needed so that the system operates successfully? What expertise is needed to achieve results?*
- *What data is available? What are the assumptions being made? What factors are being included and excluded, and why?*
- *Who are the results going to be targeted to?*

This section might be approached with in-person or virtual interactive dialogue to engage stakeholders in a scoping session. It might consider using systems mapping (e.g. collating past work on impact chains and other systems models) and/or conducting a literature review to collate required documents.
Some methods which could be helpful in this process are the following:

### 1. Rich picture diagrams

They provide a freeform, visual way to explore and express the problem, capturing the relationships, stakeholders, and key issues in an intuitive diagram.

They can be used to identify a starting point and themes to be addressed in further explorations and can be useful for group dynamics, encouraging broad thinking and setting the scene.

**Level of effort:** ●○○

### 2. Stakeholder analysis

It identifies all individuals, groups, or organisations that have an interest in or are involved with the functioning of the system or would be affected by its failure. This helps clarify the different perspectives, priorities, and concerns that must be addressed.

It can be used to ensure that the problem is framed considering all relevant viewpoints and no key issues are overlooked.

**Level of effort:** ●○○

### 3. Literature review

A systematic method for identifying, evaluating, and synthesising existing research and information relevant to a specific problem.

It can be used to compile and analyse past studies, data, and theories to ensure the problem is grounded in existing knowledge and research.

**Level of effort:** ●●○

**Output:**

**This phase can be finalised by developing a widely accepted, feasible, and appropriate project plan to undertake the stress test and defining clear objectives.**

## Defining the system

**In the following step, it is essential to clearly represent the system, either graphically, schematically, or within a modelling environment. This visualisation enables stakeholders to better understand how different system components interact and respond to external risks, such as climate-related shocks. Once represented, the accuracy and usefulness of the model must be assessed, ensuring it effectively captures the complexities of the system and its responses.**

*Keep in mind that all diagramming and mapping at this point represents the current conditions of observed risk.*

*If you already have a model of the system to be tested, you can use this section to reflect on the accuracy of your model. Does it reflect the current conditions and interdependencies? Could any of the methodologies suggested in phase 1 and 2, add value to your model?*

It is then necessary to define the situations that would constitute system "failure," which may include the inability to maintain essential functions under stress. These failure points help establish the criteria for evaluating the system's performance and set the resilience standards the system must meet. For example, setting the boundaries for acceptable risk and defining the point when the system no longer meets its objectives due to the magnitude of external changes. This foundation ensures that any stress tests or scenarios can be reliably analysed and compared against well defined benchmarks for success or failure.

The following questions can serve as a guide to develop this part:

- ***What is the system's behaviour under current conditions?***
- ***What are the acceptable performance levels under the identified risk? What situations constitute "failure"?*** *For example: Determining resilience metrics and standards, also known as key performance indicators (KPIs), which specify acceptable performance levels under stress.*
- ***How does risk interact within the system?***
- ***Who has the power to make changes in the system to address risk?***
- ***Who is most impacted by the risk?***
- ***What information do we have about potential unprecedented extremes?***

Several methodologies can be used to define and represent a system in a way that enables effective stress testing, vulnerability analysis, and resilience planning. The choice of method(s) depends on the complexity of the system and the types of risks being assessed.

### 1. Systems mapping

They visually represent the relationships between different components within a system, including feedback loops, dependencies, and flows of resources or information; tools for thinking as well as communications.

They can be used to identify interdependencies and how different elements respond to external stressors. They can be used to show the structure of the system at a point in time.

**Level of effort:**

### 2. Flow diagrams

They provide a simplified, linear representation of processes, inputs, and outputs within a system. These charts show the sequence of interactions and highlight critical pathways.

They can be used to define how different system elements interact and where potential bottlenecks or failure points might occur. These can be the base for developing impact chains in the next phase. They can also serve as a tool to visualise the data flow essential for the system's operation.

**Level of effort:**

### 3. Causal loop diagrams (CLDs)

CLDs visualise cause and effect relationships within a system, identifying feedback loops (reinforcing or balancing). They can be the base of Dynamic System Models.

They can be used to understand how different factors influence each other over time, especially when dealing with dynamic systems like climate resilience; and to start discarding elements whose variations are not important. Having these at the beginning can be valuable to building a system model and being able to revert with different iterations of the test to identify the point in the system where it might be necessary to intervene.

**Level of effort:**

### 4. Dynamic systems modelling (DSM) (e.g. STELLA)

DSM involves creating models to simulate the behaviour of systems over time. It includes time-dependent variables and considers interactions between components in dynamic environments.

It can be used to test the performance of a system under different scenarios and stress conditions, predicting potential outcomes over time.

**Level of effort:**

**Output:** **Baseline model or overview of the system under the current conditions.**

**Options to build the system's model**

**1. Basic:**

Schematic Models (Excel, flow diagrams – storylines).

**2. Moderate:**

System Mapping Academy, System Mapping Toolkit. A guided process leads you through the different stages of your mapping, with pre-designed templates (in Miro).

Kumu, free software to build systems maps.

**3. Elaborate:**

System Dynamics Tools, includes a list of different software and open-source resources to building dynamic system models.

*Think back to Margaret's case from the beginning of this guide. What would happen if she applied the steps in this guide to her situation?*

*Will she start thinking about how many tomatoes would be the minimum yield?*

*Would she have to go to the supermarket to see what tomatoes cost and calculate if buying a tarp is worth it? How would she put all this information into a model?*

# 2.2 Defining the stressors


2

**This Section will help you to:**

*Use this section if:*
*- You have a baseline model*
*- You have enough data to start constructing scenarios*

- Identify critical hazards and risks in the study area using a compound risks approach.
- Map historical stressors to develop impact chains.
- Construct a range of future scenarios (Ideally 3-5) with different levels of risk and uncertainty.
- Select the scenarios to be used for the test

**Input:** **Baseline model**

**Output:** **You will have developed a range of scenarios from key shocks and stressors and selected the ones for the stress test. You will also have a document of how these scenarios were constructed and the choices behind each decision.**

## Defining the stressors

The first step in this section is to identify critical hazards and risks present in the study area using a compound risks approach to comprehensively examine how these risks interact with the system, highlighting areas of weakness and potential points of failure.

**Input:**

**This involves developing impact chains based on past events, such as extreme weather, infrastructure failure, or socioeconomic shocks, to understand how these risks interact.**

Once historical stressors are mapped, the focus can shift to constructing a range of future scenarios, typically 3-5, representing different levels of risk and uncertainty under climate change and sociopolitical changes (including low probability but high-impact events).

The specific future climate scenarios to be used in the stress test are selected, with each scenario's potential shocks and their relevance to the system thoroughly described. This ensures a robust understanding of how the system might respond to various future conditions, guiding the development of effective adaptation strategies. Simultaneously, storyline development creates detailed, plausible stories that explore how various factors might evolve under different conditions. These qualitative narratives serve as the basis for stress testing and risk assessment, allowing for examining potential outcomes and identifying possible solutions.

The following questions can serve as a guide to develop this section:

- *What are the key shocks and stressors against which the system must be resilient /robust?*
- *What are the compound risks in the study area? What are the critical nodes (e.g. power grids, transport infrastructure, etc.) that, if they fail, could cascade into more extensive failures across the system?*
- *What are the different risk levels for each scenario?*
  *What does risk look like in a low-probability/high-impact scenario or high-probability/high-impact?*
- *What historical extreme events has the system been most vulnerable to?*
- *How will the scenarios be selected? What are the uncertainties?*

There is a range of methodologies which can be used for this stage:

### 1. City-wide risk analysis

It looks at the likelihood and potential impact of a range of risks, evaluating both natural and human-induced hazards. It involves collaboration with various city stakeholders, including government agencies, businesses, community groups, and residents, to ensure a holistic understanding of the risks.

It can be used to provide a detailed understanding by identifying, assessing, and prioritising the various risks the system faces and the capacities within it.

**Level of effort:** ●●● (3 of 3)

### 2. Impact chains

They help to identify the pathways through which risks materialise and propagate, making it easier to understand the connections between different factors and how they lead to tangible outcomes.[9]

They can be used to visually and analytically map the cause and effect relationships between climate hazards, vulnerabilities, and impacts on a specific system, region, or sector. They can be developed based on past events as historical points of reference and can be combined with storylines for future scenarios.

**Level of effort:** ●●○ (2 of 3)

### 3. Multi-hazard risk analysis

It considers how different hazards might interact, overlap, or amplify risks, evaluating the combined effects in a specific area, time, and magnitude, as well as the description of their interaction and the interpretation of their compounding outcomes on a target group.

They can be used to assess the nature and extent of disaster risk by analysing potential hazards and evaluating existing conditions of exposure and vulnerability that together could harm people, property, services, livelihoods and the environment on which they depend.[10] In a multi-hazard framework, both interrelationships at hazard and vulnerability levels are considered.[11]

**Level of effort:** ●●● (3 of 3)

### 4. Storylines

They aim to help translate uncertain climate projections into more tangible plausible (observed and modelled evidence) outcomes or scenarios as a way to understand risk complexity.[12] Storylines approach can draw on both physical climate storylines and scenario storylines.[13]

They can spark discussion and thought processes, adding nuance, structure, and meaning to evidence-based yet hypothetical scenarios. Drawing from previous analyses of past events and future-based projections, they can represent various scenarios that may emerge.

**Level of effort:** ●●○ (2 of 3)

**Output:**

**A set of scenarios developed from key shocks and stressors and a selection of the ones to be used for the stress test. This section can be finalised by documenting how the scenarios were constructed, the logic and thinking behind each choice, and the decision as to why the final ones were selected for the test.**

9 Menk et al., 'Climate Change Impact Chains'.

10 UNDRR, 'Report of the Open-Ended Intergovernmental Expert Working Group on Indicators and Terminology Relating to Disaster Risk Reduction'.

11 Hochrainer-Stigler et al., 'Toward a Framework for Systemic Multi-Hazard and Multi-Risk Assessment and Management'.

12 Sillmann et al., 'Event-Based Storylines to Address Climate Risk'.

13 Jack et al., 'Climate Risk Storylines: Navigating the Uncertainties of Climate Change. Guidelines for Humanitarian Practitioners'.

**Example 1:** Critical infrastructure resilience assessment – using UNDRR to identify cascading risk scenarios.

**Unit of analysis:**

National level infrastructure resilience across seven critical sectors, oil and gas, energy, transportation, telecommunications, water and wastewater, education, and health.

**Objective:**

To assess the capacity of disaster risk management systems to mitigate, respond to, and recover from natural disasters (e.g. earthquakes, floods, hurricanes) under increasingly extreme and unpredictable conditions.

**Methodology:**

Participants were tasked with scoring the potential of hazards to disrupt critical infrastructure functions including the distribution of electricity and the transportation of people and goods. The exercise also assessed the impact of these disruptions on the country's economy and society.

**Example 2:** Humanitarian project stress test in Burkina Faso.

**Unit of analysis:**

Food production project in rural Burkina Faso, implemented by the ICRC.

**Objective:**

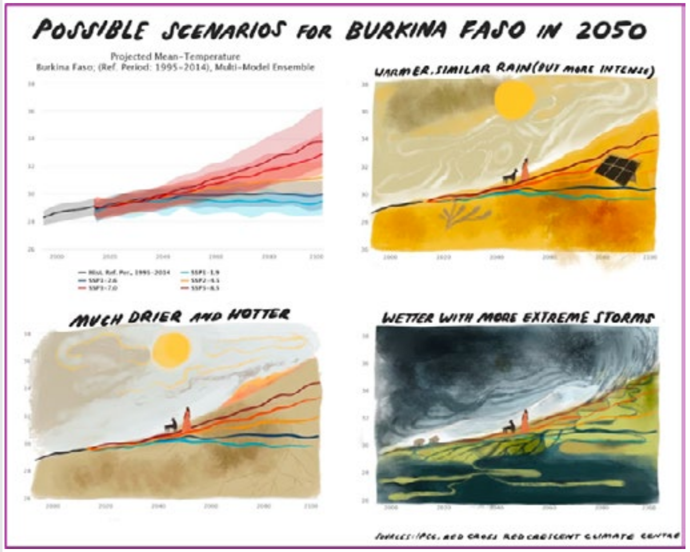
Test whether the initiated project is robust to various possible climate scenarios in the future (by 2050).

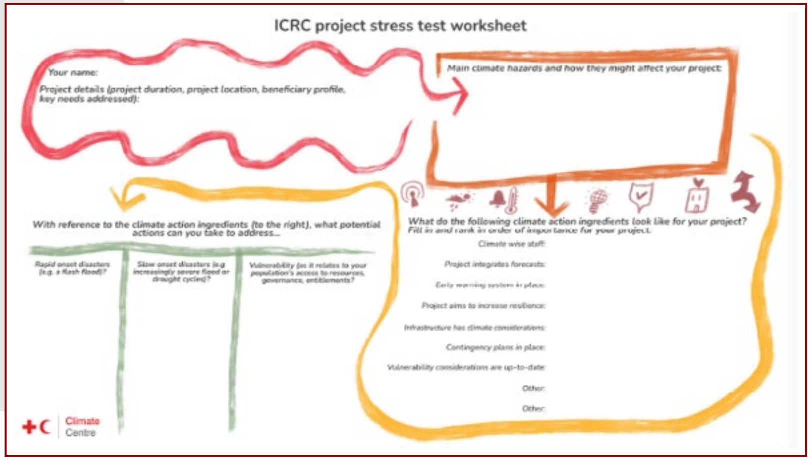
**Methodology:**

A workshop helped staff explore the available projections in a storylines narratives format, focusing on the implications for the project itself. The potential climate change scenarios were communicated through creative outputs (e.g. GIF, overlay image).

**Output:**

Workshop, visual materials, filled worksheet (see below).



## 2.3 Stress testing

3

**This Section will help you to:**

*Use this section if:*
*- You have identified the risks and stressors*
*- You have chosen the scenarios to be used for the stress test*

- Evaluating the system baseline against the different future climate scenarios
- Identifying exposure and vulnerabilities
- Identifying critical stress points to the shocks and stressors in the defined timeframes
- Evaluating the frailties and robustness of the system
- Scoping the adaptive capacity or space for change in the system
- Coming up with the first ideas of possible adaptation solutions

**Input:**

**Scenarios with key shocks and stressors for the test, including worst case scenario.**

**Output:**

**A critical evaluation of the resilience of the baseline (current conditions) of the system against each scenario. Identifying the stress points will allow for first ideas of adaptation solutions to emerge.**

**Input:**

**The process can begin by evaluating the system's baseline against the selected future scenarios.**

**Each scenario examines which parts of the system are most at risk from the identified hazards. Once the most affected and vulnerable areas are identified, it's important to set priorities. This can be done by ranking the different parts of the system based on how likely they are to fail and how big the impact would be.**

Next, a detailed analysis of the most critical and vulnerable areas is done. This helps to understand which factors or inputs have the most significant effect on the system's outcomes.

This process identifies the system's weak spots, or "stress points," where it could break down or fail. These stress points might be high-risk areas, or particular steps in a process that are likely to fail under extreme conditions, such as those caused by climate change or other evolving factors.

To identify stress points within a system, it's essential to focus on parts that are especially sensitive to change, as these are often the most vulnerable. Areas without strong backup systems or resilience mechanisms are more likely to struggle during disruptions, indicating stress points. It's also important to check how quickly the system recovers from stress, as this offers insight into the system's robustness. If recovery is slow or problems persist for a long time, these areas need extra attention.

Another important step is to look at how well the system can respond to risks. This means assessing its ability to adapt when faced with challenges and the scope for change or improvement within the system. Resilience is often measured by how well the system performs before and after an event, as well as how quickly it recovers.[14] Together, these elements provide a detailed understanding of the system's weak spots. The outcomes at this point should reveal whether additional data is required to refine the scenarios or improve the accuracy of the model being used.

Finally, the initial identification of adaptation solutions can begin by focusing on the most vulnerable areas and those with the best chances of improvement. These solutions should aim to strengthen the system so it can handle future challenges and disruptions more effectively.

*Keep in mind: When simulating each scenario, it is crucial to go through the process with a cascading or compound effects approach where one risk or failure could trigger additional failures across the system.*

*Drawing from the impact chains developed in previous steps, reflecting on major past events also helps refine this analysis by asking what might have occurred if variables like timing or location were different. This helps attribute consequences to impacts in case of indirect or delayed impacts.*

The following questions can serve as a guide to develop this section:

- *Which areas/systems/parts of the unit of analysis are most vulnerable and/or exposed to hazards?*
- *What are the frailties of the system?*
  - *Where are the stress points?*
  - *What is the correlation between the system failure threshold of this test compared to the one identified for the baseline? Where and how are the defined KPIs being compromised?*
  - *What is the robustness of the system in the different scenarios? Does the system have adequate redundancies or backups?*
  - *What is the level of adaptive capacity? How long does the system take to recover from failure? What is the capacity to mobilise needed resources and services under emergency conditions?*
- *What is the scope for change in the system?*
- *Is there any further data needed?*

Different methods can be used in the stress test process, each offering valuable insights. These include hands-on approaches like simulation exercises or multi-criteria evaluations, as well as remote or mixed methods like using scenario modelling. A combined approach can be particularly effective, mixing in-person workshops to gather ideas and review model results, while improving and expanding the analysis as you go.

**Key performance indicators (KPIs)** are used to measure performance or development based on a particular organisation's goals and objectives. They are relevant across different departments and, therefore, useful for strategic decision-making as they only track information pertinent to the organisation's strategic choices.

A range of methodologies can be used to develop a stress test:

### 1. Vulnerability and Capacity Assessment (VCA)

It can be used to identify which community members are most exposed, what coping capacities are available, and what initiatives can be undertaken to strengthen coping capacities and reduce risks.

**Level of effort:** ●●○

### 2. Simulation exercises: workshops and stakeholder consultations

It involves creating real-time simulations of how each scenario unfolds to observe how systems respond to shocks. Stakeholders can be engaged in these exercises to test the robustness of infrastructure, governance, and social systems under pressure by contributing with their lived experience.

These are useful for gathering local expertise and validating findings. Participants reflect on model outputs, share insights, and help identify potential risks that models may overlook. These sessions are suggested as an iterative process to help refine and expand the stress test scenarios and adaptation solutions.

**Level of effort:** ●●○

### 3. Dynamic systems modelling (DSM)

It uses the baseline of the system model built previously in the chosen modelling environment to run through the range of scenarios and assess how the system responds to the various stressors within the defined timeframes.

**Level of effort:** ●●●

**Output:**

**This section can be finalised by documenting a detailed outcome of the model for each of the different scenarios in terms of resilience/robustness and their corresponding frailties.**

14 Argyroudis et al., 'Resilience Assessment Framework for Critical Infrastructure in a Multi-Hazard Environment'.

**Example:** Policy stress test: social protection stress testing

**Unit of analysis:**

Social protection programmes.

**Objective:**

Gauging national crisis preparedness. To evaluate the ability of social protection systems (e.g. welfare, unemployment benefits, or pensions) to respond effectively to extreme conditions such as economic crises, natural disasters, or pandemics. Identification of potential gaps/negative outcomes/failure of the systems under various (compounding) scenarios.

**Methodology:**

1. Development of extreme scenarios (e.g. economic, social and disaster-related scenarios).
2. Using economic models or participatory approaches to test the impact of these scenarios on systems, including variables such as influence on demand, funding shortage, government budget and ability to deliver. The scenarios were combined to simulate compound/cascading/systemic risk situations.
3. Evaluation of sensitivity: looking at which variable changes and scenario combinations had the most impact and under what conditions the system maintained satisfactory performance.

**Criteria tested:**

The tool assesses if a country can respond to just some shocks but not well, to some shocks well, to all shocks well, etc. showing a type of gradation from 0 to all to illustrate areas for improvement across a spectrum.

**Output:**

Policy recommendations and contingency planning.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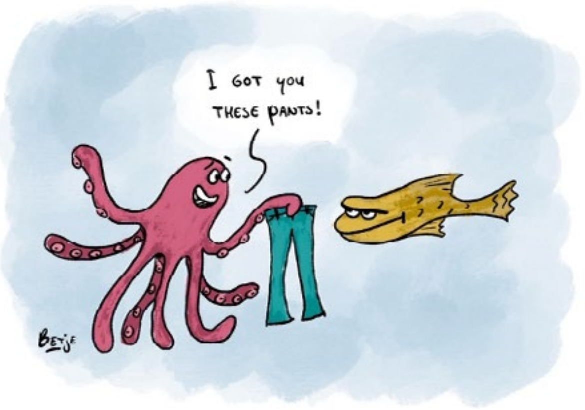
## 2.4 Exploring solutions




4

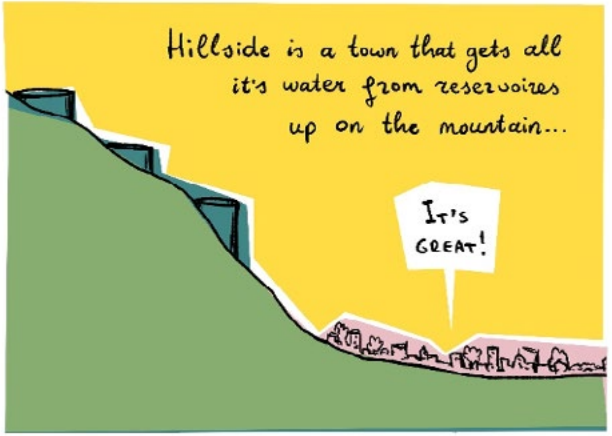
**This Section will help you to:**

- Develop adaptation solutions, and translate its components into the modelling environment
- Assess the resilience and potential outcomes for each solution under the stressed conditions
- Determine which solutions/strategies are more robust / resilient

*Use this section if:*
*- You have stress tested different scenarios in terms of resilience/ robustness*
*- You have identified stress points and frailties in the system*

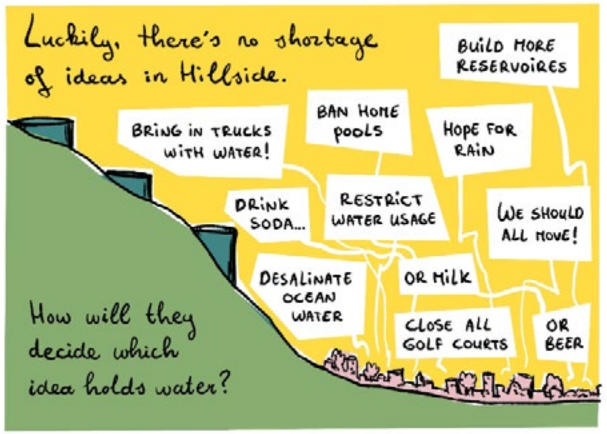
**Input:** Detailed outcomes from the stress test for each of the different scenarios

**Output:** This stage of the process will produce two different sets of adaptation solutions. The ones created as a result of the stress test and the ones that will be modified after they are stress tested.


Hillside is a town that gets all it's water from reservoires up on the mountain...
IT'S GREAT!


... except when it's not.
IT HARDLY RAINED THIS WINTER. WE'RE IN TROUBLE!
NO, WE'RE IN DEEP TROUBLE.


THERE'S A HEATWAVE COMING OUR WAY!
WE'LL NEED WATER TO EXTINGUISH BRUSHFIRES...
... AS WELL AS DRINKING WATER FOR CITIZENS AND FIRST RESPONDERS ...
... AND TO IRRIGATE OUR CROPS.


Luckily, there's no shortage of ideas in Hillside.
BUILD MORE RESERVOIRES
BRING IN TRUCKS WITH WATER!
BAN HOME POOLS
HOPE FOR RAIN
DRINK SODA...
RESTRICT WATER USAGE
WE SHOULD ALL MOVE!
DESALINATE OCEAN WATER
OR MILK
CLOSE ALL GOLF COURTS
OR BEER
How will they decide which idea holds water?

## Exploring solutions

The resulting frailties and entry points from the stress tests carried out for each scenario can serve as the basis for developing adaptation solutions. This process involves re-running the stress tests with various iterations of the proposed solutions to see how each one performs under each scenario. This iterative approach identifies the most resilient and adaptable solutions, ensuring the system can improve its coping capacity and account for future uncertainties.

**Input:**

**Frailties or stress points of the unit of analysis under the stressed conditions.**

This stage is divided into two parts. Firstly, it focuses on developing a range of adaptation solutions. To define the type of adaptations or interventions, it's important to consider the scale of application under different levels of ambition. For example;

**Low level:** Addressing a single hazard within a single part of the system.

**Moderate level:** Applying a single-hazard approach to the whole system.

**High level:** Tackling multiple hazards either within a single component of the system or across the entire system.

Once the types of solutions or strategies have been defined, the components from each intervention are translated into the model and stress tested against the previously utilised scenarios and stressed conditions. By evaluating the resilience and potential outcomes of these solutions under stress, we can compare their effectiveness against baseline scenarios. Ultimately, the goal is to identify adaptation strategies that are most robust and capable of withstanding future changes.

Determining which strategies are more robust to changes involves identifying those that perform well across a wide range of plausible futures and are adaptable enough to evolve with new information.

The following questions can serve as a guide to develop this section:

- *Does the solution respond to the hazards and stress points identified in the stress test?*
- *What is the scale of application or level of ambition?*
- *What part of the system does the adaptation solution or combination of them focus on? Is it a physical, social or economic element? Does it intervene in one or several parts or the whole unit of analysis?*
- *Are there any trade-offs resulting from implementing this solution/strategy?*
- *What is the level of ambition for this solution/strategy?*
  - *Is it meant to reduce the impact entirely? For example, is it meant to ensure critical infrastructure remains operational under the extreme chosen scenario?*
  - *Or does it aim to reduce the impact of a single hazard? For example, reduce the direct effects of floods by 60 per cent.*
- *Is the solution robust across multiple stress scenarios?*

15 Nautiyal and Goel, 'Chapter 3 - Sustainability Assessment'.

16 Beiderbeck et al., 'Preparing, Conducting, and Analyzing Delphi Surveys'.

17 Boon et al., 'Defining Successful Climate Services for Adaptation with Experts'.

The discussion of each solution's advantages and disadvantages deepens the understanding of how each approach could achieve the goal. This also brings in important factors that might not be captured in the model.

The methodologies used for this stage are the same as those used for the stress test. Additionally, the following methods can be valuable solution appraisal tools.

### 1. Multi-criteria decision analysis (MCDA)

This method ranks the performance of different solutions against a set of pre-defined criteria such as resilience, flexibility, and cost-effectiveness. It is a form of appraisal that measures variables such as material costs, time savings and project sustainability, as well as the social, environmental and monetary impacts.

It can be applied to areas where methodologies based on a single criterion are found ineffective and important social and environmental impacts cannot be expressed in terms of monetary values. Depending on the selected method, each criterion can be evaluated qualitatively or quantitatively.[15]

**Level of effort:** ●●○

### 2. SWOT and cost-benefit analysis (mixed method)

It is an analytical method used to understand key factors: strengths, weaknesses, opportunities, and threats and involves stating the objective of the project/solution and identifying the internal and external factors that are either supportive or unfavourable to achieving that objective.

It can be used to match the solution to the overall goal and level of ambition by analysing it in the environment in which it operates. The 'SWOT' is only a data capture exercise, the analysis follows later. It can be complemented with a cost-benefit analysis.

**Level of effort:** ●●○

### 3. Delphi method

It is a structured, iterative approach used to gather and refine expert opinions on a specific topic, typically for decision-making, forecasting, or problem-solving.[16]

It can be used to leverage expert knowledge systematically, providing a rigorous framework for navigating uncertainty and complexity in decision-making.[17]

**Level of effort:** ●●●

**Output:**

**This point in the process is iterative. Solutions can be stress tested as necessary, as each iteration will inform adjustment and refinement of the model, resulting in a series of validated adaptation solutions or resilience strategies.**

## 2.5 Reflection and sense-making


5

**This Section will help you to:**

*Use this section if:*
*- You have a set of adaptation solutions*
*- You have comparative metrics from the tested solutions*
*- You are ready to transform data into actions.*

- Interpret results
- Map the outputs from the scenarios into a form that is usable for decision-making processes
- Prepare to present to stakeholders and hold a sense-making workshop of the solutions/ strategy
- Communicating next steps

**Input:** Adaptation solutions or strategy

**Output:** Conclusions and recommendations

## Reflection and sense-making

Once the stress testing process has been completed, the next steps involve interpreting the results, preparing them for decision-making, engaging stakeholders in a sense-making process, and defining the way forward.

**Input:**

**The selected set of adaptation solutions, single solution or strategy.**

This phase can start by summarising the system's performance under each scenario. Identify key trends and patterns, focusing on the areas, components, or groups most vulnerable to the hazards. Pinpoint the critical stress points where the system is most likely to fail and consider any unexpected outcomes or uncertainties. This analysis provides a foundation for presenting the prioritised adaptation solutions and the change in resilience/robustness in the system due to these interventions. Understanding the impacts of these strategies is key, as is ensuring the quality and comparability of stress test results to provide reliable guidance for future adaptation efforts.

Interpreting the results allows for a clearer understanding of potential outcomes while also identifying physical, political, or informational barriers that may impede the implementation of strategies.

To effectively support decision-making processes, it is crucial to translate the results into clear, actionable formats that decision-makers can easily understand and use. Tools like charts, risk matrices, or decision trees effectively summarise findings. Interactive aids, such as GIS maps or dashboards, can help visualise complex scientific data and imagine unprecedented events and their impacts in specific contexts and make it more accessible.

These outputs could be linked to existing policies, plans, or stakeholders' organisational goals to show their relevance and facilitate integration into ongoing processes.

The following questions can serve as a guide to develop this section:

- *What are the barriers to implementing these strategies (physical, political, informational, etc.)?*
- *Does this make sense for the context? Are there any unexpected outcomes or uncertainties in the results that need further exploration?*
- *To what extent is the problem being solved?*
- *Will solutions be prioritised? If so, how?*
- *Are there interactive or visual aids (e.g., GIS maps, dashboards) that could help stakeholders understand the data better?*
- *How can the results be linked to existing policies, plans, or objectives to make them actionable?*
- *How can the results be simplified and presented to align with decision-makers' needs?*
- *Is there enough evidence for decision-making?*

Some methods which could be helpful in this process are the following:

### 1. Visualisations

Visual communication materials (videos, cartoons, illustrations, infographics, dashboards, scenario maps, etc.).

**Level of effort:** ●●○

### 2. A reflection and sense-making workshop

Allows for collaborative review and discussion. To ensure stakeholder engagement in evaluating the adaptation measures, a mix of formats, such as visual summaries, case studies, or interactive models can be used to present the results in an engaging and understandable way.

Use it to facilitate open dialogue to gather feedback, refine strategies, and build consensus on the path forward.

**Level of effort:** ●○○

### 3. Gap analysis

It identifies the gap between the current state of the system and the desired future state or objectives. It assesses where performance, policy, or capacity falls short.

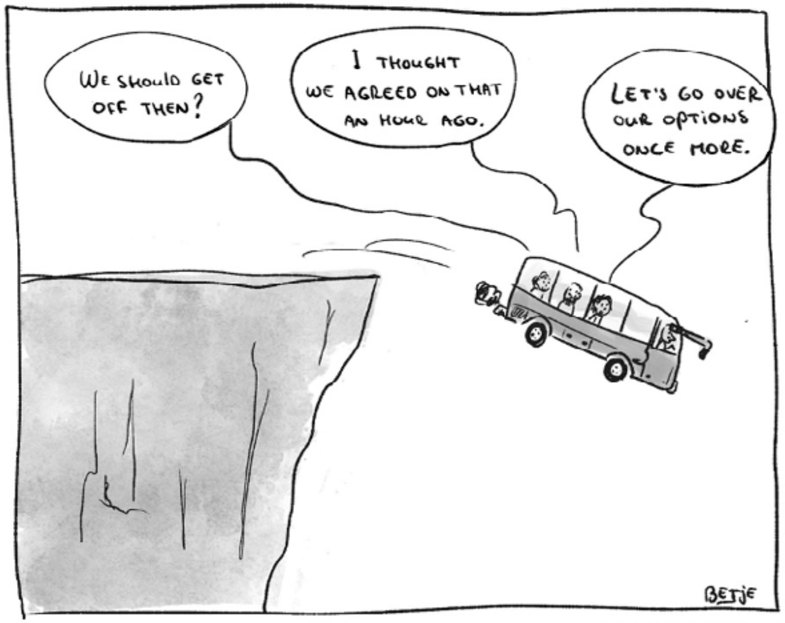
It can help to highlight the specific areas that need improvement or intervention. Gaps in structure, data, and stakeholder perspectives should be addressed to help define the next steps.

**Level of effort:** ●●○

**Output:** **Conclusions and recommendations with next steps.**

# CONCLUSIONS

Stress testing offers a valuable approach to examining complex systems by focusing on specific aspects rather than attempting to simulate the entire system. While it doesn't provide a complete view, it allows us to identify potential ripple effects within the system that could lead to significant consequences. The true value lies in the process itself, working within the system's context, immersing users in its intricacies, and exploring potential courses of action. Providing information in actionable and usable forms remains a key challenge for researchers and practitioners.[20] As we face an urgent need to adapt at scale, robustness testing becomes an accessible and efficient tool to evaluate adaptation options in a given context.

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18 Lemos, Kirchhoff, and Ramprasad, 'Narrowing the Climate Information Usability Gap'.

# Annex 1 – Examples: How stress testing has been used in PARATUS

## 1. Istanbul

The mega city of Istanbul is exploring possible compound and cascading effects at the interface of extreme weather and climate and a possible intensive earthquake. In order to understand the possible scenarios in Istanbul, the PARATUS team facilitated a workshop with the City Administration to explore different scenarios, and how this would affect the efforts of first responders.

The workshop was organized and moderated by a team of staff from the Istanbul Metropolitan Municipality (IMM) and Istanbul Technical University (ITU) in the Avcilar district of Istanbul. A total of 87 participants came from both the IMM and the Avcilar municipality, local NGOs. Heads of neighbourhoods (muhtar) were also present.

The inputs from the two sessions of group work included six earthquake scenarios based on different times of the day and weather conditions (with a climate change emphasis). Each table brought something new to the discussion and there was wide appreciation for the compounding risks approach.

In **Session 1**, each group discussed and developed narrative and spatial representations or diagrams to answer below questions:

- *What are the prominent problem areas, sectors or systems in the first 1-2 hours of the earthquake?*
- *What kind of problems can be expected to occur due to damaged regions, sectors and systems until the 24th hour of the earthquake? What are the reasons why these regions, sectors and systems are fragile/weak?*
- *State the negativities that may continue until the 72nd hour of the earthquake, in terms of spatial, sectoral and systems.*
- *Specify the regions, sectors and systems that will support the response until the 72nd hour of the earthquake.*
- *What are the systemic effects that may be experienced due to losses and damages until the 15th day of the earthquake?*
- *What are the systemic effects that may be experienced until the 3rd month of the earthquake?*
- *What are the medium-term effects of the earthquake?*
- *What are the long-term effects of the earthquake?*

In **Session 2**, each group completed comprehensive analyses on possible risks and problems that may occur in the short (first 24 hours), medium (first 72 hours – 15 days), and long term (3 months and beyond) and developed solution suggestions.

The stress testing scenario was a useful way to understand especially critical compound and cascading effects and possible bottlenecks in response and rescue efforts. The results of the stress testing are now integrated in the city plans and will hopefully lead to a more effective response.

## 2. Alps

The example in the Alps is the Brenner Pass that connects Austria and Italy. The Brenner Pass highway is an important connection for passengers and trade, so explorations around compound and cascading risk are focusing on cross-border transportation and how different sectors are impacted by extreme events, including compound and cascading risks.

In the **Learning Lab workshop** in the Alps we explored the levels of complexity with a discussion around possible worst case scenarios that could be imagined – leading to an assessment of possible existing – or new strategies required in a complex system along the linear Brenner Pass.

We then explored the complexity of the system and possible responses in a simulation game, allocating different roles to participants around a fictitious scenario illustrating compound and cascading risk.

18 Lemos, Kirchhoff, and Ramprasad, 'Narrowing the Climate Information Usability Gap'.

## 3. Bucharest

Based on impact chains of compounding events, we collaboratively engaged stakeholders in identifying which components of the hazard-impact-vulnerability-mitigation nexus require prioritized attention, to prevent (more) severe impacts from earthquakes striking Bucharest.

The **Second Paratus Stakeholder Workshop** for the Bucharest Case Study (26 September 2024) included a session where the participants collaboratively worked on the stress testing of disaster scenarios relevant to Romania's capital. Leveraging the knowledge gained during the first part of the workshop, participants were asked to complete the same three tasks working in teams, focusing on three climate-related future scenarios:

- *Task 1. To identify the impacts that may occur in the proposed scenario.*
- *Task 2. To identify new vulnerabilities that emerge in the proposed scenario.*
- *Task 3. To identify corresponding adaptation options for the emergent vulnerabilities in the proposed scenario.*

These scenarios were described in qualitative terms and featured distinctive key impacts of the set, primary (earthquake) and secondary (earthquake-triggered fires and flood). The analysis considered both day and night conditions, as vulnerability hotspots in Bucharest shift their position depending on the moment of earthquake occurrence.

- *Scenario 1: Summertime, high temperatures, dry weather conditions, limited water resources.*
- *Scenario 2: Heavy rainfall, overwhelmed sewage system, road disruption, limited first response.*
- *Scenario 3: Winter time, low temperatures, snowstorms, road disruption, limited first response.*

In the final part of this session, the three teams presented their results within 10-15 minutes each. Their insights were starting points for fruitful discussions on vulnerability dynamics and the effectiveness of adaptation options under extreme climatic conditions. This helped to increase stakeholders' awareness of the uncertainties inherent in current disaster risk management strategies.

# Annex 2 – Further reading and resources

**United Nations Office for Disaster Risk Reduction (UNDRR)**
Coalition for Disaster Resilient Infrastructure.
Global methodology for infrastructure resilience review, 2023

**World Bank.** Stress Testing Social Protection, a rapid appraisal of the adaptability of social protection systems and their readiness to scale-up, 2021

**The Omidyar Group,** Systems Practice, 2018.
A workbook that can be useful for systems mapping as it provides a step-by-step guide to building your map.

**United Nations Office for Disaster Risk Reduction.**
Technical Guidance On Comprehensive Risk Assessment And Planning In The Context Of Climate Change, 2022

**MYRIAD-EU** – Reducing Risks Together.
A project to develop a European framework for multi-hazard, multi-sector, and systemic risk management.

**URBACT** Undertaking Option Appraisal,
template for developing solutions and a step-by-step guide for option appraisal.

**Stormz,** software for Multi-Criteria Decision Making.
Use for ranking in solutions appraisal

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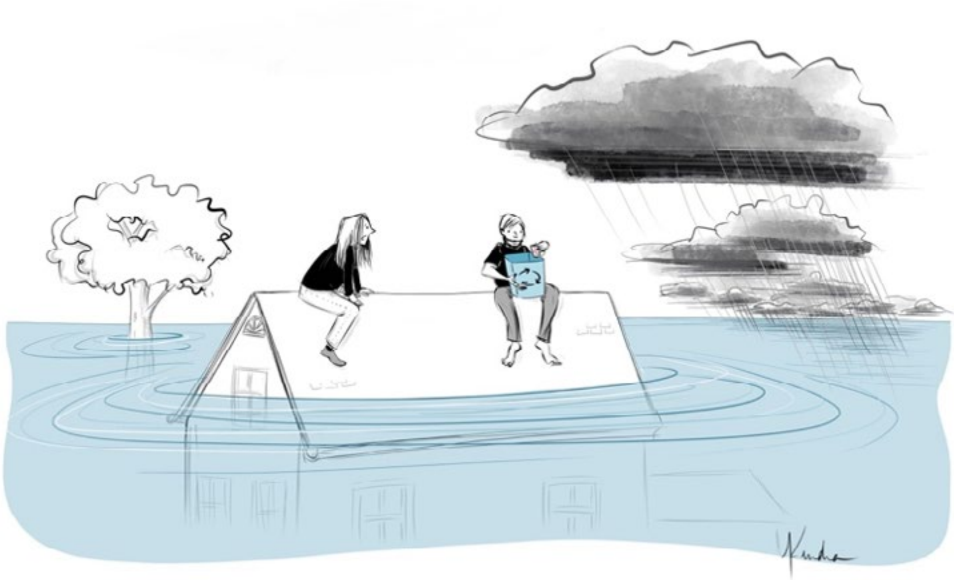

"It's not that I don't appreciate your recycling, Leo, I'm just suggesting it's not the only thing we should be doing right now."



PARATUS

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Climate Centre

Funded by the European Union