EU-CIRCLE

A pan-European framework for strengthening Critical Infrastructure resilience to climate change

CI adaptation to climate hazards model

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Statement

This document proposes a methodology allowing CI operators for identify, assess and select relevant adaptation options to improve their resilience to one or several climate change scenarios. This adaptation framework is consistent with the EU-CIRCLE risk assessment and resilience assessment frameworks.

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Executive Summary

This document proposes a methodology allowing CI operators for identify, assess and select relevant adaptation options to improve their resilience to one or several climate change scenarios. This adaptation framework is consistent with the EU-CIRCLE risk assessment and resilience assessment frameworks.

After a brief state of the art regarding existing CI adaptation frameworks and new approaches for decision-making under deep uncertainty, it proposes a two-steps (divided in seven stages) methodological framework; using inputs from the risk assessment framework [D3.5], the cost-effectiveness analysis [D4.7] and the resilience assessment tool [D4.5]; to help CI operators for the selection and prioritization of adaptation options improving their resilience.

Step	Stage	Description
A/ Identification of adaptation options	1. Establishment of the decision context	Definition of the acceptable resilience level (CI operator point of view) within climate change context; using the Resilience Assessment Tool [D4.5].
	2. Identification of options	Identification of adaptation options to reduce the damages (assessed using the risk assessment framework [D3.5]) and to improve resilience capacities (assessed using the Resilience Assessment Tool [D4.5]).
B/ Adaptation Decision Support Module	3. Identification of objectives and criteria	Regarding the decision context, determination of criteria to evaluate the adaptation options (including cost-effectiveness [D4.7]).
	4. Scoring of the expected performance in comparison to the defined criteria	Evaluation of the performance of each adaptation option against the selected criteria.
	5. Definition of weights for all criteria	Assignment of specific weight for each criterion with the decision makers.
	6. Computing the overall scoring/value for each adaptation option	Final analysis.
	7. Sensitivity analysis	Results analysis to assess their stability to changes in the input parameters (climate change scenarios, criteria weights, etc.).

This adaptation procedure, has been applied for the Case Study of Torbay, UK (CS3), as described in the last paragraph.

Contents

Table of abbreviations	
Abbreviations	Meaning
AP	Adaptation Pathways
APM	Adaptive Policy-Making
CI	Critical Infrastructure
CIWIN	Critical Infrastructure Warning Information Network
DAPP	Dynamic Adaptive Policy Pathways
EIA	Environmental Impact Assessment
EPCIP	European Programme for Critical Infrastructure Protection
MCA	Multi-Criteria Analysis
OSP	Operator Security Plan
RDM	Robust Decision-Making
SEA	Strategic Environmental Assessment

1 Introduction

EU CIRCLE project aims to provide a platform for critical infrastructures operators to assess their individual infrastructure's resilience and identify options to improve it in the context of climate change.

Task 4.4 will derive an **adaptation framework**, **consistent with the risk analysis [D3.5] and resilience framework** [D4.3]. Its framework will be supported by the respective wrapping application that will be developed in WP5, allowing for the definition, authoring, examination and consistent comparison of a large number of different scenarios that will allow CI to be able to better cope with climate change.

Taking into consideration the steps of risk management describe in the Risk Assessment Framework [D3.5], the adaptation framework addresses the steps "Selection and implementation of protective programmes including adaptation options" and "Measurement of effectiveness" (Figure below; left hand side, yellow and purple boxes).

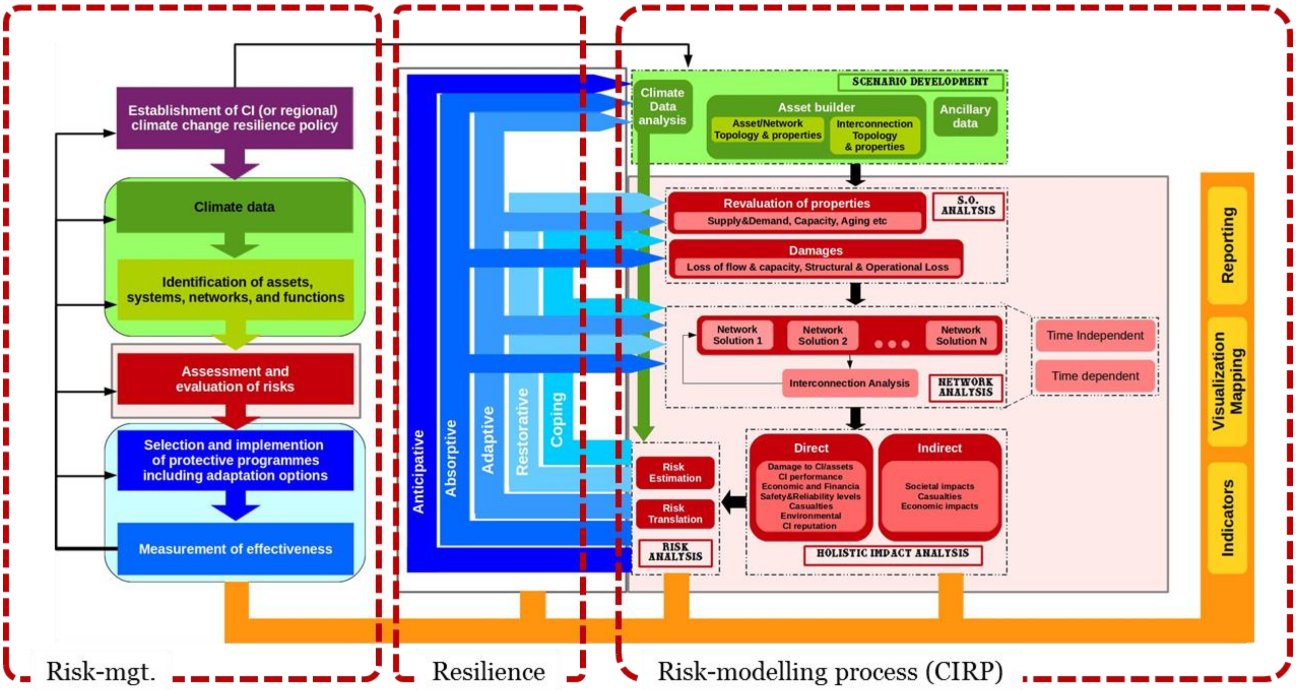


Figure 1: EU-CIRCLE framework [D3.4]

More precisely, the adaptation framework [D4.6] follows **three main steps**:

1. Using the Risk assessment and the Resilience assessment outputs, the end-user is invited to **select adaptation options:**
   a. **The Risk assessment allows identification of the most critical assets** regarding:
      - The climate scenario and hazards considered;
      - The interconnections and cascading effects.

      These critical assets are a priority for adaptation options.

   b. **The Resilience assessment provides generic information on the capacity for each asset to face climate hazards**. The critical assets that are least resilient are a priority for adaptation options. The assessment of five different capacities (anticipation; absorption; coping; restoration; adaptation) provides indications to select the most relevant options for these assets.

   Each adaptation option aims to modify the assets properties (consistent with the registry of asset provided by D3.1).

2. **The second step consists of a dual assessment**:
   a. **running the CIRP risk and resilience assessment frameworks**, taking into account the selected adaptation options (D3.5 and D4.3 modules).
   b. **making a cost-effectiveness analysis** of these adaptation options implementation (D4.7 cost-effectiveness module).

3. **The third step uses the outputs of the second to help the end-user to assess the relevance of the adaptation options to improve resilience capacities.** If the resilience is always unacceptable, the end-user is invited to revise his initial choice.

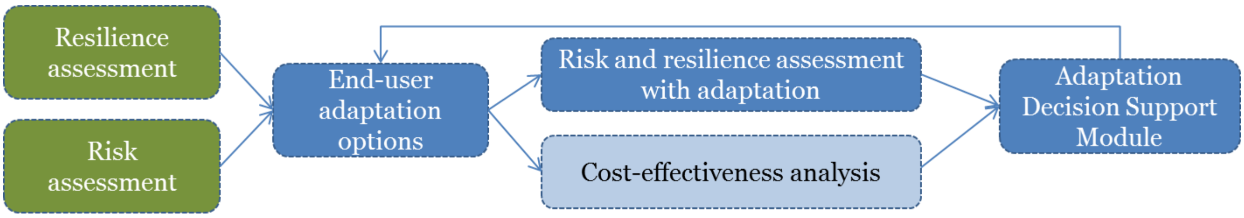


Figure 2: Articulation of the adaptation framework

1.1 Working methodology

To develop this deliverable, the following working steps were undertaken:

- Literature study on existing adaptation options and frameworks.
- Extensive analysis of D3.4-5, D4.1-3, D4.5 and D4.7, to ensure the consistence between the EU Circle CI Climate Hazard Risk assessment and resilience framework and the adaptation to climate hazards framework.
- Extensive discussion among D4.6 contributors, to develop this report.

1.2 Structure of the deliverable

- Chapter 1: Introduction.
- Chapter 2: definition and adaptation framework state of art.
- Chapter 3: review of different approaches for decision making under deep uncertainty.
- Chapter 4: EU CIRCLE adaptation approach.

2 CI Adaptation to climate change: state of the art

Climate change adaptation today relates to several other fields such as natural disaster management, crisis management, vulnerability assessment, business continuity, insurances, etc. Therefore, CI adaptation plans often consist in anticipating climate evolutions and integrate this parameter in various documentations (planning, protection plans, etc.). There is currently no dedicated standard on adaptation strategies shared at the international scale.

Existing adaptation frameworks are either policy level action plans (elaborated by national or regional governments, public institutions such as river basin, coastal areas, fire protection, etc.) or at company level (some CI have developed strategies to adapt to a changing climate). We describe some of these frameworks in the following sections.

2.1 European framework: Strategy on Climate Adaptation for CI

The European Union developed since about ten years a specific policy on adaptation to climate change, identifying critical infrastructure as a "key vulnerable sector" [17]. The EU Strategy on adaptation to climate change, published in 2013, defines several actions which lay the overall base of the European policy for CI adaptation to climate change:

- Work with Member States and stakeholders to develop *"frameworks, models and tools to support decision-making and to assess how effective the various adaptation measures are"* (Action 4).
- Develop a European platform to share information on adaptation at the European scale (Action 5). The Climate-ADAPT platform is yet operational.
- The action 7 is dedicated to the infrastructures: "Ensuring more resilient infrastructure"; programming a specific work on several aspects:
    - Revise industry-relevant standards to include adaptation for priority sectors: energy, transport and buildings.
    - Provide guidelines for project developers to develop climate-proofing investments.
    - Work on the mobilization of ecosystem-based approach for the infrastructure adaptation.

Several actions, tools and guidelines were developed to deploy this strategy for the infrastructure sector. The aim is especially to mainstream adaptation to climate change into pre-existing strategies and tools related with critical infrastructure protection; as the Directive on the identification and designation of European critical infrastructures and the assessment of the need to improve their protection [18] (i) and the European Programme for Critical Infrastructure Protection (EPCIP) (ii) [19]:

- Each CI operator had to provide an Operator Security Plan (OSP) [18]. This OSP is a good opportunity to mainstream adaptation to climate change into the risk management process of each CI.
- The CIWIN (Critical Infrastructure Warning Information Network) [19] is also a good way to share information and good practices regarding CI climate change adaptation within the European critical infrastructure community.

These actions, tools and guidelines are very relevant to build an EU-CIRCLE adaptation framework useful and consistent with the EU policies and recommendations, e.g. [20], [21]:

- The technical standards revision to include climate change resilience: the European Committee for Standardisation is working to integrate climate change in the Eurocodes.
- The mainstreaming of climate change adaptation into the Environmental Impact Assessment (EIA) and the Strategic Environmental Assessment (SEA); to force the project developers to take into account climate change and implement adaptation options into the infrastructure project development cycle.

- The development of the European Climate Adaptation Platform (Climate-Adapt[1]), which aims to share information on climate change adaptation in Europe. It especially proposes a database of adaptation options, which can be helpful for CI operators.
- The European Commission developed special guidelines to help project managers integrating adaptation options in the infrastructure project development [21]. The method has seven steps. The fourth ones are related with vulnerability and risk assessment. The fifth, sixth and seventh ones consist with the identification, appraisal and integration of adaptation options into the project to improve the resilience.

2.2 National adaptation to climate change strategies

Many European countries developed a national adaptation framework, declining European adaptation strategy. The following paragraphs propose an overview of Cyprus, Greece and France ones.

2.2.1 Cyprus Adaptation Framework

The Republic of Cyprus has developed a National Climate Change Adaptation Strategy (2016) which sets out the adaptation measures and actions that will be taken over short timescales (i.e. immediately), mid-timescales (up until 2020) and longer timescales. Adaptation measures and actions are described for the natural resources and sectors that were identified as at risk from climate change in the country's Climate Change National Risk Assessment:

- Water resources
- Land resources
- Coastal regions
- Biodiversity
- Agriculture
- Forestry
- Fishing and aquaculture
- Public Health
- Energy
- Tourism
- Infrastructure

The Adaptation Plan identified the following measures, for sectors related with CI:

Water Resources

Measure 1	Maintenance and repair of the water transportation network and all relevant infrastructure
Measure 2	Control and avoidance of water intensive activities (e.g. golf courses, tourist facilities, water intensive agriculture) in all areas with insufficient water resources. This can be achieved through planning restrictions, in which water intensive activities and industries are forbidden or controlled with requirements that such industries have private desalination plants that are run with renewable energy.
Measure 3	Enhancement of water efficiency in buildings, agriculture and industry. This can be achieved through requirements in planning permits for buildings to use water efficient technology and through changes in industrial production processes.
Measure 4	Increase use of grey and recycled water
Measure 5	Increase the use of water metering
Measure 6	The periodic reviews of the Government's Water Management Policy and Plans to include climate change

[1] http://climate-adapt.eea.europa.eu/

Measure 7	Implementation of a Drought Management Plan

Coastal Regions

Measure 1	Identification of the coastal zones that are vulnerable to climate change
Measure 2	Investigation of potential sea level rise and assessment of the impacts to existing and new coastal infrastructure
Measure 3	Development and implementation of a Strategic National Plan on the Integrated Management of Coastal Zones
Measure 4	Actions to protect coastal zones from coastal erosion, including management of the impacts of coastal buffers on marine ecosystems

Public Health

Measure 1	Provision of guidance on personal protection from heatwaves through mass media
Measure 2	Development and maintenance of urban parks and other green measures for reduction of the urban heat island effect
Measure 3	Development of a crisis management plan, which assigns and defines responsibilities of the various health centres, social services and public health centres in the event of extreme weather events (e.g. heatwaves, floods, wildfires etc.)
Measure 4	Capacity building and preparedness of medical staff and social workers related to the health impacts of climate change
Measure 5	Development of a contingency plan in the public health and social services systems as well as in local councils in order to meet increases in patient visits or health incidents due to climate change
Measure 6	Development and implementation of an awareness and information strategy on illnesses associated with climate change, including a web portal and public information campaigns
Measure 7	Implementation of Public Advice Campaigns in which the public is advised to stay indoors during hours that are high risk and on days where weather conditions breach health limits
Measure 8	Development of a Heatwave Early Warning System
Measure 9	Implementation of public cooling centres during heatwaves

Energy

Measure 1	Increase in energy production from renewable energy sources through a reduction of the connection fees of renewable power stations
Measure 2	Increase in energy production from renewable energy sources through special support criteria
Measure 3	Maintenance of transmission and distribution lines in order to minimise losses. Promotion of smart grids.
Measure 4	Subsidies programme for energy efficiency measures in the domestic sector e.g. insulation, shading etc
Measure 5	Greening of cities in order to reduce the urban heat island effect and reduce energy

	consumption for cooling
Measure 6	Increased use of natural gas in electricity production
Measure 7	Diversification of the energy mix through increased use of natural gas
Measure 8	Development and implementation of regulations on energy efficiency of new buildings and buildings undergoing substantial renovation
Measure 9	Increase in the number of new nearly zero-energy buildings

Infrastructure

Measure 1	Development of flood management projects in cities
Measure 2	Management of storm water in existing and new buildings through construction of a separate storm water drainage network
Measure 3	Review of planning policies in order to restrict development in floodplains and coastal zones
Measure 4	Improvement of the design of buildings and transport infrastructures in order to achieve climate resilient infrastructure
Measure 5	Review, selection and implementation of best practices for minimising the urban heat island effect
Measure 6	Information campaign to insurance companies to encourage them to include climate change risks in their insurance policies

2.2.2 Greek Adaptation Framework

In Greece, the Ministry of Environment & Energy (MEEN) is the competent authority for coordinating actions for climate change and works towards both mitigation and adaptation to the implications of climate change as well as the enhancement of mechanisms and institutions for environmental governance. In this capacity, MEEN is responsible for the identification of climate change impacts, the planning and coordination of adaptation measures and policies and the establishment and preparation of a national adaptation strategy. The Ministry of Environment and Energy, the Athens Academy and the Bank of Greece signed a memorandum of cooperation for the development of the "National Strategy for Adapting to Climate Change".

The first National Strategy for Adapting to Climate Change has been adopted by the Law 4414/2016 (OGG A’149) art.45 and is available on the Ministry's website (for the time being it is available only in Greek).[2]

Taking under consideration the risk and vulnerability assessment that has been conducted within this strategy, for those sectors that are expected to suffer the most, respective measures have been identified. For those sectors that are evaluated within EU-CIRCLE framework, these measures are depicted in the following tables.

Energy

Action 1	Protection of Energy Infrastructures of the main system
Action 2	Measures of protection of coastal and island energy infrastructures and systems
Action 3	Expansion and protection of water resources (regarding the hydroelectric plants)
Action 4	Research and Development (regarding cooling methods, protection from extreme weather events, etc.)

[2] http://climate-adapt.eea.europa.eu/countries-regions/countries/greece

Action 5	Horizontal and coordination actions (e.g. spatial planning, investment programs, etc.)

Infrastructures and Transportation

Action 1	Organization and decision-making process, e.g.: - Road (implementation of international standards for weather prediction and emergency) - Railway (Design of emergency routes) - Aviation (Integration of climate change parameters in the ATM design) - Inland water and sea (Development of navigation management system for emergency response due to meteorological phenomena)
Action 2	Technical content, e.g.: - Road (Improved drainage at intersections) - Railway (Protection of open - air railway infrastructure by winds) - Aviation (Embankment construction in the coastal airports) - Inland water and sea (Consideration of need for relocation, redesign and enhancing breakwaters)
Action 3	Legislative content, e.g.: - Road (More strict speed limits under storms) - Railway (Definition of speed limits under storms) - Aviation (Revision of land use and building permits near airports) - Inland water and sea (Insurance of infrastructure to compensate for potential damage.)
Action 4	Information flow and use of communication and information technologies tions, e.g.: - Road (Development of intelligent feedback systems in vehicles to communicate the user needs.) - Railway (Integration of different types of tracking data on train movements) - Aviation (Developing a measurement system for evaluation and comparison the vulnerability of airports and airspace) - Inland water and sea (Continuous monitoring of ambient temperatures infrastructure projects)

Urban environment

Action 1	Adapt urban planning to climate change and improve of the thermal environment in the cities by changing its microclimate structured environment
Action 2	Reducing the thermal and energy needs of buildings towards direction of the zero energy footprint.

2.2.3 France Adaptation Framework

French adaptation policy is led by the National Observatory for the Impacts of Global Warming, managed by the French Minister for the Ecological and Inclusive Transition. The national French adaptation strategy was published in 2006. A first action plan was adopted in 2011 for five years and is about to be followed by a second one in 2018.

Two main actions were proposed regarding CI:

- Review and adapt technical standards for construction, maintenance and operation of transport networks (infrastructures and equipment) in continental France and French overseas territories (considered as a Key measure of the Action Plan). The Centre of Expertise on Hazards, Environment, Mobility and Planning published a first report (CEREMA, 2015) identifying about 80 standards potentially requiring an update to better take into account climate change impacts, with a focus on transport infrastructures.
- Study the impact of climate change on transport demand and the consequences for reshaping transport provision;
- Define a harmonised methodology to diagnose the vulnerability of infrastructures and land, sea and airport transport systems;
- Establish a statement of vulnerability for land, sea and air transport networks in continental France and in French overseas territories, and prepare appropriate and phased response strategies to local and global climate change issues.

2.3 Other adaptation frameworks

2.3.1 Multi-criteria analysis (MCA) to analyse climate change adaptation options (USAID [22])

USAID published a report analysing the applicability of MCA for helping decision makers to prioritize adaptation options; based on the experience of the NAPA's (National Adaptation Programmes of Action) in Africa and Latin America.

The proposed method follows seven steps:

1. Identify the decision context: which are the stakeholders and their own objectives?
2. Identify adaptation options, based on the risk and resilience assessment.
3. Identify criteria to be used for the prioritization process. These criteria need to be understandable for the stakeholders and independent of each other. The range of criteria need to meet the following features (DCLG, 2009): completeness (related with the objectives); redundancy (to exclude redundant criteria); operationally (criteria need to be measurable); mutually independent; size (avoid to have to many criteria).
4. Identify the outcome and performance of each option for each criterion (for example: an option may improve the coping resilience capacity but decrease the absorption resilience capacity).
5. Assign weights to each criterion to reflect its relative importance and aggregate. Weights will reflect the preferences of each stakeholder.
6. Examine results.
7. Conduct a sensitivity analysis with different weights if needed.

Options	Impact on vulnerable groups and resources	Contribution to sustainable development	Synergy with multilateral environmental agreements	Risk reduction	Cost efficiency	Final score (rank)
Promotion of rain-fed agriculture	0	0.5	0.28	0.33	1	0.42 (5)
Intensive agro-animal husbandry	1	0.5	0.57	1	0.33	0.68 (2)
Varieties seeds resistant to drought	1	0.50	0	1	0.66	0.63 (3)
Integrated water resource management	1	1	0.14	1	1	0.82 (1)
Stocking and transformation of agriculture products	0	0.5	0.14	0.33	1	0.49 (4)

Source: Adapted from Republic of Rwanda NAPA, p. 44

Figure 3 - Example of a performance matrix (options vs criteria) for adaptation options [22].

2.3.2 OECD adaptation framework for critical infrastructure [23]

The OECD published in 2017 a working paper proposing an adaptation framework to help policymaker making their infrastructure resilient to climate change, based on case studies in Netherlands, Sweden, and Massachussets (USA).

It makes a synthesis of existing policies and regulations allowing for improve infrastructure resilience, related to those case studies and OECD countries in general:

- Mainstream adaptation into infrastructure planning, using the Environmental Impact Assessment (EIA), which has to take into account climate change impacts, regarding the UE regulation[3]; or developing a specific local or national regulation framework. In the UK, CI project developers have to comply with National Policy Statements (NPS) defining, among other things, how to take into account climate change adaptation. This regulation was for instance applied to take climate change impacts into account for Hinkley Point nuclear power station's project.
- Mobilize infrastructure regulators (as the France's Nuclear Safety Agency) to help CI operators taking into account climate change; by modifying technical' and/or service reliability' standards. For instance, the Finland's 2009 Electricity Market Act requires operators to limit power cuts due to storms or snow to a maximum of 6 hours in densely-populated areas, from 2028.
- Mainstream adaptation into CI technical and management standards. Several standardisation organizations are currently working on it, at the international scale as at the regional or local scale. For instance, the International Standards Organisation (ISO) created recently a dedicated Adaptation Task Force (2015). In the same way, the World Association for Waterborne Transport Infrastructure (PIANC) created a Permanent Task Group on Climate Change (PTG CC). The OECD estimates that one-third of its countries mainstreamed adaptation into at least one national infrastructure standard (e.g.: the Road drainage design standards in Denmark).

[3] EIA Directive: 2014/52/EU amending 2011/92/EC.

2.4 Current status of infrastructures adaptation to climate change

2.4.1 Examples of adaptation options developed by CI operator’s

The following table presents a non-exhaustive benchmark of adaptation options related with critical infrastructures, implemented in Europe and identified on different European platforms: Climate-ADAPT (EU platform); the Danish Portal for Climate Change Adaptation; the UKCIP portal on adaptation case studies; the Swedish portal on adaptation case studies; the Weadapt platform (world scale); the Polish Portal for Climate Change Adaptation (case study portal in construction); the German Portal for Climate Change Adaptation.

Source	Date	Adaptation action	Location	Type (soft / hard)	CI concerned
French National Adaptation Plan	2011	Adaptation of technical standards for transport networks construction, maintenance and exploitation.	France	Soft	Transportation
Review of the Government’s Flood and Coastal Risk Management (FCRM) ("Worsfold Review")	2014	Review of the maintenance of the Environment Agency's Flood and Coastal Risk Management (FCRM) assets, with recommendations to improve it.	UK	Soft	Governmental Services
Infrastructure, Engineering and Climate Change Adaptation – ensuring services in an uncertain future (Royal Academy of Engineering)	2011	This report examines vulnerabilities in different sectors of the national infrastructure to the effects of climate change and the modifications that would be needed to increase resilience. - Energy sector: smart grids, smart cities, alternative storage solutions, detailed risk assessments - Transport: Systematic risk assessment, amendments to design standards and operating practices, adaptation measures should be incorporated into the routine maintenance processes and the lifecycle replacement of assets, understand the impact of electric, hybrid and fuel cell vehicles and the infrastructure changes. - Communications: Regulators and backup systems. - Water: Focus on new methods and technologies, educate the public and develop proper policies, development of new water supplies.	UK	Soft	Energy / Transportation / Water / ICT
Climate Resilient Infrastructure: Preparing for a Changing Climate	2011	Response to calls from industry – infrastructure owners, investors and insurers – for a Government vision and policy on adapting infrastructure to climate change.	UK		Energy / Transportation / Water / ICT

Source	Date	Adaptation action	Location	Type (soft / hard)	CI concerned
Agrawala, S., et al., (2011), "Private Sector Engagement in Adaptation to Climate Change: Approaches to Managing Climate Risks", OECD Environment Working Papers, No. 39, OECD Publishing	2011	This paper examines the private sector's progress in adapting to climate change by considering information from sixteen case studies, drawn from a range of industries across the private sector. It explores companies' motivations for implementing adaptation measures, and establishes common factors which can affect companies' capacities to adapt, their incentives for action, and their perspectives on the need to adapt.	OECD countries		All
European Commission (2011), Investment needs for future adaptation measures in EU nuclear power plants and other electricity generation technologies due to effects of climate change, final report, conducted by ECORYS Nederland BV, contract TREN/09/NUCL/SI2.547222, Brussels.	2011	The aim of this report is to present key preconditions for EU power plants (depending on technology) to operate successfully, to present the selected climate change and electricity scenarios for this study, to present the results of the consultation with EU power plant operators and to present a coherent risk assessment framework for analysing the investments needed for power plants to adapt to future climate change effects.	EU		Energy
RESNET: Resilient Electricity Networks for Great Britain	2011-2016	Analyse of climate-related changes in the reliability of the UK's electricity system, and development of tools for quantifying the value of adaptations that would enhance its resilience.	UK		Energy
White roof, innovative solar shadings and bioclimatic design in Madrid	2010-2012	Construction of an adapted building (for the energy department of the Madrid Institute for Advanced Studies): > bioclimatic architecture > Water-saving systems > Parking permeable surface	Spain	Structural	Governmental Services
Floating or Elevated Roads	2015	Option proposed to cope with storm water runoff (case study in Brabant).	EU	Structural	Transportation

Source	Date	Adaptation action	Location	Type (soft / hard)	CI concerned
Integrated System for the Safeguard of Venice and its Lagoon against flooding	2014	To defend Venice against flooding, an integrated system of interventions was implemented: construction of mobile barriers enabling a temporary separation of lagoon and sea during events of high water level in Adriatic.	Venice, Italy	Structural	Governmental Services
Integrated Management and Adaptation Strategies for Cork Harbour	2014	Preparation of an Adaptation Strategy for Cork Harbour, focusing on flood management by 2030 thanks to an Innovative partnership between the local authority and multidisciplinary academic experts. The Strategy identifies actions and activities: - Robust decision making processes and structures to be instituted - Critical infrastructure to become flood resilient - Help society to have a proactive involvement in building resilience - Make timely and accurate prediction of flood magnitude and extent - Integration of planning processes to ensure coherent flood management responses - Environmental management to be informed by system approaches.	Cork Harbour, Ireland	Soft	Governmental Services
Green roofs in Basel, Switzerland: combining mitigation and adaptation measures	1996	Increase the coverage of green roofs in the city of Basel through the use of a combination of financial incentives and building regulations.	Basel, Switzerland	Soft	Energy / Governmental Services
Temporary flood water storage in agricultural areas in the Middle Tisza River Basin	2007	The Hungarian Government has been pursuing a new flood defence strategy for the Tisza based on temporary reservoirs where peak flood-water can be released.	Middle Tisza River Basin, Hungary	Structural	Governmental Services
Implementing climate change allowances in drainage standards across the UK railway network	2011	The plans reflect upon the impacts from weather variability, regional climate change projections and actions being taken to increase resilience; including investment in drainage systems and implementation of an Integrated Drainage Management Policy. Actions are mostly: to remediate to flawed flooded site and improve drainage management capability by introducing new mobile works tools.	UK, railway network	Structural	Transportation

Source	Date	Adaptation action	Location	Type (soft / hard)	CI concerned
Climate resilient retrofit of a Rotterdam building [Climate adapt platform case study]	2011	Climate adaptation and mitigation measure implemented is the energy-efficient cooling and heating system of an old office building at Groot Willemsplein. Implementing a proper cooling system in accordance with the city heat network and settling a rooftop garden.	Rotterdam , Netherlan ds	Structural	Energy
Implementation of the integrated Master Plan for Coastal Safety in Flanders [Climate adapt platform case study]	2007	Elaboration of an Integrated Master Plan for Coastal Safety. The Master Plan includes both soft and hard measures. Soft measures consist of beach and dune nourishment. The Master Plan also foresees the construction of storm walls to protect coastal cities and harbours.	Flemish coastline, Belgium	Soft	Governmental Services
New locks in Albertkanaal in Flanders [Climate adapt platform case study]	2012	Construction of Big Archimedes screws, which will contain the water in case of drought and produce electricity in case of an excess of water.	Albertkana al, Belgium	Structural	Energy
Implementation of guidelines helping to control temperature and runoff [Climate adapt platform case study]	1994	Berlin Biotope Area Factor (BAF). The BAF is an important mechanism to reduce local vulnerability as its measures help to lower the temperatures and improve the runoff management. All potential green areas, such as courtyards, roofs and walls are included in the BAF.	Berlin, Germany	Soft	Governmental Services
Integrating adaptation in the design of the Metro of Copenhagen [Climate adapt platform case study]	2009	- Protect the metro against climate change: entrances, ventilation (plus other infrastructure elements) to stations and shafts near the harbour and the coastline should provide sufficient protection against storm surges. - Building proper run offs for water near metro stations, installing pumping systems in underground stations, building floodgates, installing drains along the tracks, protecting the underground stations against backflow from city's sewage system, installing waterproof outer doors to the technique rooms.	Copenhage n, Denmark	Structural	Transportation
Multi-Hazard Approach to Early Warning System in Sogn og Fjordane [Climate adapt platform case study]	2008	The overall aim of this project is to set, test and demonstrate a modern emergency population warning system by disseminating phone-based warning messages in a specified geographic area.	Sogn og Fjordane, Norway	Soft	ICT

Source	Date	Adaptation action	Location	Type (soft / hard)	CI concerned
Keeping children's feet dry [Danish Portal for Climate Change Adaptation]	2013	Rebuilding a day-care children institution on a hydraulic island with pumps.	Himmelskibet, Denmark	Structural	Governmental Services
New model identifies vulnerable areas [Danish Portal for Climate Change Adaptation]	2014	The Danish Road Directorate has developed a new model for risk mapping roads vulnerable to extreme rainfall. The analysis model in question calculates the probability as well as the impacts of flooding events.	Denmark	Soft	Transportation
Sluice system at Aarhus River reduces the risk of flooding [Danish Portal for Climate Change Adaptation]	2016	The construction serves two purposes. Firstly, four sluice gates will protect the city against intruding seawater during high sea levels, and, secondly, six powerful pumps will pump water away from the river and into the sea during cloudbursts.	Aarhus river Denmark	Structural	Energy
Slotsholmen in Copenhagen is now well protected from the next cloudburst [Danish Portal for Climate Change Adaptation]	2016	The quay walls around Frederiksholms Kanal have been reinforced and raised over the years. However, the intention to protect the city against seawater has had the unfortunate consequence that during heavy rainfall the rainwater cannot run out into the harbour. To prevent this phenomenon stormwater gates have been installed along the sides of all streets in order to lead the excess of water in underground drains which ended in the sea through none return valves.	Slatsholmen, Copenhagen, Denmark	Structural	Governmental Services
One of the first climate streets in Denmark [Danish Portal for Climate Change Adaptation]	2014	The small streets in the City of Frederiksberg has been covered with a new type of water-absorbing surface, this new surface quickly absorbs stormwater and stores it under the ground, so the water does not stay on the street or penetrate the buildings in the area.	Frederiksberg, Copenhagen	Structural	Governmental Services
Embankments protect against future flooding [UKCIP portal on adaptation case studies]	2003	The municipality decided to reinforce Hammarslundsvallen and at the same time construct new embankments to protect other parts of the city from the River Helge’s high tides. Rain that falls inside the embankments does not have any natural drainage, and so in 2014, 5 pumping stations were installed to pump out rainwater in the future	Kristianstad, Sweden	Structural	Governmental Services

Source	Date	Adaptation action	Location	Type (soft / hard)	CI concerned
Action taken in Botkyrka in the event of a heatwave [UKCIP portal on adaptation case studies]	2016	The residents felt unwell in the heat and the staff found it difficult to work in the heat and give them their best care. They created a tool to map how many people in the municipality were particularly vulnerable in the event of heatwaves and where they lived. This tool now helps them to send extra staff to elderly people houses when it is needed.	Botkyrka, Sweden	Soft	Health

2.4.2 Feedback on current level of Climate Change Adaptation of Business Continuity systems

In the context of the CI climate related business continuity model elaboration [D4.4], a questionnaire (see Annex of related report [D4.4]) has been designed and distributed to several CI operators through the partners. The questionnaire was divided in two sections, the first regarding the Business Continuity Management system in general and the second regarding the climate adaptation of the BCM system. The feedback collected until the submission of [D4.4] (M28) consists of nine (9) responses which have been analyzed and presented within the respective deliverable. Additional two (2) responses have been gathered, within EU-CIRCLE framework, which have been added and analyzed hereafter.

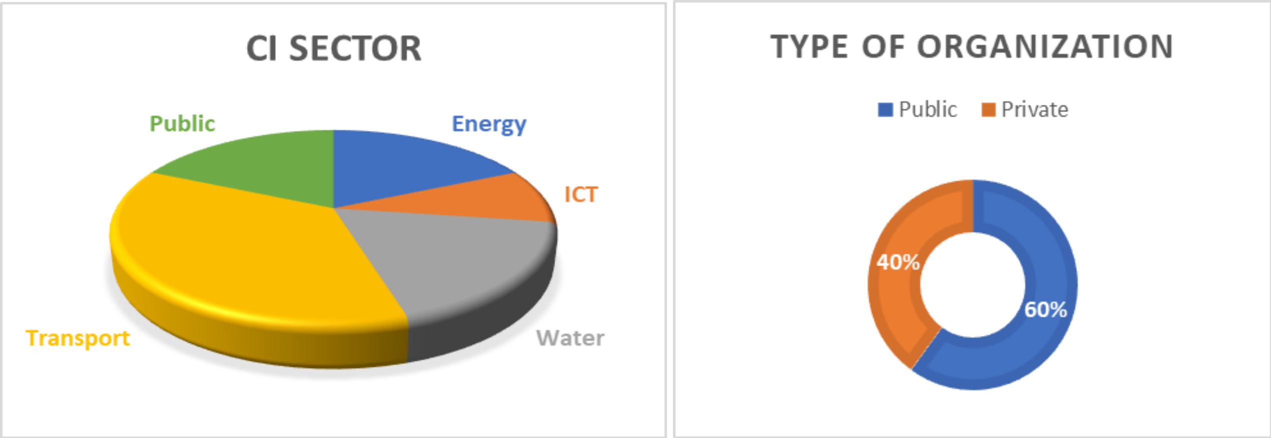


Figure 4 Sector (left) and type (right) of the CI

As depicted in Figure 4 above, most of the CIs comes from the public sector and are providing Transport services (including Railway, Urban, Road and inland water sectors). Responses came from EU countries including Germany, France, UK and Poland.

In the following table, responses (where available) related to adaptation of BCM to climate change are presented. This question is applicable only to the participants (7+2) that do have a BCM in their organisation. Based on the responses in almost all of the cases, organisations declared that have not conducted any action related to climate change adaptation.

Questions related to adaptation of BCM to climate change		
Question	Yes	No
Have your Organization defined key external and internal factors relating to climate threats?	44.44%	**55.56%**
Have your Organization identified any interested parties and requirements?	**75.00%**	25.00%
Have your Organization reviewed and amended the scope of its BCMS	33.33%	**66**.67%
Have your Organization reviewed and amended its BC policy	25.00%	**75.00%**
Have your Organization defined any new roles, responsibilities and authorities	22.22%	**77.78%**
Have your Organization reviewed and amended their Business Impact Analyses	12.50%	**87.50%**
Have your Organization implemented any Climate risk assessment	0.00%	**100.00%**
Have your Organization identified any adaptation options	14.29%	**85.71%**
Have your Organization defined a Maximum Tolerable Frequency of Disruption	0.00%	**100.00%**
Have your Organization selected and implemented any climate change adaptation options	37.50%	**62.50%**
Have your Organization changed the way of performance evaluation	0.00%	**100.00%**
Does your organization monitor the impact of weather events to your business (length of disruption, cost, adaptation actions …)?	44.44%	**55.56%**

The next question regarded examples of climate-driven disruptions, which are the following:

- Event:
  - Heavy storm
  - Strong wind
  - Heavy rain
  - Snow and ice
  - Extreme hard sea
  - Cyclone Kyrill (2010)
  - Storms and flash floods
  - Floods
  - Ice in Münsterland
- Impact:
  - Blocked roads
  - Tram and track damage
  - Harbour closing
  - Transformer/Distribution facilities flooded
  - Electric lines and pylons out of order

In the next question, regarding indicators used in BCM systems of the organisations related to climate threats, none of the responders declared having something.
Finally, in the following table some critical climate thresholds (where applicable) are indicated, as well as some climate patterns.

Critical thresholds of weather/climate variables that have significant impact to a critical process			
Variable	Threshold	Impact	Response
Weather	Flooding above track	Lower line speeds or trains on stop	Flood water recedes, assess situation etc
Wind	No for SaR		Wind over 15 m/s stops mechanical recovery
Sea state	No for SaR		Sea state over 5 stops mechanical recovery
Sea state	No for SaR		Sea state over 6 stops all crane operations
Snow	Three steps are defined on snow height		Different intensity to clear the pedestrian areas at the stops
Storm	Not specified		
Snow	Not specified		
Rain	Not specified		
Flood	River gauging level		Staff is alerted and command post is set up
Rain	alerted above > 40mm precipitation		

climate patterns that have significant impact to a critical process				
Variable1	Variable2	Variable3	Timeframe	Impact
Weather	Lack of maintenance	Damage to asset	Variable	Slower speeds. Train delays, financial impacts etc
Wind	Sea state	Visibility	12 hours	Personnel fatigue, response effectiveness, lack of aerial support

2.4.3 Overall synthesis of infrastructures adaptation to climate change

Despite the multiplication of vulnerability assessments to climate change and/or the integration of climate change as a parameter in risk management policies, the implementation of adaptation remains limited, both at territorial level and for CI operators: today, the vast majority of measures are incremental – related to standards and regulation evolution [23] – and very few transformational measures are observed.

According to I4CE [1], the integration of the stakes of climate change into decision-making for infrastructure development is not sufficient today for 3 main reasons:

- The lack (or absence) of integrative vision between climatic, territorial and infrastructure policies.
- The limited interactions between specialists of climate change and infrastructure stakeholders: as a result, capturing gradual and non-gradual changes, as well as climate uncertainties is still challenging for decision-makers.
- The limited capacity of decision-making tools to integrate these dimensions: for example, planning tools rely on past events and trends, failing at integrating potential ruptures.

EEA is confirming this statement in its report [2], stating that despite the implementation of a lot of adaptation measures in the transport sector, "*the dominant approach for reducing the vulnerability of transport systems up until now has been to make incremental changes. While this approach works well for many cases, it can be insufficient to deal with disruptive or very fundamental changes in climate, the society or the economy. When changes of this sort happen, transport systems will need to adopt a more fundamental and comprehensive change, involving both the use of new technology and the implementation of alternative approaches to adapt*."

As a conclusion, since adaptation to climate change has to deal with gradual, sudden and non-gradual changes, as well as multiple uncertainties, classical approaches for planning, based on rational and linear hypothesis, are not relevant anymore to plan adaptation of infrastructures and territories.

In that context, new approaches should integrate transparency, robustness and flexibility [1].

- **Transparency**: moving away from opaque decision-making models, often called "black boxes" which make it impossible to discuss the basic assumptions used. On the contrary, all the variables of the decision must be made visible to be questioned and discussed.
- **Robustness**: as we do not know exactly how tomorrow will be like, it is better to test the effectiveness of options in achieving specific objectives across a wide range of plausible futures.
- **Agility and flexibility**: we can no longer think of a system in a fixed and static way. It may therefore be desirable to favor flexible, sometimes reversible options and to reduce the time horizons of the decision. An option should not be selected without asking the question of the point in time to which it brings us and the margin of evolution that it leaves us. The idea is to stagger decisions over time, identifying the moments - during the life cycle of the infrastructures - where adjustments will be possible.

3 Approaches for decision-making under deep uncertainty and applications to CI adaptation

Today, according to the literature review, a consensus is emerging on the need for new ways to organize decision-making in the context of climate change. “Adaptive management” approaches appear to be the most relevant way to deal with challenges by incorporating transparency, robustness and flexibility in adaptation planning, especially with regards to infrastructures.

Adaptive management consists in implementing adaptation actions while, at the same time, keeping an eye on the on-going process and preserving maneuver margins in case of evolutions or crisis.

From a very concrete point of view, the aims of adaptive management approaches are the followings:

- facilitate adaptation action short-term implementation, while avoiding maladaptation in the future;
- select and prioritize actions in an evolving, uncertain and complex environment, stressed by climate change and other changes;
- allow trajectory changes in case of the acceleration of climate change or the occurrence of shocks.

There are four main approaches related to decision-making under deep uncertainty [4]:

- **Robust decision making (RDM):** confronting a “basic plan” to multiple futures and increasing its robustness on an iterative way.
- **Adaptive policy-making (APM):** identifying the vulnerabilities of a “basic plan” and developing a contingency plan to adapt it to new information or a change in the context.
- **Adaptation pathways (AP):** combining and sequencing short term, middle term and long term actions according to defined thresholds, in order to cope with a long term objective.
- **Dynamic adaptive policy pathways (DAPP):** combination between adaptive policy-making and adaptation pathways.

These approaches are valuable for infrastructure planning and management:

- In a very recent paper on climate-resilient infrastructure [3], OECD mentions the value of “***decision-support tools that incorporate deep uncertainty into asset appraisal, such as Robust Decision Making (RDM****) that can be used to guide infrastructure investments. These decision-making approaches aim to identify options that would perform well in a range of potential futures, rather than optimizing against a single projection”.*
- Same for I4CE (Institute for Climate Economics) [1] citing *“**RDM** and **Dynamic Adaptation Pathway**s as appropriate methods for adaptation in the transport sector”.*
- Already some application for infrastructures are described in the literature (see “Applications” in Part 3 [4]

3.1 Robust decision-making (RDM)

Developed in the United States in the 1980s by the RAND Corporation, RDM approach originates from classic risk management. Its aim was to test the robustness of infrastructures at different levels of hazards.

RDM consists in confronting adaptation options to a multitude of possible futures and to distinguish the range of futures in which the options perform well from those in which they perform poorly. This information is then used by the decision-maker to adjust options in an iterative way, and options are implemented once they are judged successful in a satisfactory number of scenarios.

In practice, RDM relies on computer modeling to generate hundreds to thousands possible futures (rather than to try to describe a best-estimate future) and on statistical analysis / visualization to test the performance of the options (measured by a specific criterion) in each of them.

RDM has been applied to strategic planning problems with regards to water resources management, climate change adaptation, inland and coastal flooding management, energy policy [4].

As described in [5], the approach follows four steps:

a. Step 1: defining the goals, uncertainties and choices under consideration (*decision structuring exercise*)
b. Step 2: computer modeling to generate a large range of cases, each one representing the performance of the option in one plausible future (*case generation*)
c. Step 3: assessing the vulnerability of the options, by identifying clusters of scenarios in which they perform poorly, using computer visualization and statistical analysis (*scenario discovery*)
d. Step 4: adjusting the options to increase their robustness (back to step 1), or evaluating whether the proposed options are sufficiently robust to be adopted (*trade-off analysis*).

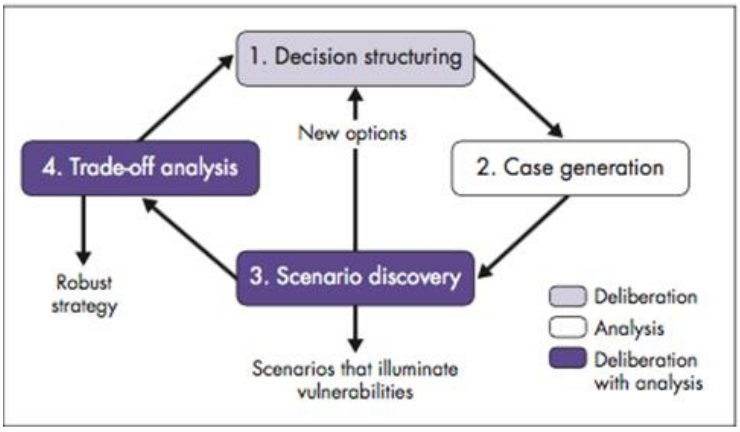


Figure 5 – Robust Decision Making process (RAND Corporation, [5])

3.2 Adaptive policy-making (APM)

Adaptive Policy-Making was conceptualized by researchers from RAND Europe in the Netherlands in the early 2000s (Walker et al., 2001), originally to address the issue of extending Schiphol Airport in Amsterdam in a context of uncertainty about future demand.

This approach consists in identifying the vulnerabilities of an action plan to the external context (and the assumptions that underpin it), adjusting it accordingly and then developing a contingency planning to adapt it to changes of context and new information. A signpost is associated with each vulnerability point of the plan, and triggers beyond which the plan must be adjusted are specified.

APM has been applied in various contexts, among which: transport sector strategic planning (airports and port infrastructures in the Netherlands, urban transport, road pricing), policy-making related to energy transitions and flood risk management under climate change [4].

APM consists of five steps [6]:

a. Step 1: analyzing the existing conditions of a system and specifying the objectives for future development (*setting the stage*)

b. Step 2: developing a basic plan designed to meet the objectives, and defining conditions for success (*assembling a basic plan*).

c. Step 3: identifying external context changes that may degrade or improve the plan's performance, and specifying adjustments to be implemented immediately to increase the robustness of the plan. Robustness can be increased through four types of actions: mitigating actions (reducing the adverse effects of the plan); hedging actions (spreading / reducing the uncertain adverse effects of the plan); seizing actions (taking advantage of opportunities); and shaping actions (reducing failure risk or increasing chances of success). (*Increasing the robustness of the basic plan*)

d. Step 4: establishing a monitoring system, by identifying "signpost" (i.e. variables to monitor throughout implementation) and specifying critical values (triggers) for each variable, beyond which an adjustment of the plan (or additional actions) is required (*contingency planning*)

e. Step 5: identifying the actions to be implemented during implementation phase, when a trigger is activated. Four types of actions can be taken in response to a trigger: defensive actions (aiming at preserving the policy’s benefits without changing the basic plan); corrective actions (adjusting the basic plan); capitalizing actions (taking advantage of opportunities to improve the plan’s performance); and reassessment of the plan if a critical threshold is reached that questions the validity of the whole plan.

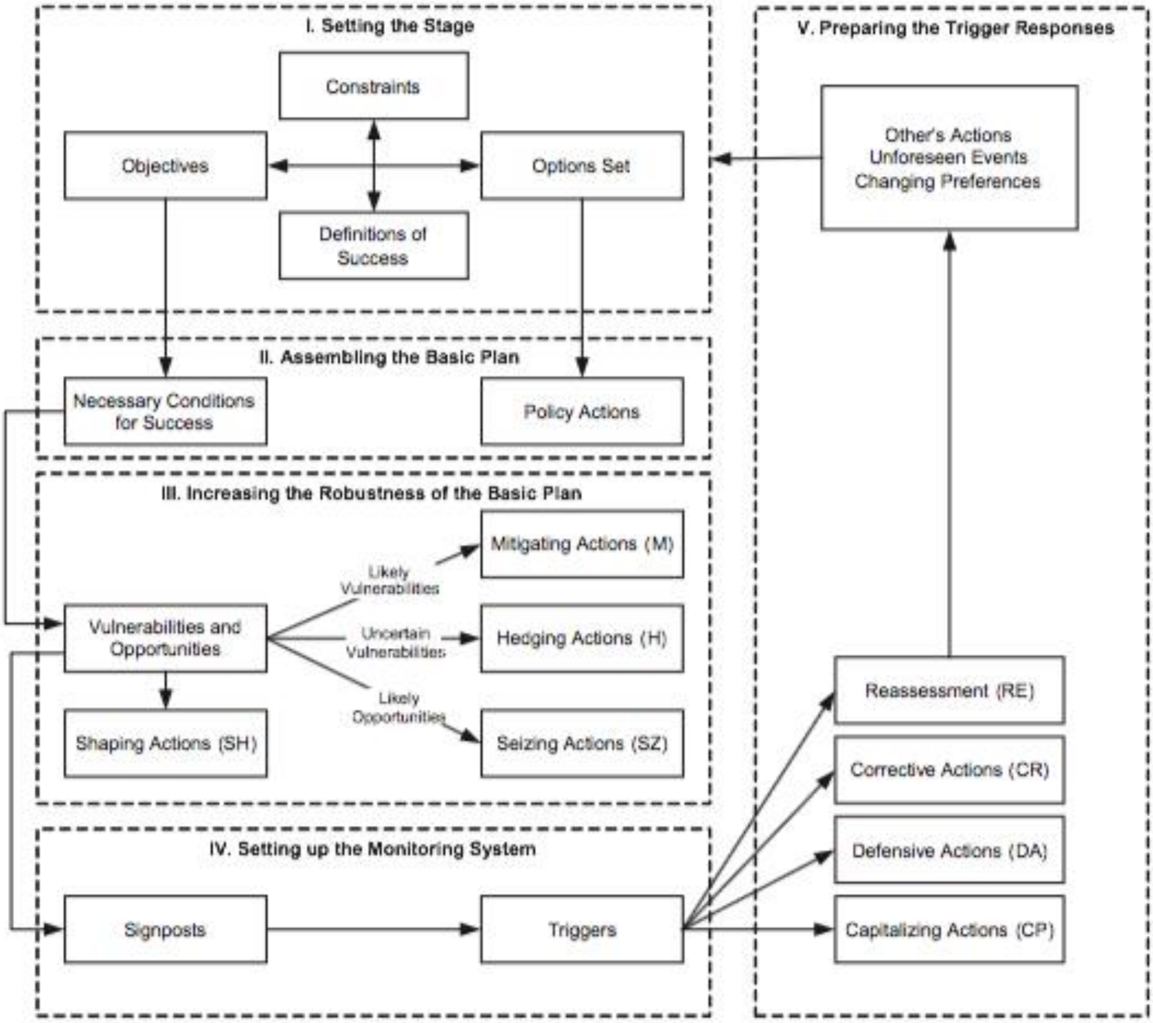


Figure 6 – The Adaptive Policymaking (APM) approach (Kwakkel et al. 2010)

3.3 Adaptation Pathways (AP)

The ‘Adaptation Pathways’ approach was developed as part of the Thames Estuary 2100 project (adaptation of the Thames Estuary to sea level rise) under the name of "routemaps" (Ranger, Reeder , 2011), then conceptualized under the name of "pathways" by researchers from the University of Delft and Deltares in the Netherlands for the adaptation of the Rhine Delta to climate change.

This approach is based on the combination and sequencing of short-, medium- and long-term adaptation actions to meet a given objective. In other words, it aims to draw possible paths to reach an adaptation goal, by selecting set of actions and identifying decision points from which a reorientation of the action must be considered. The concept of "tipping points" (conditions under which an action no longer meets the specified objectives) is central to this approach. The AP approach explores various sequences of actions that can be implemented once the tipping point is reached.

An Adaptation Pathways map presents an overview of relevant pathways, i.e. alternative routes to get to the same desired point in the future.

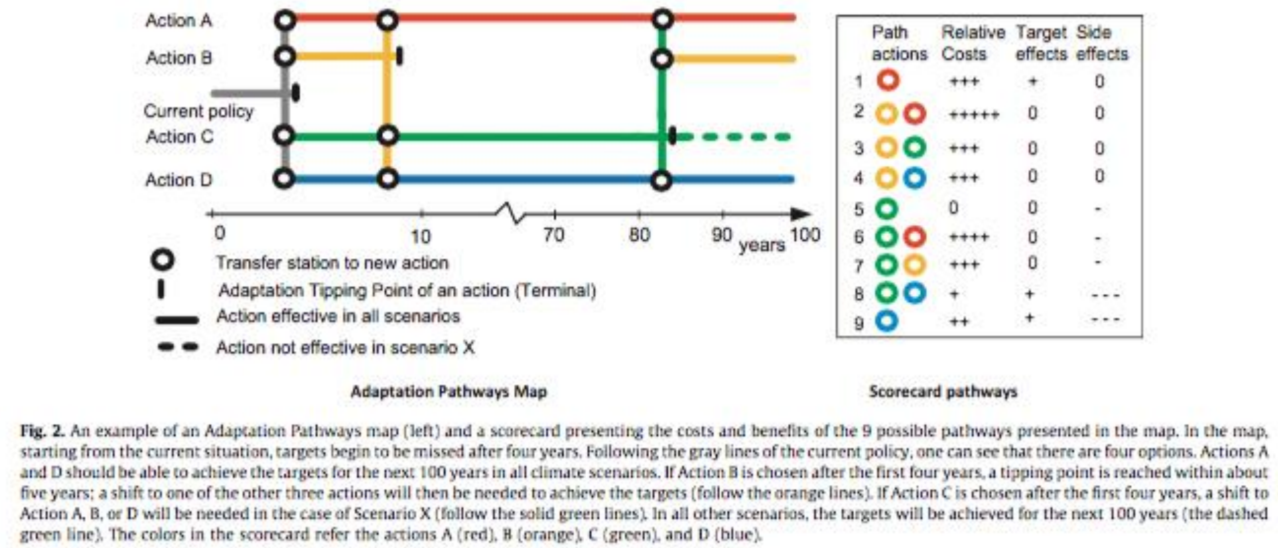


Figure 7 – Adaptation Pathway map (Haasnoot et al., 2013 [6])

The adaptation pathway approach was tested by the Delft University team using a hypothetical case called “the Waas”, close to the Rhine delta in the Netherland. The approach was applied in the field of risk management, especially adaptation of infrastructures to sea level rise.[4]

3.4 Dynamic adaptive policy pathways (DAPP)

DAPP was developed by University of Delft and Deltares. This approach combines 'Adaptive Policy-making' and 'Adaptation Pathways'. After defining the objective of the action plan, alternative pathways are developed for this same point of arrival. Each pathway is evaluated according to a multi-criteria analysis (costs, benefits, co-benefits) and the preferred pathway is selected. During the implementation phase, a dual monitoring system is put in place [6]:

- The first one aims to monitor the occurrence of a tipping point which must lead to bifurcate from one action to another on the selected path (in accordance with the "Adaptation Pathways" approach)
- The second one aims to make sure that the selected pathway remains relevant with regards to the evolution of the context, and to adjust / correct it, or even chose another pathway if the context requires it (in line with the APM approach).

To date, DAPP has been tested using a virtual case inspired by the Rhine Delta situation in the context of climate change.

More complex than a traditional planning strategy, DAPP follows ten steps, as described in Haasnoot et al., 2013 [6]:

a. Step 1: describing the current situation and possible futures, the system's characteristics and current management plan, the objectives and constraints, as well as the indicators that will be used to evaluate the performance of actions ("outcome indicator", or indicator of success)

b. Step 2: defining possible future situations and comparing current situation and possible future situations to the specified objectives in order to identify vulnerabilities (context evolution that can prevent from reaching the objectives) and opportunities (context evolution that can help achieving objectives). Vulnerability and opportunity analysis is generally performed using a computational model.

c. Step 3: identifying a large set of possible actions that can be taken to meet the objective (indicator of success) given the analysis performed in Step 2. Actions can be categorized as in the APM approach (mitigating, shaping; hedging, and capitalizing actions).

d. Step 4: evaluating the effect of each action on the outcome indicators in each possible future situation. Actions are evaluated using scorecards (multicriteria analysis). Only the satisfactory actions will be used in the following steps to elaborate Adaptation Pathways.

e. Step 5: elaborating adaptation pathways, by combining and sequencing individual actions depending on their "sell by date" and identified tipping points. As in the AP approach, this process results in Adaptation pathway maps where each pathway represents a possible route to achieve a given objective.

f. Step 6: selecting a number of preferred pathways (two to four), by evaluating each pathway against a set of criteria (economic, social etc.). At this point, the restricted number of pathways forms the basic structure of the dynamic adaptive plan.

g. Step 7: as in APM, improving the robustness of the preferred pathways through three types of contingency actions (corrective, defensive, capitalizing actions) associated with signposts (variables to monitor) and triggers (critical values beyond which a contingency action must be taken).

h. Step 8: developing the dynamic adaptive plan, identifying the actions that should be taken right now and the actions that can be postponed until a trigger event occurs. The objective here is that the plan keeps the preferred pathway opened for as long as possible.

i. Steps 9: implementing the plan and establishing the monitoring system.

j. Step 10: Monitoring the performance of the preferred pathway, and monitoring the external context during the whole implementation phase, in order to activate the next action on the pathway (or change pathway if required) when a trigger event occurs.

k. **Fig. 4.** The Dynamic Adaptive Policy Pathways approach.

l. Figure 8 – Dynamic Adaptive Policy Pathways [6]

3.5 Relevance for EU-CIRCLE approach

Adaptive management approaches (especially adaptation pathways) described above appear to be the most relevant way to deal with adaptation planning, especially with regards to infrastructures. As a result, it seems relevant to assess how EU-Circle adaptation framework and tools could fall within adaptive management principles.
Two important features emerge from the analysis of the four examples of adaptive management approaches (see above):

- Setting an operational target (related to the infrastructure's characteristics) at the very first stage of the adaptation process.
- Identifying climatic thresholds above which the infrastructure's performance (its ability to meet the operational target) is surpassed (without and with adaptation). The use of the climatic threshold is effective because, to some extent, it eliminates uncertainty related to climate change IPCC scenarios (i.e. temporal horizons).

Hereafter is presented a simplified approach for implementing Adaptation pathways using EU-Circle tools. The proposed approach is illustrated with the example of the Thames Estuary 2100 Project (Reeder and Ranger, 2011[4]).

1- Set a clear (and quantified) objective, against which the performance of the system (and adaptation options) can be assessed.
This objective should be expressed in terms of "operational target". **Within EU CIRCLE approach, this target is an acceptable resilience level for the CI operator (regarding the RAT results).**

Example from Thames Estuary 2100 Project Operational target = protection against 1/1000 flooding event

2- Develop a fine knowledge of the current system and its limits in a climate change context.
The objective is to identify a climatic threshold above which the system does not perform according to the operational target (the resilience level is not acceptable). This could be done by running several climate change scenarios in CIRP and assessing the performance of the current system (is the operational target reached?) in each scenario, using the RAT.

OUTPUT: **Climate threshold for existing system (above which adaptation is needed because operational target is not met: resilience level is not acceptable for the CI operator).**

Example from Thames Estuary 2100 Project Current barrier is efficient up to +0.5m SLR → Threshold for existing system= 0.5m

3 – Identify a large set of potential adaptation options.
The objective is to establish a typology of adaptation options to increase the resilience capacities (absorption, coping, restoration, etc.), which can be useful to ensure the set of potential actions is large enough. Actions can then be ranked:

- from incremental (close to the current system, easy to implement) to transformational;
- by resilience capacities increased (anticipation, absorption, coping, etc.).

[4] Reeder, Tim and Nicola Ranger. "How do you adapt in an uncertain world? Lessons from the Thames Estuary 2100 project." World Resources Report, Washington DC. Available online at http://www.worldresourcesreport.org

OUTPUT: **a ranked list of adaptation options (individual actions or pooled actions), allowing to reach the target taking into account climate change.**

Example from Thames Estuary 2100 Project Adaptation options include: -Raising the existing dike -Developing flood storage -Creating a new barrier -Creating a new barrage -Etc.

4- Evaluate adaptation options: assess the range of efficiency of actions.

The objective here is to evaluate each pool of options in order to identify their new climate threshold and ensure that they allow reaching the operational target (acceptable resilience). This could be done by iteratively running the CIRP and the RAT, for each climate scenario, with each pool of adaptation options. Options can then be organized in a pathway map (see next page).

OUTPUT: **Climate threshold for each option / each pool of options; and pathways map**.

Example from Thames Estuary 2100 Project -Raising the existing dike allows meeting the target up to +0.8m SLR → 0.8m = threshold -Flooding storage: 1.5m -Building new barrier: 2m -Creating a new barrage: 4m

5 – Select preferred options.

Tools like multi-criteria analysis, cost-benefits analysis, cost-efficiency analysis can be used to select the preferred options, given their range of efficiency and acceptable costs for the operator and society.

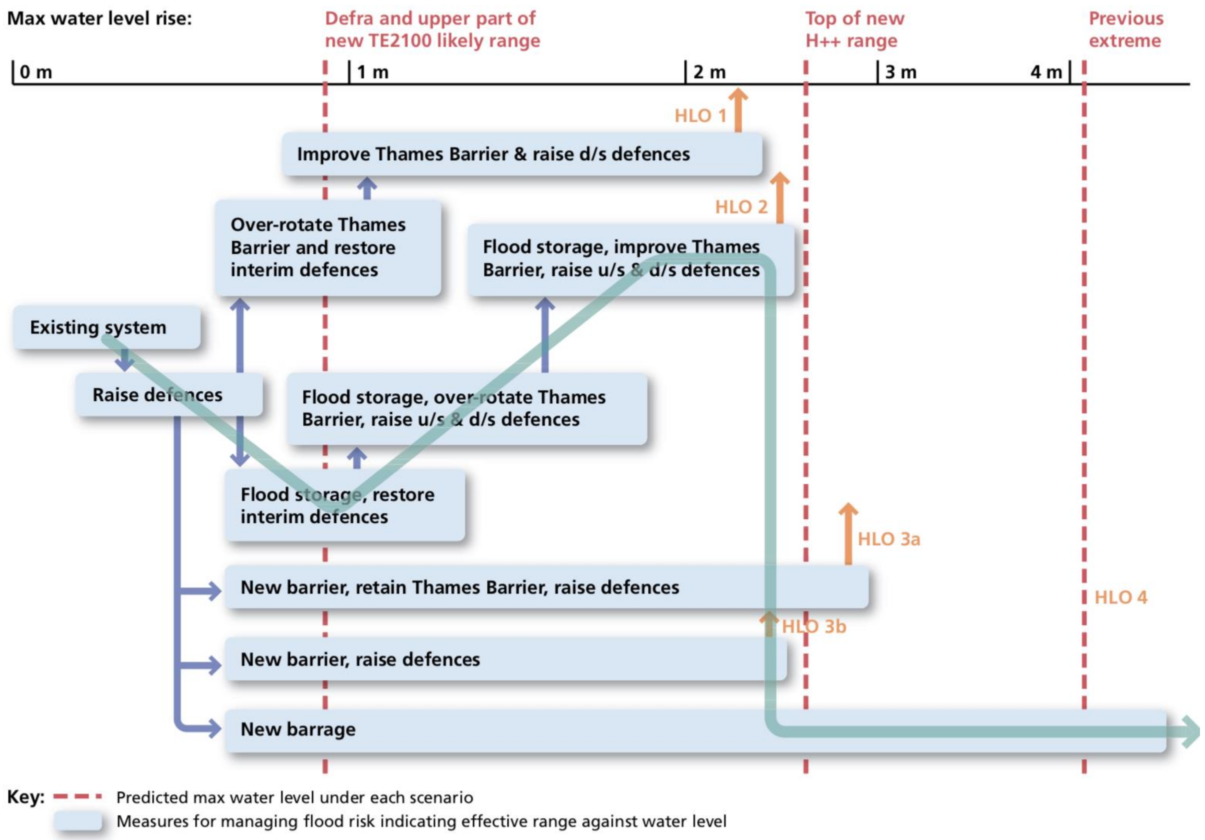


Figure 9 – Thames Estuary 2100 Project Pathways map (Reeder and Ranger, 2011)

The following table proposes a synthesis of the translation of these five steps within EU-Circle approach:

Steps		Translation within EU-CIRCLE Approach	EU-Circle tools	Consistence with the adaptation framework (see below)
1	Define a clear objective (operational target).	Objective within EU-Circle approach: maintain an acceptable resilience level (CI operator point of view) within climate change context.	The RAT [D4.5] allows CI operator to define if the resilience level is acceptable or not regarding a climate scenario (current situation and climate change scenarios).	Risk and Resilience assessment *(outside the framework of adaptation)*
2	Develop a fine knowledge of the current system and its limits in a climate change context.	> Identify the climate change scenario in which this objective of an acceptable resilience level need to be reach (CI operator point of view); regarding the assets lifespan for example. > Measure if the objective is reached or not with this climate change scenario regarding the current status of the CI.	> The CIRP allow running a risk analysis for various climate change scenarios [D3.5]. > The RAT allows assessing the CI resilience level taking into account the climate change scenario (or the range of scenarios) chose by the CI operator [D4.5].	
3	Identify a large set of potential adaptation options.	> If the objective is not reached with the climate change scenario, identify a set of adaptation options to improve the resilience until reaching an acceptable resilience level; changing the CI current status.	> The RAT allows identifying the lowest resilience capacities. > The adaptation framework [D4.6; step 1] propose: • some example of adaptation options, to change the CI current status and increase the resilience capacities. • a template to characterize each option chosen (cost, who is in charge of the action, etc.).	Step 1
4	Evaluate adaptation options: assess the range of efficiency of actions.	> Measure if the proposed adaptation options allow reaching the objective.	> The adaptation framework [D4.6; step 2] allows comparing, for each option, the results of the resilience assessment without and with adaptation options which allows seeing the improvement of resilient capacities, using the RAT outputs [D4.5] for the climate change scenario (or the range of scenarios) chose by the CI operator.	Step 2
5	Select preferred options.	> Select a pool of adaptation options which allow reaching the objective while being the most cost-effective.	> The adaptation framework [D4.6; step 2] allows assessing the cost effectiveness of each option. > The adaptation framework [D4.6; step 2] is done to help CI operators to select this pool of options, according to the efficiency of and cost-effectiveness of each.	Step 2

4 The proposed EU-CIRCLE adaptation framework

4.1 CI adaptation to climate change: definition

CI adaptation to climate change aims to **increase CI resilience capacities by implementing options modifying the infrastructures and assets properties [D3.1], described in the Resilience Assessment Tool end user questionnaire [D4.5]:**

- Some of these actions can reduce the potential damages caused by climate hazard, increasing for example the anticipation resilience capacity (construction of a dike to reduce flood damages).
- Others don't reduce the potential damages but improve the ability to maintain the service provides by the infrastructure during the crisis, despite the damages (increasing of the coping resilience capacity).

EU-CIRCLE Taxonomy (D1.1) provides two definitions of CI climate change adaptation:

- **Modification** CI structure its components and subsystems parameters and its operating environment parameters to achieve its characteristics **that allows its functioning in its operating environment changed by climate change.**
- The **process of** critical infrastructures **adjustment** to climate change in response to actual or expected climatic stimuli or their effects. This involves the initiatives, which moderate harm or exploit beneficial opportunities, **to reduce the vulnerability** of critical infrastructures to climate change **or increase resilience** of critical infrastructures to expected climate change impacts.

Adaptation to climate change therefore addresses a wide range of strategies and actions. There are a significant number of typologies to classified adaptation options. The most probably shared is the IPCC one [REF], which considers **three types of adaptation:**

- **Anticipatory adaptation** (or proactive adaptation) – Adaptation that takes place before impacts of climate change are observed.
- **Autonomous adaptation** (or spontaneous adaptation) – Adaptation that does not constitute a conscious response to climate stimuli but it triggered by ecological changes in natural systems and by market or welfare changes in human systems.
- **Planned adaptation** – Adaptation that is the result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state.

4.2 Scope of the EU-CIRCLE adaptation framework

4.2.1 Adaptation framework: generic scope

A CI adaptation framework aims to select and prioritize relevant options to implement in order to improve CI resilience to climate hazards. It includes typically three stages [11]:

1. Identification of a range of adaptation options to improve CI resilience; previously assessed according to a climate hazard scenario provided by running the Risk Assessment Framework (with climate change).
2. Prioritization of the selected adaptation options according to:
   a. Their impact on interconnected CI vulnerability / resilience level [D3.5; D4.3]; regarding various climate scenarios if needed (at different time horizons; with different climate scenarios, etc.).
   b. Their cost-effectiveness [D4.7].
   c. The CI operators' own objectives (acceptable level of risk/resilience and willingness to pay).

3. *Implementation of priority adaptation options and monitoring (outside EU-CIRCLE perimeter).*

4.2.2 From generic to EU-Circle scope

Considering EU-CIRCLE approach, these generic stages have been adapted in a two-steps methodological framework (see paragraph 4.4) to ensure consistency with other EU-CIRCLE frameworks and CIRP modules, especially the Holistic CI climate hazard risk assessment framework [D3.4; D3.5], the CI resilience framework to climate hazards [D4.1; D.4.3] and the Resilience Assessment Tool [D4.5].

According to these previous frameworks and modules, the adaptation framework aims to help CI operators to identify, select and prioritize options to improve their resilience; as the fifth and final step of the EU-Circle overall process (see figure 2 below):

1. Definition of a scenario without climate change, running the risk evaluation (layer 3 – [D3.5]) within the CIRP and crossing:
   - the considered interconnected infrastructures attributes (layer 2 – [D4.5 and D3.1]);
   - climate data from the current situation without climate change (layer 1).
2. Resilience assessment without climate change, running the Resilience Assessment Tool (layer 4 – [D4.5]) with inputs from the RAT end-user questionnaire and from the CIRP (risk evaluation).
3. Definition of a scenario with climate change, running a risk evaluation (layer 3) crossing:
   - the same considered interconnected infrastructures attributes (layer 2– [D3.1]);
   - climate data from the situation with climate change (layer 1).
4. Resilience assessment with climate change (layer 4 – [D4.5]).
5. **Adaptation framework: selection and prioritization of adaptation options, changing the interconnected infrastructures attributes to improve resilience, if the resilience assessment with climate change (fourth step) is not acceptable for the CI operators.**

   Within this final step, **the prioritization is made by running:**

   a. **the risk evaluation** (layer 3 – [D3.5]), to define a scenario with climate change and with adaptation, crossing:
      - *the considered interconnected infrastructures attributes, taking into account adaptation options (layer 2– [D3.1]);*
      - *climate data from the situation with climate change (layer 1).*

      It allows assessing the consequences of adaptation options on the CI vulnerability to climate hazards taking into account in the scenario.

   b. **the cost-effectiveness analysis** [D4.7], to measure the cost effectiveness of each option or of the range of options, comparing the scenario with and without adaptation.

   c. **the resilience assessment tool** with climate change and adaptation (layer 4 – [D4.5]), to measure the resilience improvement due to each option.

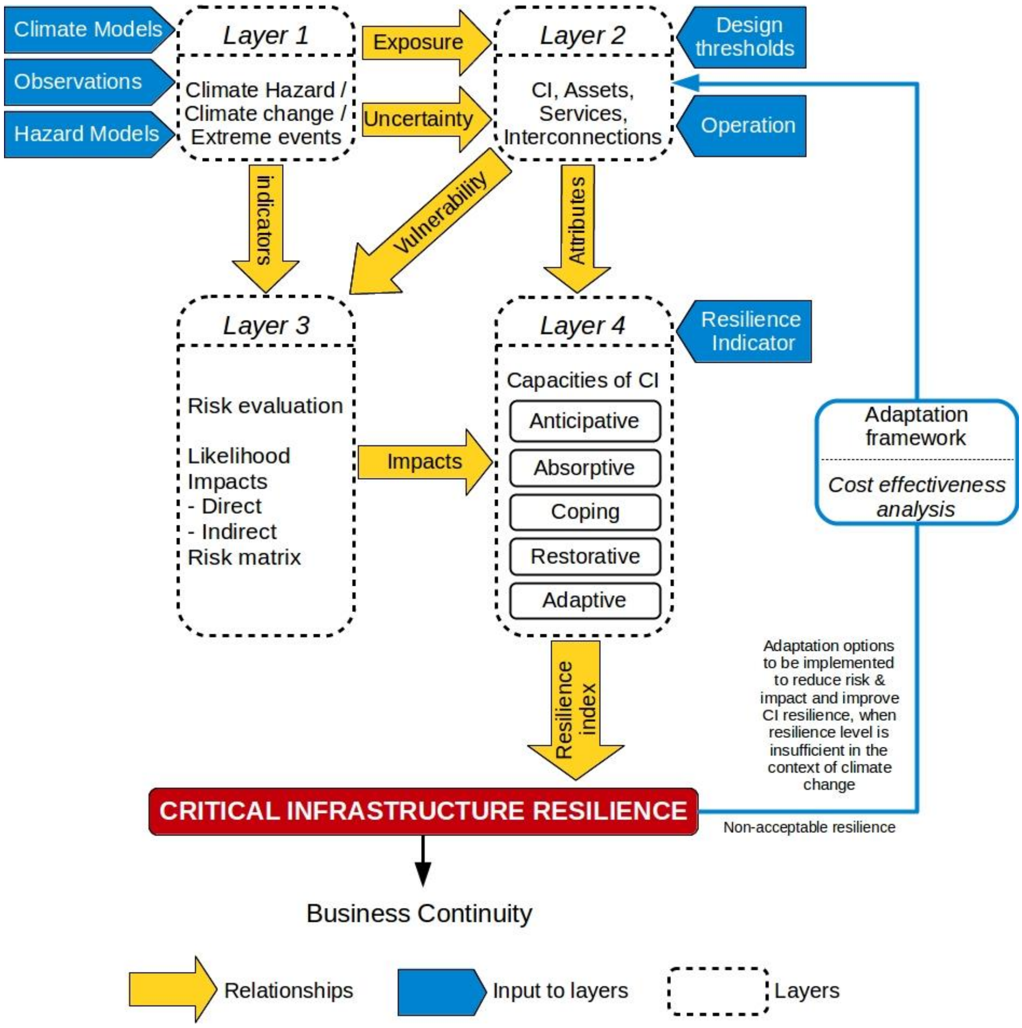


Figure 10 – EU-Circle overall approach [D4.3]

As such, the adaptation framework is a decision-making tool supporting CI end-users to select and prioritize their climate hazards adaptation actions.

4.3 Objectives of the adaptation framework

Considering EU-CIRCLE overall approach, **the EU CIRCLE adaptation framework shall help CI owners and operators adapt their risk management actions to improve their resilience to climate hazards** in the context of climate change.

All CI operators are implementing options to manage the risks to which their infrastructures are exposed; at least to comply with legislation. Furthermore, in many cases, the operators have implemented (or plan to implement) complementary options after a natural disaster has severely impacted the CI capacity to provide its service (damage on the CI assets, economic loss due to business discontinuity, etc.).

The adaptation framework aims to analyze a set of adaptation options, assessing:

- **their impact on interconnected CI vulnerability** highlighted by the Climate Hazard Risk Assessment [D3.5] **and on resilience capacities** [D4.3, D4.5];
- **its cost-effectiveness**.

The aim of this analysis is **to help CI operators identify additional adaptation options and reevaluate them through the same analysis to allow comparison between a different set of adaptation options**. The number of iterations is not limited so that the end-users may reiterate this process until resilience is judged acceptable.

4.4 Overview of the adaptation framework

The EU-CIRCLE adaptation framework is built around **two main** steps (see the detailed scheme below):

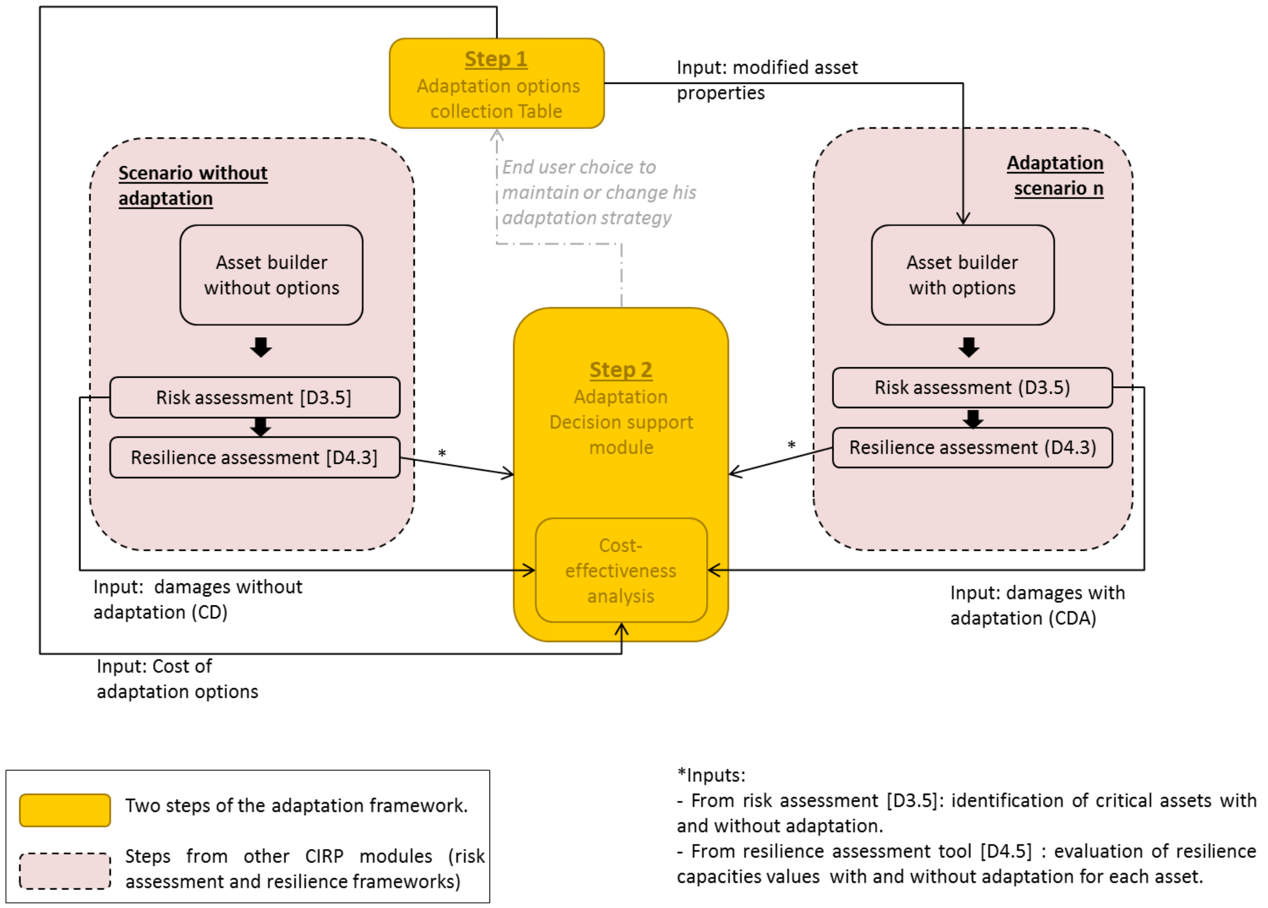


Figure 11: EU-CIRCLE adaptation framework

Step 1: Identification of adaptation options (also known as natural hazards risk management options).

Based on the results of the risk analysis [D3.5] within the CIRP and the resilience assessment tool [D4.5], the end-user is invited to identify a set of adaptation options. He can select options from a list[5] and/or define some others, completing a collection table. This table classifies and characterizes these options in technical and economic terms (assets involved, change in properties, option costs, etc.).

The identification of the options results from answering successively two questions:

(i) Which are the most critical assets, according to the risk analysis [D3.5]? The most critical assets are those for which adaptation options should be selected / defined.

(ii) For those most critical assets, what are the lowest resilience capacities, according to the resilience assessment tool results [D4.5]? This information allows identifying the action levers to improve the resilience of the considered asset.

[5]Collaborative list developed by the case studies.

Adaptation option table contents		[Inputs from]
Name of the action		**[Adaptation module / end users]**
Climate Hazard considered		**[Risk assessment module - Climate data]**
CI asset considered		**[Risk assessment module - Asset builder]**
Description of the action		
	Objectives	*[Adaptation module / end users]*
	Mean	*[Adaptation module / end users]*
	Picture	*[Adaptation module / end users]*
	Cost	*[Adaptation module / end users]*
CI properties changed by the action		[Risk assessment module - Asset builder]

Name of the action		**Replace wood electric poles to metal material**
Climate Hazard considered		**Forest fire**
CI asset considered		**Electric lines**
Description of the action		
	Objectives	*Avoid fire physical impact on the line by electric poles destruction.*
	Mean	...
	Picture	
	Cost	*1500 €/electric pole*
CI properties changed by the action		Electric pole material (physical property)

Figure 12: Collection table (generic approach and example)

<u>Step 2:</u> Adaptation Decision Support Module

The second step aims to provide a relevant framework to help end-users to prioritize the adaptation options they identified at the first step. Such prioritization is based on three criteria:

(i) The cost effectiveness analysis results (output from [D4.7]), at the asset and at the interconnected CI scales.

(ii) The comparison between the results of the resilience assessment without and with adaptation options[6], which allows seeing the improvement of resilient capacities at the asset scale.

(iii) The choice of end-users, taking into account the two firsts criteria and their own priorities.

Concretely, the decision support module will provide a table classifying the adaptation options regarding various criteria (including cost-effectiveness), as define below.

Cost-effectiveness analysis of the adaptation options identified: [D4.7] outputs

The cost-effectiveness of the selected adaptation options – as a criterion to classified the adaptation options into the adaptation decision support module – is fed by three inputs:

(i) The cost of impacts for the scenario without adaptation (reference provided by the risk assessment [D3.5], running the CIRP).
(ii) The cost of impacts for the scenario with adaptation, taking into accounts the asset properties / attributes [D3.1] changes due to those options (provided by the risk assessment [D3.5], running the CIRP).
(iii) The cost of adaptation options, provided by the collection table for each option.

Schematically:

Cost-effectiveness value = Cost of impacts for the scenario without adaptation - (Cost of impacts with adaptation + Cost of adaptation options).

This cost-effectiveness analysis will be conducted at the asset scale, to assess the cost-effectiveness of each individual adaptation option; and at the interconnected CI scale, to assess the cost-effectiveness of the set of adaptation options regarding the network of infrastructures.

In the light of these results, the analysis can terminate here if the end-user considers the adaptation scenario acceptable. Otherwise, the end-user is invite to revise the initial collection table using the decision support module.

Thus, these three steps can be repeated until resilience level is judged acceptable by the end-user:

- **Revision of the set of options to introduce additional or alternative adaptation options by the end-user.** As step 1, this step is performed by the end-user (feedback loop). The adaptation option collection table is modified and/or complemented, using the Adaptation Decision Support Module. This revision can lead to abandon some options, revise the characteristics of existing options and propose complementary options.
- **Assessment of this new set of options.** These new datasets are then input to the CIRP to run through the same scenario analysis as described above. Results can be compared with the reference and first adaptation scenarios.

[6] The resilience assessment with adaptation is provided running the resilience assessment tool [D4.5] with two inputs: the scenario with adaptation (outputs from the CIRP / risk assessment [D3.5]); and the RAT end-user questionnaire modified taking into account the adaptation options.

4.5 Detailed structure of the adaptation framework

Adaptation is considered integral to risk management of climate change as part of a process of risk assessment, action, monitoring, re-assessment and response (IPCC, 2012; Kingsborough 2016). In the EU-CIRCLE risk management framework, adaptation is a key tool for managing the risks of climate change to CI. The EU-CIRCLE risk management framework (D3.4) is made up six steps: 1) establishment of CI policy; 2) identification, collection and processing of climate related data; 3) interdependent infrastructure analysis and identification of assets and networks; 4) Assessment and evaluation of risks; *5) selection and implementation of adaptation options; and 6) measurement of effectiveness*. The EU-CIRCLE adaptation framework uses the outputs of steps 1-4 as inputs into steps 5 and 6 to help CI operators identify and develop CI adaptation plans and protective programmes for managing climate change risks to their assets and networks.

Climate change poses a significant challenge to infrastructure operators and infrastructure projects, due to uncertainties related to climate projections (Ranger et al 2013) including uncertainty in the range of projected changes; the scale of the projected changes; local vs global climate change; and the timescales of predicted changes (short-term vs long term timescales) (Hallegate 2009; Wilby and Dessai, 2010; Ranger et al 2013; Kingsborough 2016). CI infrastructures, being long-lived structures, are likely to experience changes in the climate over their lifetimes, changes that are beset by deep uncertainty. Adaptive and protective measures to CI can be expensive and have long lifetimes, meaning that the choice of adaptation measures is vital to ensure that CIs are not locked into a path dependency that may prove to be maladaptive and costly in the future. As discussed in Section 3 above, there are various decision-making processes that can be used under conditions of deep uncertainty. The EU-CIRCLE adaptation framework will use a hybrid of these approaches.

4.5.1 Step 1: Identification of adaptation options

Inputs	Identification of the most critical assets, according to the risk analysis (taking into account climate change scenarios and parameters) [D3.5]. For those most critical assets: identification of the lowest resilience capacities [D4.5] and those which needed to be improved according to the CI policy [D3.5].
Outputs	Collection table by adaptation option (each adaptation option modified the asset properties to improve the resilience). Overall adaptation options table (one line by option)

Analysis:

The first step of the EU-CIRCLE adaptation framework is the identification of adaptation options. Adaptation to climate change can be divided into three approaches: retreat (avoid); protect; and accommodate (GTZ). Measures within each approach can be further sub-divided into hard and soft adaptation measures which can then be categorised as either short-term or long-term adaptation measures. In order to address the long timescales of future climate change, adaptation plans which incorporate a mix of the various approaches, categories and timescales are increasingly being developed (Kingsborough et al., 2016; Ranger et al., 2013; Rosensweig and Solecki, 2014).

Approaches to Adaptation	
Retreat	**Relocation** of critical infrastructure from areas that are at high risk of a climate hazard e.g. flooding, sea level rise, storms etc. **Avoid** building and development in areas that are at high risk of a climate hazard.
Protect	**Protection** of critical infrastructure using either *hard* measures such as building flood defences or sea walls; or using *soft* measures such as using ecosystem services and natural resources for protection e.g. sand dunes which can protect from storm surges
Accommodate	**Modification** and **adjustment** of critical infrastructure to withstand higher values of climate variables e.g. higher temperatures or higher levels of flooding.

There are two main processes that can be used in identifying possible adaptation options:

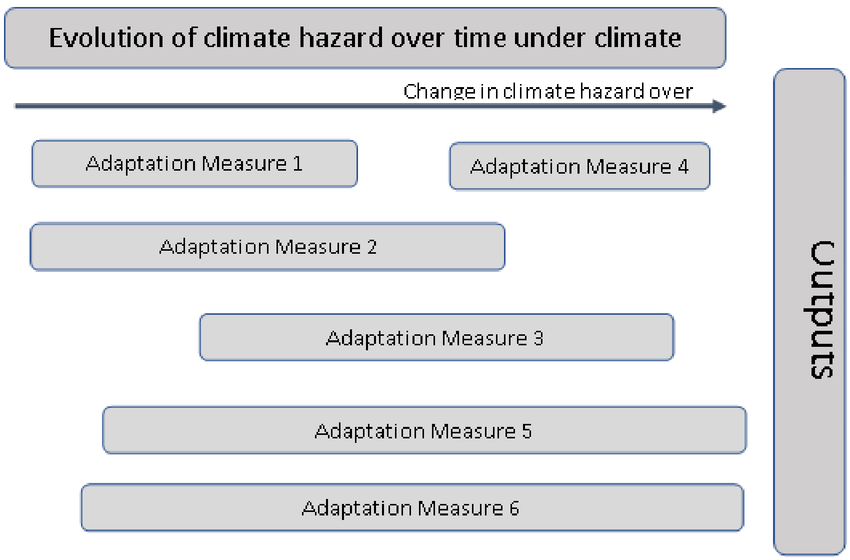
1) top-down, in which the process of identification begins with the scientific analyses of risks, in this case with climate change projections and scenarios;
2) bottom-up, in which the process begins with a description of CI policy and objectives.

As set out in D3.4, the EU-CIRCLE risk management process begins with the formulation of the relevant CI policy and objectives in collaboration with CI operators and other CI stakeholders. In this step the relevant operational objectives and targets of the CI asset or network are defined, this may include: Key Performance Indicators; regulatory targets; and reliability targets particularly related to extreme weather events and other climate incidents; design parameters related to climate parameters e.g. to which return periods of a given climate hazard the CI asset have to be able to face; etc. Potential constraints such as financial constraints; constraints related to the values of customers and the public should also be defined. These objectives correspond to an acceptable level of resilience for the CI operator, whatever the climate scenario. E.g.: the CI has to be able to face a centennial flood, whatever the characteristics of such flood (which can be different depending on the climate scenario considered).

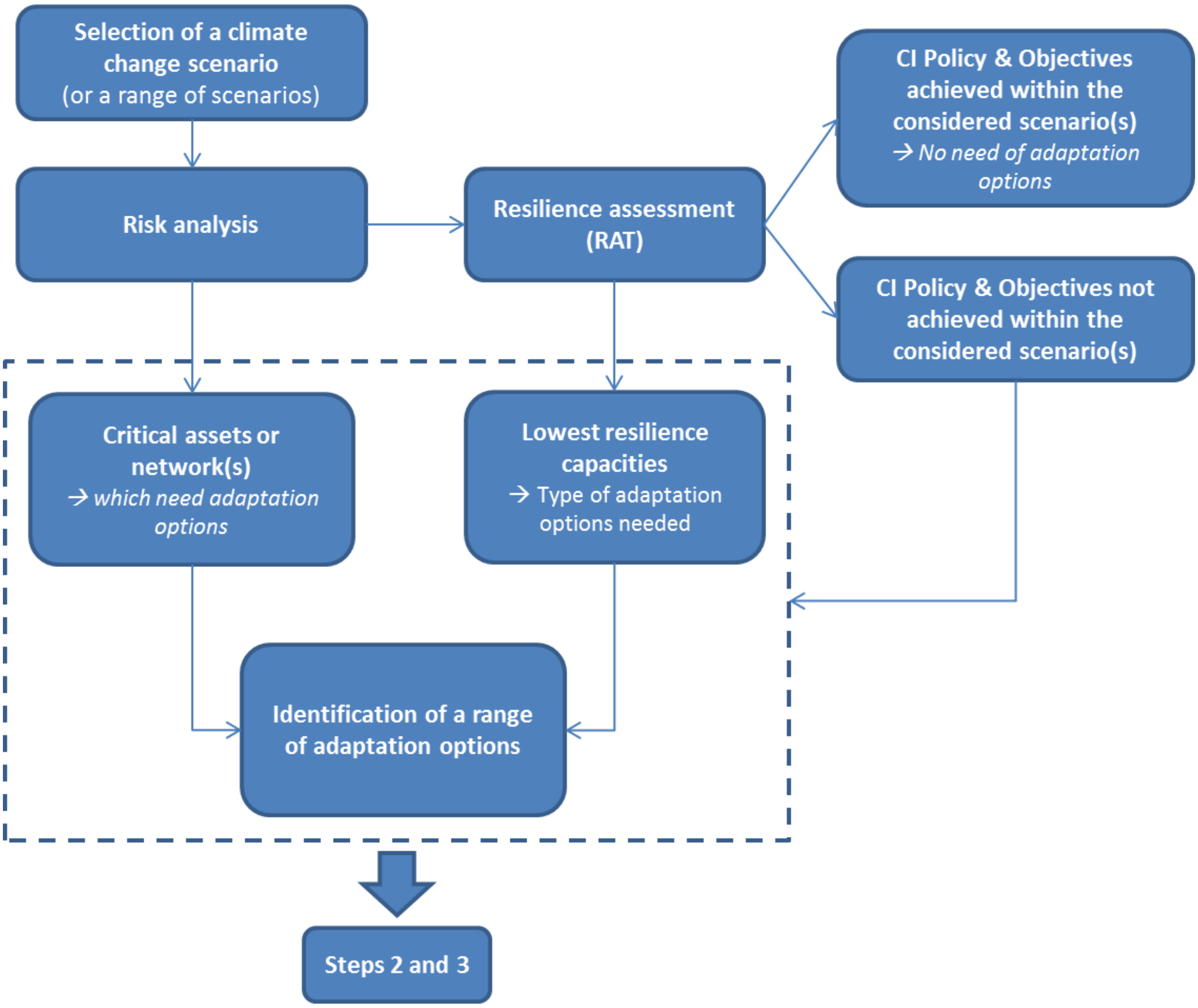
Following the definition of the CI policy and objectives, the operator is invited to select a climate change scenario (or a range of scenarios) – e.g.: a 2050 scenario which may correspond to the lifetime of the infrastructure. The risk analysis [D3.5] and resilience assessment (using the RAT) [D4.5] allow the CI operator to check if its CI policy and objectives are met under the selected projected climate scenario (or for the range of scenarios). If not, the risk analysis allows identification of the assets and network(s) that are critical; along with all (inter)dependencies with other CI assets and networks. These critical assets and network(s) are those for which adaptation options should be defined / selected in order to achieve the CI policy and objectives under the selected climate change scenario (or range of scenarios). The resilience assessment identifies for each critical asset the lowest resilience capacities: it aids in the identification of the type of adaptation options needed to improve the resilience capacities of the CI assets and networks in order to achieve the CI policy and objectives for the considered climate change scenario. E.g.: the absorptive capacity may be low because the safety design standards used do not take into account the evolution of climatic thresholds evolution under climate change within the selected scenario.

This analysis can be done for various climate change scenarios under different concentration pathways and different timescales e.g. short-term climate projections vs long-term projections up to 2100 which can enable CI operators to consider different critical points over time over the CI lifetime. Such an approach supports the identification of adaptation options relevant for a wide range of possibilities and so better equipping CI operators to face uncertainty. E.g.: an option consisting of updating and refining a safety standard related to flood depths under climate change will take into account the higher flood depths of all the scenarios considered.

Using outputs of the resilience assessment for each critical asset, CI operators and stakeholders can then identify a suite of adaptation options starting from no-regret options that reduce risk immediately and cost-efficiently under a range of climate change scenarios. These measures can be a mix of hard and soft measures and can act as a good starting point allowing for lessons to be learnt which can be fed into any major investment decisions related to future climate change. Following the projected changes of a climate hazard within the considered scenario(s), further adaptation measures are identified to manage impacts. Where measures are hard measures related to significant investments in infrastructure, the lead time required for such measures to be in place must be taken into account to ensure that they are adequately planned for and included in the adaptation plan.



A list of potential adaptation options is provided in the Table below to act as an illustrative guide when using the adaptation framework. The list is not exhaustive, and it is recommended that the adaptation measures are jointly arrived at with the CI operators and stakeholders.


Selection of a climate change scenario
(or a range of scenarios)
Risk analysis
Resilience assessment (RAT)
CI Policy & Objectives achieved within the considered scenario(s)
→ No need of adaptation options
CI Policy & Objectives not achieved within the considered scenario(s)
Critical assets or network(s)
→ which need adaptation options
Lowest resilience capacities
→ Type of adaptation options needed
Identification of a range of adaptation options
Steps 2 and 3

Each adaptation measure is designed to minimise and manage the impact of a given value of a given climate hazard as it evolves in time under a given climate change scenario.

An illustrative list of possible adaptation measures:

Sector	Examples of adaptation options	Climate Hazard	Type of measure	Resilience capacity(ies) improved
Water	Long-term planning to include adaptation to climate change	All	Soft measure	All
	Leakage reduction	All	Soft measure	Absorptive
	Increase water re-use	Drought	Soft measure	Coping Adaptive
	Demand reduction	All	Soft measure	Adaptive
	Storage capacity increase- new reservoirs	Drought	Hard measure	Coping Adaptive
	Desalination	Drought	Hard measure	Coping Adaptive
	Enhanced Drainage systems	Flood	Hard measure	Adaptive
	Insurance and early warning systems	All	Soft measure	Anticipatory Restorative
	Improving/raising existing defences	Flood and sea level rise	Hard measure	Anticipatory Absorptive
	Incorporating 'structural' flexibility so that defences can be retrofitted, adjusted or enhanced in the future with minimal cost	Flood and sea level rise	Hard measure	Adaptive
	Inclusion of safety margins to flood defences i.e. where flood defences are over-engineered to cope with greater than expected change (Ranger et al)	Flood and sea level rise	Hard measure	Adaptive
	Coastal-defences-sea-walls	Flood and sea level rise	Hard measure	Anticipatory
	New flood barriers	Flood and sea level rise	Hard measure	Anticipatory
	Retreat	Flood and sea level rise	Hard measure	Coping
Public	Use of new construction materials or construction	Extreme	Hard measure	Anticipatory Adaptive

Sector	Examples of adaptation options	Climate Hazard	Type of measure	Resilience capacity(ies) improved
	designs that reduce a building's cooling and heating needs and energy consumption	Temperatures		
	Planting of trees in urban areas to reduce the urban heat island effect	Extreme Temperatures	Soft measure	Absorptive
	Air conditioning in hospitals	Extreme Temperatures	Soft measure	Coping
Energy	Improve energy efficiency standards to manage demand	All	Soft measure	Anticipatory
	Include extreme temperature scenarios in future grid planning	Extreme Temperatures	Soft measure	Adaptive
	Elevate critical equipment in plants that are sited in flood prone areas or areas at risk of sea level rise	Flood and sea level rise	Soft measure	Adaptive
	Expand capacity, increase redundancy	All	Hard measure	Absorptive
	Incorporate more robust design specifications	All	Hard measure	Anticipatory
	Use of wastewater to maintain adequate water supplies in refineries	Drought	Soft measure	Coping
	Use of desalination technologies to maintain adequate water supplies in refineries	Drought	Hard measure	Coping Adaptive
	Siting policies that restrict power plants or transmission substations in areas that are prone to flooding or sea level rise	Flood and sea level rise	Hard measure	Adaptive
	Use pipeline materials that are less likely to leak or rupture from impacts (e.g., coated steel rather than cast iron or bare steel)	Storms, floods	Hard measure	Absorptive Adaptive
	Increase redundancy in transmission system	All	Hard measure	Absorptive Coping

Sector	Examples of adaptation options	Climate Hazard	Type of measure	Resilience capacity(ies) improved
	Limit customers affected by outages by installing additional substations and breakaway equipment, and by sectionalizing fuses; develop island-able "microgrids"	All	Hard measure	Absorptive Adaptive
	Replace wood poles and support structures with fire-resistant materials (e.g., steel or concrete)	Wildfires	Hard measure	Absorptive Anticipatory
	Utilise mobile transformers and substations	All	Soft measure	Coping
Transportation	Increase network road redundancy	All	Hard measure	Absorptive
	Inclusion of sea-level rise consideration in maintenance of wharves	Sea level rise	Soft measure	Anticipatory
	Incorporate future temperature projections into design when replacing road materials and rail equipment	All	Soft measure	Anticipatory Adaptive
	Increase and improve drainage systems of roads to improve surface draining	Floods	Hard measure	Absorptive Adaptive
	Update design specifications for temperature ranges for road infrastructure	Extreme temperatures	Soft measure	Adaptive
	Increase maintenance of infrastructure	All	Soft measure	Anticipatory

4.5.2 Step 2: Adaptation Decision Support Module

Inputs	Outputs from the resilience assessments without and with adaptation options. Cost of impacts for the scenario without adaptation (reference provided by the risk assessment [D3.5], running the CIRP): at the asset and interconnected CI scale. Cost of impacts for the scenario with adaptation, taking into accounts the asset properties / attributes [D3.1] changes due to those options (provided by the risk assessment [D3.5], running the CIRP): at the asset and interconnected CI scale. Costs of the adaptation options - capital expenditures (CAPEX) and operating costs (OPEX)
Outputs	Ranking/Prioritization of adaptation options

Analysis:

Following the identification of adaptation options, these options have to be assessed by a method which allows the identification of the most appropriate adaptation measure taking into account also specific requirements regarding data basis and their scale.

As described in the report Cost-Effectiveness Analysis [D 4.7] there are several methods and approaches which can be used to assess different adaptation options (see EU CIRCLE consortium, 2017[7]). D 4.7 mentioned four mainly used approaches for the economic assessment of infrastructure projects in general. These evaluation methods are the Cost-Benefit Analysis (CBA), Cost-Effectiveness Analysis (CEA), Macroeconomic Analysis (MA) and Multi-Criteria Decision Analysis (MCDA). After the collection of advantages and disadvantages of the described methods the table below from chapter 6 from D 4.7 can be used to find an appropriate assessment tool for a specific infrastructure adaptation option.

[7] EU-CIRCLE consortium (2017): D 4.7 Cost-Effectiveness Analysis

Table 1: Advantages and disadvantages of the assessment methods

Approach	Description	Strengths	Weaknesses	Scope (i.e. more applicable in specific industry, CI etc.)
CBA	Comparison of costs and benefits in monetary values regarding different project alternatives	• Monetarization of input parameters → clear and transparent comparison criterion for decision makers • Gathering of local and global effects • Due to the clear assignment of costs and benefits it is a transparent procedure → easier understanding and acceptance	• Monetarization of input parameters → especially intangible impacts are sometimes difficult to assess with a monetary value→ subjective assessment possible • Effects of compensation • NPV considers “only” the set of alternatives, not applicable to discover the most appropriate option overall • Defined discount rate of costs and benefits have significant can Influence on results	• Commonly used method in most infrastructure projects, especially in transport related projects (e.g. modified approach in “Bundesverkehrswegeplan” in Germany

Approach	Description	Strengths	Weaknesses	Scope (i.e. more applicable in specific industry, CI etc.)
CEA	Economic Analysis comparing costs in monetary terms with effects in qualitative terms of different alternatives	• Useful alternative to CBA in areas where benefits can-not be quantified monetarily to compare alternative adaptation options with a view to identifying the option which can reach a well-defined objective in the most cost-effective way. • It is particularly useful where there is a need for the analysis of benefits in non-monetary terms, notably in areas that are difficult to value, such as ecosystems or health.	• CEA is less suitable for complex or cross-sectoral risks • It can be often be difficult to identify a single common metric for analysis, because there are many types of risks across and even between sectors. • CEA tends to focus on technical options, because these can be easily assessed in terms of costs and benefits (effectiveness). However, adaptation is now seen as a process as well as an outcome, and capacity building and non-technical (soft) options are considered an important and early priority. Such non-technical options do not lend themselves easily to the quantitative analysis in CEA, thus they tend to be given lower priorities (or omitted).	• Most useful for short-term assessment, for market and non-market sectors. It is most relevant where there is a clear headline indicator and a dominant impact • It is also most appropriate where climate uncertainty is low, and good data exists for major cost/benefit components. • It is a useful tool for consideration of low and no regret option appraisal (short-term), especially for non-market sectors, and as a potential decision support tool as part of an iterative risk management framework.

Approach	Description	Strengths	Weaknesses	Scope (i.e. more applicable in specific industry, CI etc.)
MA	Linear Economic Analysis measuring the holistic impacts to the all (or certain) economic sectors of a region/country. Mainly in monetary terms	• the ability to reflect the economic interdependencies within a regional (or national) economy in detail for de-riving higher order effects, and partly on its simplicity • The basic production relations of an I-O model are comprehensive with respect to all in-puts, not just primary factors (capital and labor), so these models are especially useful in evaluating re-source-use implications of economic trends and policies	• Linearity • rigid structure with respect to input and import substitutions • lack of explicit resource constraints • lack of responses to price changes • the inability to analyse price and quantity impacts simultaneously	• CIs included in Council Directive 2008/114/EC (for methodologies IIM & DIIM) • Applicability for evaluating macroeconomic impacts in region-al/national level of a sector disruption
MCA	MCDA is a type of decision analysis tool that is particularly applicable to cases where a single-criterion approach falls short, especially where significant environmental and social impacts cannot be assigned monetary values. This method is generally used at the end of a process that clears up the different options	• it is open and explicit • the choice of objectives and criteria that any decision making group may make are open to analysis and to change if they are felt to be inappropriate • scores and weights, when used, are also explicit and are developed according to established techniques. They can also be cross-referenced to other sources of information on relative values, and amended if necessary	• MCDA is not considering public expense efficiency at all.	• MCDA allows decision makers to include a full range of social, environmental, technical, economic, and financial criteria

Within EU-CIRCLE the objective is to propose a way to assess especially adaptation measures which aims to enhance the resilience of critical infrastructure components in the respective case studies. The potential assessment approaches are described in [D4.7]. Regarding the different datasets, requirements and case specific circumstances it has to be mentioned that there is no holistic and best practice procedure for an assessment of all kind of adaptation options and all kind of different CI sectors.

This is justified by the main disadvantages of the assessment measures. For example it is not possible or at least not easily measureable to attach a monetary value to specific input parameters (CBA, CEA). This is due to ethical concerns or because some components are not traded on markets directly etc. Also it is difficult to find an objective way to balance a large scale of benefits in non-monetary units with costs in monetary units (CEA) (see Zerbe, R.O., Bellas, A.S., 2006[8]).

So the task is to propose an assessment procedure which aims to compare adaptation options within the scope of the EU-CIRCLE case studies. Therefore a Multi-Criteria Decision Analysis can be defined as the most useful method to cover most of the adaptation assessments regarding the requirements of applicability [22]. Concretely a kind of Utility Analysis is recommended for the validation of the case studies. However, this is an assessment that is suitable with a high probability for a large scale of adaptation options because input parameters with different scales can be normalised and included together in the approach. Indeed, the individual case has to be analysed regarding the existing data and specific requirements. A collection of potential procedures can be found in [D 4.7].

Within EU-CIRCLE a first step has to be the definition of a set of objectives. A main-objective could be to ensure or enhance the performance of a critical infrastructure during climate pressure (to improve its resilience). Such a main-objective should be divided into sub-objectives to ensure a detailed analysis.

One opportunity of measuring the performance of an infrastructure in EU-CIRCLE can be the utilization of outputs from the impact analysis [D3.5] and in the resilience assessment [D4.5] in a scenario with and without adaptation. Thereby the scenario without adaptation operates as reference case.

The EU-CIRCLE adaptation assessment approach uses as input parameter data from the Holistic CI Climate Hazard Risk Assessment Framework [D3.4], more precisely the Structural & Operational Analysis (SOA) provides information on how different assets react to different hazards (see EU-CIRCLE consortium 2016[9]). Step 4 of the Structural & Operational Analysis provides impacts which can be used as input to estimate the cost-efficiency. The impact assessment is part of D 3.3 Inventory of CI Impact Assessment Models for Climate hazards. Therefore impacts are divided into the two sub-categories direct impacts and indirect impacts (as described in D 3.4):

- **Direct Impacts related to the operation of the CI**: i. Damages to CI assets, ii. CI performance, iii. Safety Indices, iv. Casualties, v. Economic and Financial Perspectives, vi. Environmental Losses, vii. CI reputation.
- **Indirect Impacts affecting society as a whole**: i. Impact on societal groups, ii. Casualties, iii. Economic consequences.

These types of impacts are related to the damage assessment which is done in several loops at the asset and network level. The reduction of the described impacts and the improvement of each resilience capacities assessed with the Resilience Assessment Tool [D4.5] can be defined as the sub-objectives of the defined main-objective (ensuring/enhancing the performance of critical infrastructure under climate pressure). For example the difference between the damage to CI assets in a scenario without adaptation

[8] Zerbe, R.O., Bellas, A.S.(2006): A primer for Benefit-cost Analysis, Cheltenham
[9] EU-CIRCLE consortium (2016): D3.4 Holistic CI Climate Hazard Risk Assessment Framework

($impacts_0$) minus the damage to CI assets in a scenario with adaptation ($impacts_1$) results in the reduced impacts of damage to CI assets (Δ impacts).

Based on the aforementioned a general assessment procedure is recommended when based on the input parameters there is a high uncertainty which assessment measure is the most appropriate one. An Utility Analysis with normalisation of input parameters can be choose to evaluate different adaptation options regarding their degree of achievement of different objectives, divided into main-objectives and sub-objectives. The following procedure describes this assessment approach referring to chapter 5.2 of [D4.7] (Department for Communities and Local Government, 2009[10]). Also in Annex A there is an example for a criteria-adaptation option matrix.

Stage 1: Establish the decision context

It has to be defined which are the aims of the assessment procedure. Also the decision makers must be identified and included/involved in the appraisal procedure.

Stage 2: Identification of options

This is done in Step 1 of the adaptation framework. A finite number of adaptation options were selected for the assessment. This is not about an optimisation like finding the best option out of an infinite number of adaptation options.

Stage 3: Identification of objectives and criteria

As described before the main objective could be to ensure the performance of critical infrastructures in case of climate hazards. This step also aims to define criteria which could be used to evaluate a certain degree of achievement of an adaptation option regarding the specific criteria. This degree of achievement will be used to measure how appropriate an option is to fulfil the purpose of a certain criterion. These criteria can also be divided into main-criteria and sub-criteria representative for objectives and sub-objectives. It is also possible to include an extra assessment procedure for a criterion (e.g. efficiency) and use the output of this assessment as input for the respective criterion. As an example the criterion efficiency could be measured by a cost-efficiency analysis (see chapter 3 of D 4.7). The resulting cost effectiveness ratio could subsequently use as input for the Utility analysis in the main assessment procedure by transforming it in a degree of achievement in relation to cost efficiency ratios of other adaptation options. A potential way of transformation is described in Stage 4.

Potential criteria within EU-CIRCLE are the costs of an adaptation options. This means both implementation cost and maintenance costs respectively capital expenditures (CAPEX) and operational expenditures (OPEX). Compared with this there are criteria which measure the mentioned degree of achievement of a certain objectives/criteria. This means these criteria assess the efficiency of an adaptation measure. In EU-CIRCLE the outputs of the impact assessment can be used to compute this achievement degree as the difference between impacts with and without adaptation. All or certain sub-category of direct and indirect impacts can be used as criteria in the assessment procedure.

In addition the out of the resilience assessment (RAT) can also be included as a criterion. This could be done as integration of the overall resilience index or for each category of the different resilience capacities.

Stage 4: Scoring of the expected performance in comparison to the defined criteria

This stage aims to evaluate the performance of each adaptation option against the selected criteria. This leads to two main challenges. The first challenge is that the impacts of one criterion have to be measured for all adaptation options in the same unit, no matter if this unit is the physical, natural or monetary unit. This has to be ensured by the damage and impact analysis in during the analysis in CIRP, and by the resilience analysis (using the RAT).

[10] Department for Communities and Local Government: London (2009): Multi-criteria analysis: a manual, http://eprints.lse.ac.uk/12761/1/Multi-criteria_Analysis.pdf

Other challenges are the scales and units of different criteria which usually will be measured in their natural scale. In order to ensure an appropriate assessment procedure the different scale of criteria need to be transformed into a common scale. One proposition to manage this problem is to implement a kind of transformation respectively standardisation. SMART - Simple Multi-Attribute Rating Technique (see section 5.2 in D 4.7; DTU Transport, 2014[11]) - can be used for a transformation of the performance of all treated adaptation options into a degree of achievement which ranges for example from 0 to 100 points or percentage. This standardisation can be applied for all criteria. The precondition is that the performance of all adaptation options was computed in the same scale and unit for a specific criteria/input. It is not necessary that all performances in all criteria/impacts were measured in the same scale. SMART can be applied with the following formulae:

$$\frac{\Delta\, impact\ of\ an\ option\ regarding\ a\ certain\ criterion}{sum\ of\ all\ \Delta\, impacts\ of\ all\ options\ regarding\ a\ certain\ criterion} = degree\ of\ achievement$$

Stage 5: Definition of weights for all criteria

To reflect the relative importance of different criteria the assignment of specific weight is useful. As mentioned before this part is sufficient described in section 5.2 of D4.7. The procedure can follow the SMART, SWING, or SIMOS approach. Following exemplarily the formulae for SMART:

$$\frac{points\ for\ a\ certain\ criterion}{sum\ of\ all\ points\ fraom\ each\ criteria} = weight\ for\ certain\ criterion$$

This procedure is proposed to put weights on each resilience capacity within the RAT.

This requires an interaction with the decision makers because the assignment of weights is a very subjective process.

Stage 6: Computing the overall scoring/value for each adaptation option

To estimate an overall value for each adaptation option it is necessary to link the calculated weights and impact differences with each other. This can be done with a simple multiplication of both to obtain an overall value. It is subsequently also possible to rank the options referring to their total value.

Stage 7: Sensitivity analysis

Due to uncertainty it is necessary to investigate the results of the assessment procedure regarding their stability to changes in the input parameters. This sensitivity analysis should be executed based on different scenarios with varying input parameters. This includes both changing in weights and impacts. A possibility is the assessment of a worst case scenario and best case scenario. This sensitivity analysis can also be executed directly together with the operators and decision makers by "playing" with different input parameters to see directly what are the consequences of these changes.

[11] DTU Transport (2014): "The Simple Multi Attribute Rating Technique (SMART)", part of "Multi-criteria decision analysis for use in transport decision making", http://miroslawdabrowski.com/downloads/MoV/The%20Simple%20Multi%20Attribute%20Rating%20Technique%20(SMART).pdf;.

Conclusion of the assessment procedure within EU-CIRCLE

As mentioned before there is a figure in Annex A with a potential criteria-adaptation option matrix and assessment procedure. It should be mentioned that there are some points which have to be critically analysed and considered. The development of an adaptation assessment approach that can handle a large scale of input parameters and adaptation options leads to the necessity to convert parameters into common scales which always means simplification of information or a loss of information.

Dependent on the observed geographical area, included hazard scenarios and investigated CI sectors there are a large scale of potential adaptation options which aren't always comparable with each other or at least it can be difficult to find an appropriate assessment method for a common appraisal.

Other challenges are difficulties referring to the definition of objectives and criteria respectively the measuring of these. Common metrics for a specific criterion aren't always guaranteed. It is also possible that different criteria act against each other because of a diversity in their target functions. For example an adaptation option could improve the resilience and thus achieve a reduction of damages to the CI assets but on the other hand there could be environmental losses due to the new construction or impacts of the adapted infrastructure (e.g. higher traffic density leads to increased air pollution).

Related to different scales and metrics is the difficulty of providing a transparent data base. The Analysis in the context of EU-CIRCLE – not only in the adaptation framework – is closely connected to the availability, applicability and currency of data. This includes also the dependency to operators, decision makers, authorities and policy makers which are the main providers of data.

External factors are another point which is outside the scope of EU-CIRCLE. Within the project only climate related factors will be considered. Risks for critical infrastructure aren't only related to climate aspects. Also threats like cybercrime, terrorism, diseases etc. can affect critical infrastructures. Also it is possible that changes regarding the infrastructure due to an adaptation measure results in other impacts than the defined ones under direct and indirect impacts. Therefore a proxy is recommended for impacts which aren't related to security parameters like casualties or reduced damages. Exemplarily for this kind of impact are time savings/losses for passengers of a new road which was built as an adaptation of a previous road.

In order to ensure an appropriate prioritization of adaptation options all this aforementioned aspects should be kept in mind when the specific assessment procedure will selected.

4.6 First application within the Torquay case study[12]

The adaptation procedure, as described in the previous sections has been applied within EU-CIRCLE for the Case Study of Torbay, UK (CS3). The research team (UNEXE and SATWAYS) have been in contact with the local partners, Torbay Council (TORBAY) from the start of the project. Consequently the two steps and seven stages of the adaptation framework (as describe above) have been applied as follows.

Step 1 - Stage 1: Establish the decision context

The decision context for this CS involves strategic options for increasing the resilience of the region to flooding (pluvial, fluvial and coastal) for the Torbay region (Torquay, Paignton and Brixham). It was decided which extreme flooding events would be investigated and what tools would be used for decision making. CADDIES [33] was selected for flood simulation, while CIRP [34] was selected for damage and risk assessment. It was also decided that the assessment of damages would include cascading effects from flooding [35] affecting the rest of the critical infrastructure (railways, power, transport, sewerage) and business continuity, especially regarding tourism, which is very important for the region.

Step 1 - Stage 2: Identification of options

After the initial simulations of flooding in the area, a number of adaptation options have been selected by the local partner (Torbay Council) that would be feasible and relevant. The option of providing a secondary set back wall, in Paignton, was selected as the most effective intervention, but the height needed for this wall remained unknown at this stage and subject to further simulations with CADDIES and CIRP.

Step 2 - Stage 3: Identification of objectives and criteria

The main objective of any proposed adaptation option for Torbay, would be minimising the flood impact in the urban area and the damage to infrastructure and businesses. The criteria involved minimising the area being flooded and especially the damages, estimated through damage curves in CIRP. The damage curves were estimated based on local experience and through consultation with the local partner and local stakeholders.

Step 2 - Stage 4: Scoring of the expected performance in comparison to the defined criteria

The performance of the options was evaluated using the predicted flooding for each option. For each wall height the effects of flooding within the urban were assessed based on the number of properties flooded, the effects on critical infrastructure and the associated damage costs for each option.

Step 2 - Stage 5: Definition of weights for all criteria

Within this area of Torbay coastal overtopping of the sea defenses currently results in significant flooding to residential buildings, commercial buildings (hotels, guest houses, shops, etc.), highways, electricity sub-stations, sewage pumping stations and railways. It was considered that for any adaptation measures proposed the importance of each affected receptor should be weighted. Within the case study the priority weighting was given to reducing the risk of flooding to properties (residential and commercial) followed by the associated damage costs.

[12] The full and detailed report about the Case Study in Torbay and the application of this methodology can be found in Deliverable 6.4, which will be submitted separately.

Step 2 - Stage 6: Computing the overall scoring/value for each adaptation option

The overall scoring and value for each adaptation option was carried out using damage curves and flooded areas from CADDIES through CIRP. The results are summarized in the following table.

Scenario	Climate Change	Number of Residential Properties Flooded	Number of Commercial Properties Flooded	Damage Costs (£)
Current Situation	No climate change	65	97	
	20 years of climate change	91	123	
	50 years of climate change	185	176	26,166,412
Secondary Set Back Wall 1.0m in Height	No climate change	0	0	
	20 years of climate change	2	2	
	50 years of climate change	7	4	640,774
Secondary Set Back Wall 1.6m in Height	No climate change	0	0	
	20 years of climate change	0	0	
	50 years of climate change	1	2	60,693

Step 2 - Stage 7: Sensitivity analysis

Torbay Council had carried out a sensitivity analysis using different storm return periods (50, 75, 100, 200 and 1,000 year storm events). The overtopping rate for each storm event based on various secondary defense wall heights has been calculated. Higher overtopping rates will result in more properties and more critical infrastructure being affected as a result of flooding. Hence for the objectives set for the adaptation measures the sensitivity analysis has resulted in the wall height for the secondary defense being 1.6m as this will result in an acceptable level of flooding. Details of the sensitivity analysis are contained in the following table.

Climate Change Scenario	Storm Return Periods	Overtopping Rate in l/sec/m			
		Wall Height 1.0m	Wall Height 1.2m	Wall Height 1.3m	Wall Height 1.6m
20 years	50	0.17	0.00	0.00	0.00
	75	0.20	0.00	0.00	0.00
	100	0.22	0.07	0.06	0.00
	200	0.37	0.15	0.08	0.00
	1000	2.16	0.92	0.59	0.16
50 years	50	0.46	0.00	0.00	0.00
	75	0.47	0.00	0.00	0.00
	100	0.58	0.23	0.15	0.04
	200	1.06	0.42	0.27	0.09
	1000	5.82	2.74	1.87	0.57

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6 Annexes

6.1 Annex A: example for criteria-adaptation option matrix

	user weights	calculated weights	scoring			
criteria	180	100%	adaptation option 1	adaptation option 2	adaptation option 3	adaptation option 4
Implementation/Maintenance costs						
Capital expenditures (CAPEX)	10	5,56%	0	0	0	0
Operarting costs (OPEX)	10	5,56%	0	0	0	0
Resilience capacities						
Anticipatory capacity	10	5,56%	0	0	0	0
Absorptive capacity	10	5,56%	0	0	0	0
Coping capacity	10	5,56%	0	0	0	0
Restorative capacity	10	5,56%	0	0	0	0
Adaptive capacity	10	5,56%	0	0	0	0
Direct impacts						
Reduction of damages to CI assets	10	5,56%	0	0	0	0
Reduction of CI performance losses	10	5,56%	0	0	0	0
Safety indices	10	5,56%	0	0	0	0
Reduction of casualties	10	5,56%	0	0	0	0
Reduction of economic and financial losses	10	5,56%	0	0	0	0
Reduction of environmental Losses	10	5,56%	0	0	0	0
CI reputation	10	5,56%	0	0	0	0
Indirect impacts						
Reduction of impact on societal groups	10	5,56%	0	0	0	0
Reduction of casualties	10	5,56%	0	0	0	0
Reduction of economic consequences	10	5,56%	0	0	0	0
Proxy (for not climate caused impacts)	10	5,56%	0	0	0	0
		Totale Value	0,00	0,00	0,00	0,00
		Ranking	1	1	1	1