EU-CIRCLE

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

D1.4 Report On Detailed Methodological Framework - Initial Version

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This document highlights the methodical framework of the EU-CIRCLE, a roadmap on how different users can apply it to estimate resilience of interconnected critical infrastructures to climate stresses.	

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Executive Summary

One of the three priorities of the EU Adaptation Strategy[1] [1], [2] is to promote better informed decision-making by addressing existing gaps in the knowledge on climate change impacts and adaptation. EU-CIRCLE aims to contribute to this direction by defining a proper conceptual framework that may address concepts and state of the science based tools for enhancing the resilience of critical infrastructures to climate stressors.

Critical infrastructures refer to the array of physical assets, functions and systems that are vital to ensuring the EU's health, wealth, and security, thus is a main concern to sustain the service continuity. The main threats presented by climate change to infrastructures include damage or destruction from extreme events, which climate change may exacerbate [3]. Given the high level of interconnectedness of infrastructures, cross-sectorial consideration of adaptation and climate resilience should be promoted. This is critically addressed by the EU-CIRCLE framework, to support the identification and improving the knowledge of cascading effects caused by climate change on critical infrastructure. This will be implemented by using evidence-based information from a range of previous cases, as well as an in-depth analysis of critical systems and their mutual interconnectivity and (inter-) dependency.

Deliverable 1.4 describes the EU-CIRCLE methodological framework and the methodological steps for using this framework for assessing climate related risks to CIs and elaborate relevant adaptation measures. The project organized a consolidation workshop in Milan in order to adopt a common conceptual framework and terminology among participants and to promote discussions to define the project's problem space e.g. as concerns types of infrastructure elements, climate change risk drivers, hazardous events, networks of services, consequences of climate change and challenges related to CIs impact and societal disruptions.

The work described in this deliverable refers to the development of a conceptual modelling framework for resolving the EU-CIRCLE problem space as a whole, carrying out a comprehensive analysis of the relations between climate change potential, critical infrastructure capacities and the consequences generated by their interaction and interdependencies. This will be further considered in D1.5, using this modelling framework to describe and interrelate a number of case studies and scenarios of climate change originated cascading effects and the disruptions of infrastructures that they may trigger.

The methodological framework described in this document will be used for leading the development of the CIRP platform as well as for providing a step by step guide on how to use the EU-CIRCLE outcome for assessing risks and adapting critical services to unfolded challenges that the climate change may cause.

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

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1 Introduction

There are already numerous examples of how short term climate variability and long term climate change maladaptation actions impacted the service levels of critical infrastructure and the economy. Climate events in recent years have offered insight into what continued changes might mean for infrastructure: floods affecting transportation management and road systems megafires disrupting societal cohesion and economy, more extreme weather events inundating coastlines and disrupting essential services. At least 23 people were killed when floods swept the Turkish city of Istanbul, swamping houses, turning highways into fast-flowing rivers and drowning seven women in a minibus that was taking them to work[2]. Since 24 August 2007 Greece has been experiencing a number of wildfires in forests and villages in most of Peloponnesus peninsula. These fires have already burned hundreds of thousands of square kilometres of forest areas, olive groves as well as a vast number of residences in villages[3].

Climate hazard impacts on critical infrastructures may rise significantly in Europe. Damages could triple by the 2020s, multiply six-fold by mid-century and amount to more than ten times by the end of its end. Projected damages are expected to be highest for transport and energy sectors [4]. The strongest increase in damages is projected for the energy (16-fold increase by the end of the 21st century) and transport (15-fold increase) infrastructures Present overall climate hazard damages relate mostly to river floods (44%) and windstorms (27%) [4]. In the future, droughts and heat waves may become the most damaging hazards to CIs[4] [5]. Hazard impacts in the different sectors vary depending on infrastructure-specific vulnerabilities to the different hazards and the rate and magnitude of change in the latter in view of global warming. According to the latest IPCC report Southern European countries [6] will be most impacted [7]. EU-CIRCLE takes into consideration relevant accumulated knowledge and after a critical evaluation process, proposes a relative conceptual framework for supporting decisions to insure adaptation and strengthen resilience of EU member states in context of this gradually changing reality.

Adapting to climate change is critical to avoid breakdowns in the essential services delivered by key (ageing-) infrastructures in the face of extreme events, as well as to ensure resilience in the face of more incremental, but potentially cumulative impacts. Climatic changes are not taking place in a vacuum; as impacts continue to be felt amidst other economic, social and environmental stressors, the difficulty of maintaining robust and resilient infrastructure systems increases. Given the interdependencies, this also means that resilient infrastructure could mitigate negative economic, social and environmental impacts, to human health or household energy costs.

The EU-CIRCLE conceptual framework for assessing and managing climate change risks to critical infrastructure assets and networks is based upon a continuous process that brings together the involved stakeholders and the stakeholder community in an interoperable manner, aiming to address a common policy objective and/or a business decision. The EU-CIRCLE approach builds on the selection and application of appropriate modelling tools that allows users to evaluate climate related impacts to the CI operations and subsequently on the society, and define adequate responses focusing on technical aspects (e.g., modifying the design of infrastructures to make them more resistant to the increased intensity of floods), policy and legal elements (e.g., new building codes), financial aspects (e.g., specific funds allocated to support the maintenance of

[2] http://glidenumber.net/glide/public/search/details.jsp?glide=18892&record=18&last=27
[3] http://glidenumber.net/glide/public/search/details.jsp?glide=17841&record=4&last=7
[4] http://climate.ncsu.edu/edu/k12/.heatwaves

infrastructure), socioeconomic aspects (e.g., relocation or abandonment of infrastructures, change in habits and behavioral patterns associated with the use of infrastructures) and institutional aspects (e.g., awareness raising and capacity building of the infrastructure sector on climate adaptation).

Climate change and its impacts may seem a long-term challenge. However, the scale of investment in infrastructure, and the increasing exposure to climate risk, means that action to improve the climate resilience of infrastructure is needed as identified in related EUROCODES and other related standards:

- Existing infrastructure has been engineered and built for a past or current climate and may not be resilient to the future climate.
- New infrastructure will often have a life of 50 to 100 years (or more).

To ensure its viability over its lifetime, it needs to be resilient to a climate that could be significantly different. When making decisions about the provision of national infrastructure it will therefore be important to allow for future climate change and avoid closing off options, making it harder and costlier to adapt infrastructure in the future.

2 Deliverable scope and objectives

This deliverable introduces an overview of how the EU-CIRCLE project may be applied in order to have a scientifically validated response for specific policy objective and/or science question and/or a business decision. It provides the consortium's overview and approach on how to set up a methodological framework for anticipating climate change implications to the capacity and operations of the essential services of a country and thus determine appropriate *adaptation* measures to strengthen operational and societal resilience of the respective CI. Resilience, in the context of critical infrastructure and defined in the scope of D4.1, as a set of capacities to anticipate, absorb, cope, restore and adapt to disturbance.

The main objective of this deliverable is to provide a viable way of introducing the stakeholder community that will be called to use EU-CIRCLE approach and interpret the obtained results. The methodological approach that is introduced in this report is based upon the working knowledge of the partners through their participation in multiple EU funded projects, and organization of large scale table top exercises and large scale events.

The methodology introduced in this report was discussed with the EU-CIRCLE project Advisory Board and invited guests on the Annual Workshop that was organised in Milan on 18th of May 2017. Elaboration of the feedback provided by the stakeholders is provided in this deliverable, while use of the refined methodology is made in D1.5. The proposed methodological framework process, shown in Figure 1, builds upon the strategic context of the project that was decided in the 1st project meeting in Cyprus and introduced in D1.3 report on the EU-CIRCLE Strategic Context.

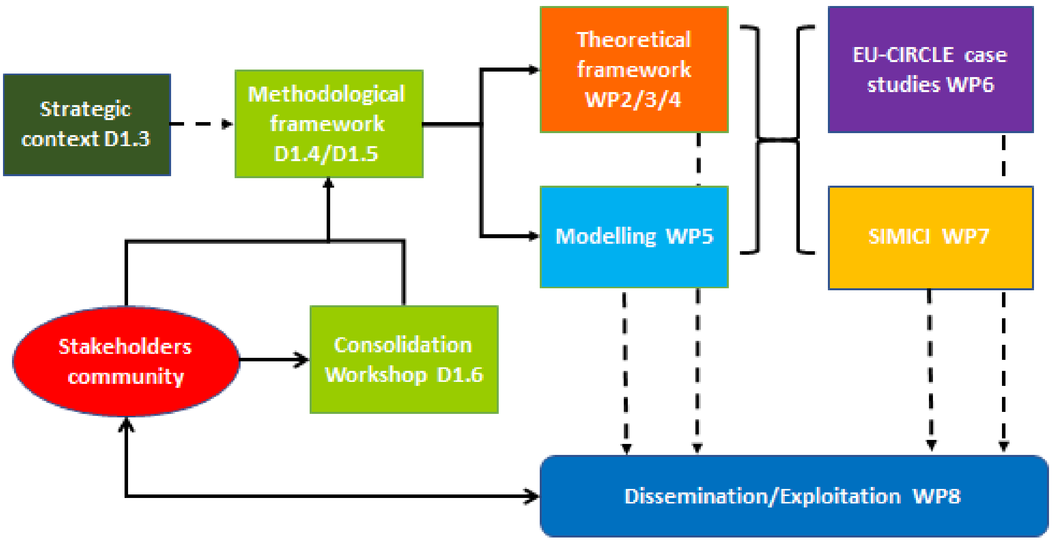


Figure 1. EU-CIRCLE conceptual framework process

In principle, climate projections is the estimation of the response of the climate system to different greenhouse gas scenarios, often build on elaborate simulations by climate models. Climate projections are distinguished from climate predictions in order to emphasise that climate projections depend upon the emission/concentration/radiative forcing scenario used, which are based on assumptions, that may or may not be realised, and are therefore subject to substantial uncertainty not related to the climate system [8]. A climate change projection is the difference between a climate projection and the current climate[5]. Climate scenario is often used synonymously with climate projection[6].

For the IPCC Fifth Assessment Report (AR5) [9], [10] another approach has been taken. Basically, the socioeconomic scenarios (called Shared Socioeconomic Pathways - SSPs) have now been decoupled from the GHG concentration scenarios (now called Representative Concentration Pathways - RCPs). This change of approach stems from the recognition that the SRES scenario's do not cover the range of uncertainties that models could represent, e.g. that even high growth scenarios may be realised at low emissions, assuming that sufficiently 'green' technologies will become available.

The greenhouse gas concentrations are used in a global climate model (GCM). Other inputs to a GCM are topography, physiography, vegetation and land cover, scenarios of other factors and a representative initial state of the atmosphere and oceans for starting the simulation. The GCM produces global climate scenarios of a range of atmospheric and oceanic variables at a pre-defined temporal resolution. The most common variables are related to temperature and precipitation, for which both mean conditions and extremes are derived. The global climate scenarios typically have a spatial resolution of 100-300 km.

To get higher resolution and a more detailed results the global scenarios can be used as input to a regional climate model (RCM). The RCM also use topography, physiography and land cover etc. as inputs, usually more detailed compared to the GCM input. The RCM produces regional climate scenarios for a predefined area of the globe.

The global or the regional climate scenarios can be used for **Impacts, Adaptation & Vulnerability** (IAV) studies of critical infrastructures. Climate change researchers provide the capability of running global and regional models to predict climate related hazards. Additional impact models are used by hazard modelers and consequences analysis is performed jointly by CI authorities (or operators) in order to identify the result of existing vulnerabilities and assess related impacts. All this aims to define adequate and proper adaptation measures that may ensure operational, societal, environmental and economic resilience against eventual climate changes. This is the process (introduced in Figure 2) that EU-CIRCLE uses to move from climate change scenarios to risk assessment and resilience planning.

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

- **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.

[5] https://www.ipcc.ch/publications_and_data/ar4/wg1/en/spmsspm-projections-of.html

[6] http://www.ipcc-data.org/guidelines/pages/definitions.html

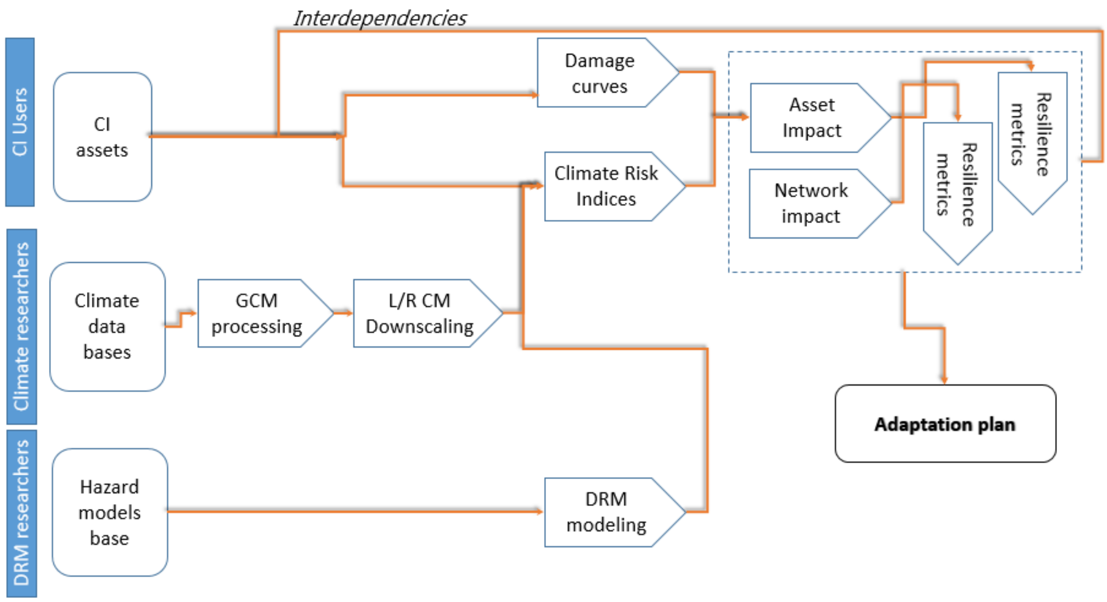


Figure 2. Scenario building and risk assessment process flow in EU-CIRCLE

The Sendai Framework[7] calls on countries to update their plans considering present and future risks, based on an improved understanding of present and future disaster risks and founded on solid scientific basis [11]. The Sendai Framework process considers risk assessments are the first steps in improving the understanding risks, which will then enable the prioritization of which sectors to focus on which measures to do first. The importance of mapping of present and the future growth of hazards and the vulnerabilities of people, infrastructures and economic activities exposed to these hazards is key. In attaining a complete understanding of risks, the importance of following a multi hazard approach, is stressed and particularly considering hazards which have either previously being ignored or have not fully considered.

A more efficient understanding of risk analysis, the importance of developing risk maps at local, regional, national and even cross-border levels, helps EU-CIRCLE potential users to fully understand the risks of the interconnected CI networks in question. The combination of common practices in disaster risk assessment and climate adaptation strategies, can be a pivotal element on how CI owners/operators and emergency responders are responding or adapting to disaster risks.

One approach followed within EU-CIRCLE is that we conducted an online questionnaire and personal interviews on how CI operators exposed to hazards understand the threats and their previous responses to them. Section 4.1 describes the scope and analysis of this process. It led the EU-CIRCLE to a better understanding of CI resilience perceptions of which organizations or persons, current operator security planning process with respect to climate change and how those responded believe that such information should be delivered. The importance of existing Operator Security Plans linked to extreme climate phenomena and natural disasters was highlighted. For example, it was proposed that a comprehensive risk mapping exercise needs to be undertaken to determine not only what worked in the past and the gaps and challenges that

[7] http://www.unisdr.org/we/inform/publications/43291

needs to be addressed in the future, but also to determine what are actually being planned disaster management in the years to come.

EU-CIRCLE shall build on existing historical disaster damage and loss data and databases, which will allow this improved understanding of risks. Without having a complete and consistent knowledge of what is being lost to disasters historically, it would be difficult to devise an appropriate response plan . EU-CIRCLE’s work on WP3 aspires to establish a consistent framework for introducing historical data in the risk assessment process, whereas the extensive use of climate data will allow potential users of the system to project and extensively assess the growth of risks into the future in the context of the changing climate.

EU-CIRCLE also could be used as the basis for developing training programs that target CI owners/operators, government officials (e.g. planners, emergency responders) from the national to the local levels. These programmes should inform about disaster risks to interconnected infrastructures and approaches such as how to mainstream CI disaster risk reduction and optimal adaptation into planning.

Several countries and organizations have been using the Hyogo Framework for Action Monitor to report on the progress made in disaster risk reduction, including in this process institutional, legislative and policy frameworks, early warning, disaster preparedness for response as well as risk assessment, education, research, and fostering public awareness and a common understanding of disaster risk have shown progress. Recent assessment of the Hyogo Framework Agreement - Action 4 [12] proposed the identification and reduction risk drivers and tackling the causes of risk creation through the introduction of disaster risk reduction into public investment, land-use planning and infrastructure projects. EU-CIRCLE aspires to contribute with a sound scientific approach on how risk will impact the exposure of European interconnected infrastructures to climate hazards and thus optimize both adaptation measures but also make more efficient use of infrastructure to the local communities.

EU-CIRCLE could contribute to a diverse number of such initiatives related to the Sendai Framework for DRR such as

- ✓ ***improving risk understanding - hazard characterization***: WP2 is completely devoted to the understanding of how climate parameters and secondary hazards (forest fires, floods, landslides) will change in magnitude and frequency under different future climate scenarios.
- ✓ ***exposure and vulnerability analysis***: The hazard characterization when combined with CI related data (related climate thresholds, building standards such as EUROCODES) could provide as assessment of the CI exposure to multi-hazards and links between vulnerabilities of CI and damages caused by extreme hazards (WP3)
- ✓ ***risk assessment***: The risk will be determined using a multi-hazard approach fully compatible and interoperable to existing frameworks set out in the National Risk Assessment Plans and the Directive 114/2008 on CI protection. Risk estimates will be based not only on direct impacts to the CI but also on the society.(WP3)
- ✓ ***improving institutional capacity on disaster risk reduction:*** the potential use of the EU-CIRCLE by the end-user community (Section 5) will allow to significantly enhance the CI capacity for enhancing CI resilience against multiple hazards, even domino ones.
- ✓ ***strengthening Early Warning Systems***: Although not within the scope of the project per se, EU-CIRCLE could be used as an early warning system for early identifying risks to

interconnected CI. The substitution of climate data with seasonal prediction models or even operational numerical weather products could provide a unique service for CI operators, as presently such systems are not available.

- ✓ Deploy EU-CIRCLE as a ***multi-dimensional and multi-hazard decision support tool*** for examining the validity and optimality of disaster reduction plans and strategies on different levels (infrastructure, region, city, …), as identified in the through the European Climate Change Programme (ECCP)
- ✓ Contribute to the ***capacity building of CI community to respond to extreme events***, accounting linked to sustaining a minimum accepted level of business continuity on stressing climate conditions
- ✓ ***Build new, strengthen and/or expand existing CI*** according to future climate conditions and adaptation needs on a facility level.

EU-CIRCLE could provide solid scientific support in improving disaster risk governance and in particular whenever there is a documented need by the project's potential users to revise its commitments to incorporate disaster risk reduction into their long term development plans as a matter of priority, and to allocate specific budgets nationally and locally to reduce disaster risks to the infrastructures. The introduction of the project's methodological approach significantly enhanced with high added value data on the CI operation, can provide decisions support on where to locate assets and provide optimal adaptation options.

EU-CIRCLE could contribute to the improvement in building codes and practices. Using CI specific climate related information (in terms of hazards, magnitudes and frequency) the proposal for construction codes and standards that address the future and new hazards not just the historically known ones would be of high added operational value in the CI community. Norway has emerged as a leader in rigorous building safety standards in terms of floods and storm surges. Over the past four years national legislation has designated a three-level classification system for all new construction. Buildings regarded as critical infrastructure, such as hospitals, must be built to withstand a 1-in-1,000 year flood in their given location.

EU-CIRCLE is about the concept of resilience to infrastructures. Although very frequently resilience is somewhat perceived as the opposite of vulnerability, resilience tends to be in line with the capabilities of people and systems to absorb a shock or stress, the effect of a specific hazard. Components/elements of resilience include inclusiveness and equity, adaptive capacity, availability, robustness, redundancy and diversified resources such as income, commodities and assets including social and ecological assets.Very often small-scale disasters are forgotten although they provide a wealth of information. These are disasters that are more frequent, smaller in size, localized and not systematically recorded.

In the past there has been too much focus on the large scale but infrequent disasters, or the intensive risks, and with very little understanding of the effects of small-scale disasters and how to address them. The accumulated consequences of recurrent small or medium-scale disasters have the greater impact .EU-CIRCLE will provide a generic approach able to handle different types of hazards and disasters to interconnected CI greatly supported by recorded losses, and also allowing to introduce the impacts from such small-scale disasters or even ageing of the CI in the process. The use of recorded disaster losses and consequential impacts will enable EU-CIRCLE to and quantify the CI impacts and socio-economic costs of recurrent disasters.

3 Define the EU-CIRCLE underlying question

There is a wealth of business decisions that EU-CIRCLE conceptual approach has to back, while complying to focused policy objectives and considering relevant scientific hypotheses. The proposed methodological framework will ensure the cooperation and synergy among the stakeholders comprising national authorities, critical infrastructure operators and researchers from the climate change and the hazard modelling communities in order to plan for resilience strengthening against climate change impacts. Such decisions may include the following:

- Increase the magnitude of design parameters or safety factors
- Perform formal risk assessment and carry out climate change risk management
- Review existing practices and consider new design and planning solutions
- Develop contingency plans for infrastructure failure
- Identify infrastructure that is at risk because of a changing climate and retrofit priority assets
- Consider increased deterioration rates in design and maintenance plans
- Consider different climate change scenarios or models for design, maintenance or planning
- Identify locations that may be vulnerable to climate change impacts and avoid them altogether or modify designs accordingly

The impacts of climate related hazards may overwhelm the capacities of critical infrastructure, causing widespread disruption of essential services across the EU member states. Extreme weather events are already affecting the production and distribution of energy, causing disruptions in electricity supply. In addition, an increase in summer temperatures and decrease in winter temperatures may lead to an increase in net electricity use. Furthermore, sea level rise, extreme storm surges, higher tides and climate-related changes in water availability could threaten coastal infrastructure that depends on energy systems.

The Intergovernmental Panel on Climate Change [8] uses the term climate change specifically as a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. EU-CIRCLE aims to support operational or entrepreneurial decisions, downscaling the analysis of time in days and of space in few kilometres. Future climate and weather patterns are projected to be markedly different across Europe [8], [13] with scientific estimates warning of the tangible threat of high-end climate change that will distend the adaptive and resilient capacities of societies and critical infrastructure to the limit [14]–[16].

Whilst climate change is described in terms of average changes in temperature or precipitation, most of the social and economic costs associated with climate change will result from shifts in the frequency and severity of extreme events [17]. Moreover, people typically experience and respond to shorter-term hazards rather than long-term trends with [18] arguing that from the perspective of the person on the ground, these distinctions are not so important it is both the risk of extreme events now and the possible longer run change in their frequency that is of concern. Although increasingly sophisticated projections are now available for climate variables such as temperature and precipitation, some of which now incorporate a probabilistic dimension, changes in (induced hazard) extreme weather events (floods, droughts, heat waves, etc.) are more difficult to model. The expected climate change effects that may have impact to the critical infrastructures in Europe, provided in [63], are revised in Table 1.

Table 1. Eventual Climate Changes in Europe and potential impact (Adapted from Koetse and Rietveld, 2009)

Climate Change effects
Slightly higher increase in mean temperatures than global mean *(problems may arise linked to telecommunication network coverage etc.)*
Warming in northern Europe largest in winter (*eventual rapid ice melting and unexpected flooding*), for the Mediterranean largest in summer (*increase of energy demand for cooling*..)
Lowest winter temperatures increase more than average temperatures in northern Europe *(icing, snow avalanches etc problems increased)*, highest temperatures increase in summer more than average in southern and central Europe *(drought and forest fire problems increased)*
Mean precipitation increase in northern Europe (*probability of more frequent flooding*) and decrease in most of the Mediterranean area (*increase of wildfire propagation rate of spread*)
Extremes in precipitation very likely to increase in northern Europe (*flooding incidents*). Increase in risk of summer drought in central EU (*increase demand for water and cooling*)
Changes in wind strength uncertain, although it is more likely that average and extreme wind speeds will increase (*coastal flooding, storm surges, eventual impact to renewable energy farms and ageing infrastructures*)
Duration of snow season and snow depth very likely to decrease , but extreme events may occur *(transport problems, damages from avalanches etc.)*

Regional vulnerability and adaptive capacity to climate change differ in the various EU regions. Southern EU and the Mediterranean basin are expected to be vulnerable mainly due to temperature rise and precipitation decrease. Mountainous areas, in particular Alps in Central Europe shall experience temperature rise larger than average in EU MS, which may contribute to landslides and flash flooding. Coastal zones are expected to suffer from sea-level rise (also linked with Arctic sea ice coverage) and increase of sea surface temperature, which may jeopardize fish stocks. An infographic of the expected changes of climate that may have implications to the critical infrastructures across the regions of the EU, provided by [19] is shown in Figure 3.

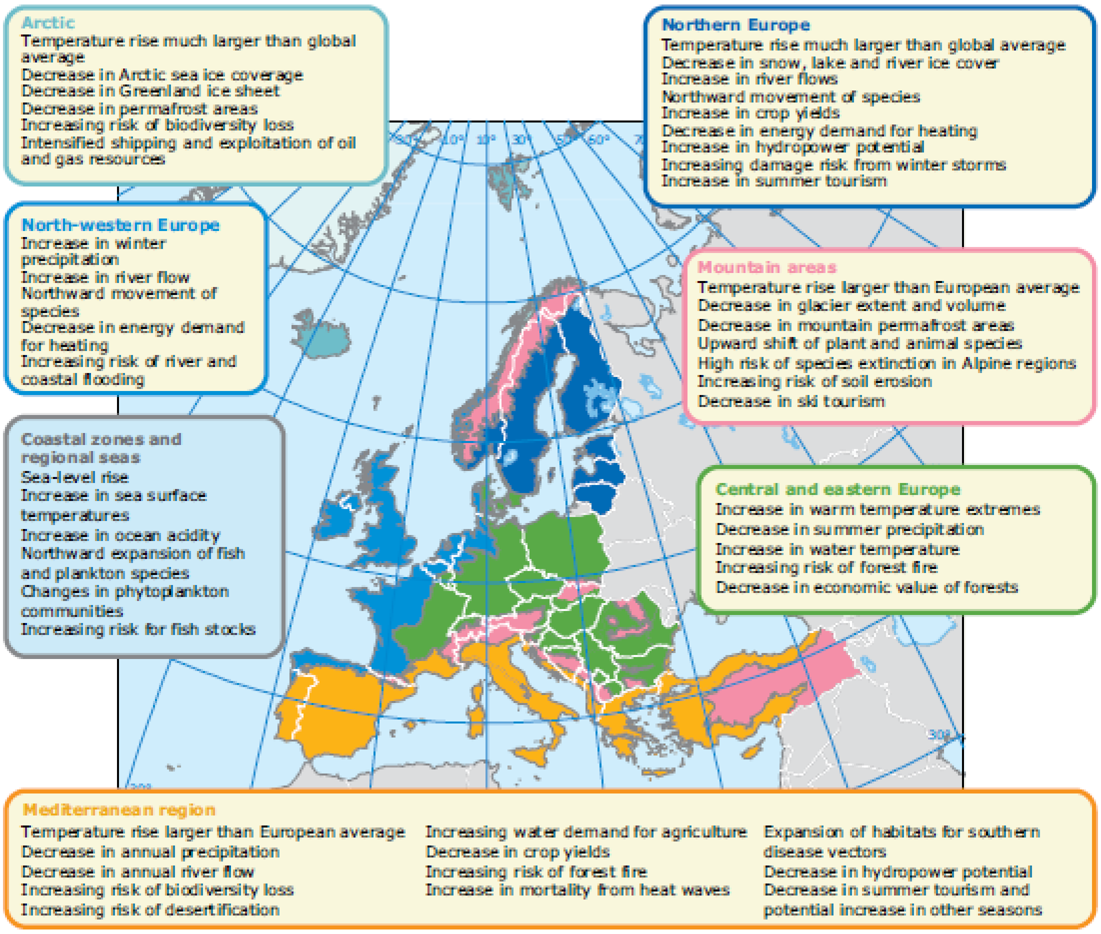


Figure 3. Key observed and projected changes in climate in Europe (Source [19])

The conceptual framework of EU-CIRCLE is properly defined to be able to address risk assessment, impact and consequences analysis and planning of service resilience in line with the above mentioned context of climate change. Appropriate modelling and simulation approaches are incorporated into the CIRP project platform supporting quantitative probabilistic risk analysis of a single CI. However use of tools such as the Risk and Vulnerability Analysis, the Preliminary Hazard Analysis (PHA), Probabilistic Safety Analysis and Quantitative Risk Analysis offer a methodological framework that identifies, prioritizes, assesses and manages risks to complex, large-scale systems.

3.1 Link to EU policies

The methodological framework proposed by EU-CIRCLE is based on a synthesis of various policies for providing valid scientific support to national and European authorities with regard to the strengthening of critical infrastructures' resilience;

- The EU Strategy on Climate adaptation, as identified in [20] - An EU Strategy on adaptation to climate change, and detailed in SWD (2013) 137 [21] - Adapting infrastructure to climate change
- National Risk Assessment Plans (NRA) as identified in SWD (2014) 134, Brussels, 8.4.2014 [22], where CI have been identified as a national priority in several countries (DE, NL, IE,…)

- Directive 2008/114/EC [23], on the identification and designation of European critical infrastructures and the assessment of the need to improve their protection, 8.12.2008
- Reports by the IPCC[8] [9], [10].

A synthesis of the above policy documents delineates the EU-CIRCLE approach for managing climate change impact to the critical infrastructure operation along the following driving lines:

i. The protection of CI is a collaborative process, where any change in its properties and operational characteristics to combat extreme weather phenomena shall by no means compromise other functions such as security levels, health and safety operations, and vice versa.
ii. According to the "all hazards" approach, risk assessment should include any type of risk whether is man-made, technological accident or stemming from natural causes including climate related events, in a way that will allow prioritization of risk.
iii. Risk Assessment should be comparable across sectors and diversified to capture the unique nature and characteristics of each CI type, whereas impacts should include as common best practices from NRA and Dir 114/2008.
iv. As CI are projects scheduled to last for decades, the ageing element should be an inherent part of the analysis.

Additionally, a core component of our proposed methodological approach is to introduce the interdependencies of heterogeneous types of CI into this analysis.

3.2 State of the art review

Scientific predictive forecasting indicates that the foremost consequence of climate change and global warming is a greater frequency and severity of extreme weather events with potentially catastrophic effects for organizations, industries, and society [24]. A study conducted by [25] analysed changes in daily precipitation extremes under climate change using output from an ensemble of transient climate model simulations and concluded that the return period of extreme precipitation events may, on average, be reduced by a factor of two. This means that, under a changed climate, a current 20-rainfall event could be expected every 10 years, on average, by the end of the 21st century. This is a critical finding directly linked with the resilience of critical infrastructures designed according to eventually inadequate climate projections.

Accordingly, factoring in 'change' is a primary challenge for vulnerability and risk assessment when considering climate change as what were traditionally observed as constants are now becoming variables. For example, Hydroelectric installations in the Alps which primarily rely on glacial thaw, are likely to face difficulties in managing varying flows both seasonally and annually, culminating in increased run-off than designed for, thusly impacting on the management of flood defence or irrigation in warmer periods. Moreover, flow extremes in conjunction with other environmental change factors can induce hazards such as subsidence, landslides and siltation. The fluctuations can disrupt hydroelectric power generation, erode infrastructure and damage valuable regional industries. Nuclear power generation may also face challenges in ensuring output and site security. Reactors usually require a large amount of water for cooling, as a result, they are generally situated in areas that are susceptible to environmental change - normally either located in coastal areas making them increasingly vulnerable to sea

[8] https://www.ipcc.ch/report/ar5/

level rise, extreme weather and storm surges, or located rivers, lakes or reservoirs and are dependent on increasingly valuable, and variable, freshwater supplies [26].

Climatic variability in temperature extremes has the potential to cause maintenance problems, according to a study of climate impacts on transportation systems in the U.S. [27]. A higher frequency of very hot days will lead to a greater need for maintenance of roads and asphalt pavement, rail tracks and freight facilities, vehicles, and facility buildings and structures because of degradation of construction materials – where the drying-out of the ground can result in pipeline breaks and undermine any infrastructure built on top of it [28], [29]. In terms of energy supply, although major oil and gas pipelines generally run underground, past events indicate that they may be vulnerable to floods, particularly in areas where flooding can result in high water speeds that can cause soil erosion and lead to exposure of buried pipes. As [30] highlight, in 2000 in Mondego, Portugal, prolonged and heavy rains caused overtopping of dams and several levee breaks, exposing a major underground gas pipeline and posing a threat to nearby settlements.

Obviously, there is a need to build anticipatory adaptation and organizational resilience to the relatively uncertain and unexpected impacts of climate change on CI. Hence, allowing for future climate change adaptation in the design and operational parameters of new and current CI is of fundamental and pressing strategic importance, to ensure cost effective fit for purpose CI over the lifetime of the assets. There is an obligation to revisit the risk posed to new and existing CI and to develop practical (evidence based) responses by risk-based techniques and a set of validated tools and data sets tailored to practical needs reflecting the level of the risk and the severity of impact (such as social, economic, environmental) that would result in CI failure due to climate change.

An extensive literature review of published papers concerning climate change combined with critical infrastructure

The number of available methodologies and funded projects in risk assessment for CI is large. The majority of funded projects is focused on assessing impacts specific to certain types of infrastructures and with different scope and time frame of the analysis. Another complicated issue pertains to the complexity of the interconnected infrastructures [31], relating to the time and computational expressiveness of a modelling system to effectively analyze risk and resilience across large networks.

3.3 Adaptation options typologies

Adaptation options are defined by the IPCC in [10] as "the array of strategies and measures that are available and appropriate for addressing adaptation needs. They include a wide range of actions that can be categorized as structural, institutional, or social." Figure 4, presents a visual notation of the concepts introduced in the following paragraphs.

Adaptation to climate change addresses a wide range of strategies and actions. There are different typologies to classified adaptation actions:

- The IPCC [8] 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 is 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.
- UKCIP [32] proposes another typology for planned adaptation based on the following distinction[9] :
  - “Building adaptive capacity” options, which aim is to improve operators capacity to implement adaptation actions (capacity building, knowledge diffusion, etc.).
  - “Delivering adaptation actions” which rely on practical actions to reduce vulnerability or exploit positive opportunities.
- The European Commission [33] makes a distinction between:
  - Structural adaptation measures on “grey infrastructures”: engineering options to make buildings and infrastructures more resilient to CH.
  - Structural adaptation measures on “green infrastructures”: preserve natural ecosystems to maintain ecosystem services.
  - Soft measures (non-structural): economic incentives, awareness raising, governance, etc.
- Another typology used by UKCIP [32] is based on the type of action[10]:
  - Temporary (e.g. use large umbrellas to reduce solar heat gains)
  - Managerial (e.g. introduce flexi-time; facilitate working from home)
  - Technical (e.g. refurbish building; enhance flood defences)
  - Strategic (e.g. commission new building with climate resilient design as part of a planned programme).
- In [34], [35] the distinction is made between:
  - Incremental measures: adjustments or extension of actions already implemented. Ex: increase dikes’ height to address sea level rise.
  - Transformational measures (when incremental options are insufficient): these options should satisfy the following criteria: its aim is to adapt to climate change (not only to climate variability); it’s a new options for the CI.
- Carter Typology [36] makes a difference based on mobilized means:
  - Structural options.
  - Evolution of legal framework.
  - Evolution of standards and regulations.
  - Institutional actions.
  - Education.

[9] http://www.ukcip.org.uk/about-adaptation/

[10] http://www.ukcip.org.uk/wizard/adaptation-options/

  - Funding actions
  - Research and development.
  - Market mechanisms.
  - Technological developments.
- In its latest assessment report [35], the IPCC describes adaptation options
  - Structural and Physical Options
    - Engineering and Built Environment
    - Technological Options
    - Ecosystem-Based Adaptation
  - Service Options
  - Social Options
  - Institutional Options

Table 2. Example of adaptation actions categories from the IPCC WGII AR5 report [9], [10]

Table 14-1 | Categories and examples of adaptation options.

Category		Examples of options*
Structural/ physical	Engineered and built environment	Sea walls and coastal protection structures (5.5.2 and 24.4.3.5; Figure 5-5); flood levees and culverts (26.3.3); water storage and pump storage (Section 23.3.4); sewage works (3.5.2.3); improved drainage (24.4.5.5); beach nourishment (5.4.2.1); flood and cyclone shelters (11.7); building codes (Section 8.1.5); storm and waste water management (8.2.4.1); transport and road infrastructure adaptation (8.3.3.6); floating houses (8.3.3.4); adjusting power plants and electricity grids (10.2.2; Table 10-2)
	Technological	New crop and animal varieties (7.5.1.1.1, 7.5.1.1.3, 7.5.1.3; Box 9-3; Table 9-7); genetic techniques (27.3.4.2); traditional technologies and methods (7.5.2, 27.3.4.2, 28.2.6.1, and 29.6.2.1); efficient irrigation (10.3.6 and 22.4.5.7; Box 20-4); water saving technologies (24.4.1.5 and 26.3.3) including rainwater harvesting (8.3.3.4); conservation agriculture (9.4.3.1 and 22.4.5.7); food storage and preservation facilities (22.4.5.7); hazard mapping and monitoring technology (15.3.2.3 and 28.4.1); early warning systems (7.5.1.1, 8.1.4.2, 8.3.3.3, 11.7.3, 15.4.3.2, 18.6.4, 22.2.2.1, 22.3.5.3, and 22.4.5.2); building insulation (8.3.3.3); mechanical and passive cooling (8.3.3.3); renewable energy technologies (29.7.2); second-generation biofuels (27.3.6.2)
	Ecosystem-based[a]	Cross Chapter Box CC-EA, Ecological restoration (5.5.2, 5.5.7, 9.4.3.3, and 27.3.2.2; Box 15-1) including wetland and floodplain conservation and restoration; increasing biological diversity (26.4.3); afforestation and reforestation (Box 22-2); conservation and replanting mangrove forest (15.3.4 and 29.7.2); bushfire reduction and prescribed fire (Section 24.4.2.5; Box 26-2); green infrastructure (e.g., shade trees, green roofs) (8.2.4.5, 8.3.3, 11.7.4, and 23.7.4); controlling overfishing (28.2.5.1 and 30.6.1); fisheries co-management (9.4.3.4 and 27.3.3.1); assisted migration or managed translocation (4.4.2.4, 24.4.2.5, 24.4.3.5, and 25.6.2.3); ecological corridors (4.4.2.4); ex situ conservation and seed banks (4.4.2.5); community-based natural resource management (CBNRM) (22.4.5.6); adaptive land use management (Section 23.6.2)
	Services	Social safety nets and social protection (Box 13-2; 8.3, 17.5.1, and 22.4.5.2); food banks and distribution of food surplus (29.6.2.1); municipal services including water and sanitation (3.5.2.3 and 8.3.3.4); vaccination programs (11.7.1), essential public health services (11.7.2) including reproductive health services (11.9.2) and enhanced emergency medical services (8.3.3.8); international trade (9.3, 9.4, and 23.9.2)
Social	Educational	Awareness raising and integrating into education (11.7, 15.2, and 22.4.5.5); gender equity in education (Box 9-2); extension services (9.4.4); sharing local and traditional knowledge (12.3.4 and 28.4.1) including integrating into adaptation planning (29.6.2.1); participatory action research and social learning (22.4.5.3); community surveys (Section 8.4.2.2); knowledge-sharing and learning platforms (8.3.2.2, 8.4.2.4, 15.2.4.2, and 22.4.5.4); international conferences and research networks (8.4.2.5); communication through media (22.4.5.5)
	Informational	Hazard and vulnerability mapping (11.7.2, 8.4.1.5); early warning and response systems (15.4.2.3 and 22.4.5.2) including health early warning systems (11.7.3, 23.5.1, 24.4.6.5, and 26.6.3); systematic monitoring and remote sensing (15.4.2.1 and 28.6); climate services (2.3.3) including improved forecasts (27.3.4.2); downscaling climate scenarios (8.4.1.5); longitudinal data sets (26.6.2); integrating indigenous climate observations (22.4.5.4, 25.8.2.1, and 28.2.6.1); community-based adaptation plans (5.5.1.4 and 24.4.6.5) including community-driven slum upgrading (8.3.2.2) and participatory scenario development (22.4.4.5)
	Behavioral	Accommodation (5.5.2); household preparation and evacuation planning (23.7.3); retreat (5.5.2) and migration (29.6.2.4), which has its own implications for human health (11.7.4) and human security (12.4.2); soil and water conservation (23.6.2 and 27.3.4.2); livelihood diversification (7.5.1.1, 7.5.2, and 22.4.5.2); changing livestock and aquaculture practices (7.5.1.1); crop-switching (22.3.4.1); changing cropping practices, patterns, and planting dates (7.5.1.1.1, 23.4.1, 26.5.4, and 27.3.4.2; Table 24-2); silvicultural options (25.7.1.2); reliance on social networks (Section 29.6.2.2)
Institutional	Economic	Financial incentives including taxes and subsidies (Box 8-4; 8.4.3 and 17.5.6); insurance (8.4.2.3, 13.3.2.2, 15.2.4.6, 17.5.1, 26.7.4.3, and 29.6.2.2; Box 25-7) including index-based weather insurance schemes (9.4.2 and 22.4.5.2); catastrophe bonds (8.4.2.3 and 10.7.5.1); revolving funds (8.4.3.1); payments for ecosystem services (9.4.3.3 and 27.6.2; Table 27-7); water tariffs (8.3.3.4.1 and 17.5.3); savings groups (8.4.2.3 and 11.7.4; Box 9-4); microfinance (Box 8-3; 22.4.5.2); disaster contingency funds (22.4.5.2 and 26.7.4.3); cash transfers (Box 13-2)
	Laws and regulations	Land zoning laws (22.4.4.2 and 23.7.4); building standards (8.3.2.2, 10.7.5, and 22.4.5.7); easements (27.3.3.2); water regulations and agreements (26.3.4 and 27.3.1.2); laws to support disaster risk reduction (8.3.2.2); laws to encourage insurance purchasing (10.7.6.2); defining property rights and land tenure security (22.4.6 and 24.4.6.5); protected areas (4.4.2.2); marine protected areas (Box CC-CR Chapter 6; 23.6.5 and 27.3.3.2); fishing quotas (23.9.2); patent pools and technology transfer (15.4.3 and 17.5.5)
	Government policies and programs	National and regional adaptation plans (15.2 and 22.4.4.2; Box 23-3) including mainstreaming climate change; sub-national and local adaptation plans (15.2.1.3 and 22.4.4.4; Box 23-3); urban upgrading programs (8.3.2.2); municipal water management programs (8.3.3.4; Box 25-2); disaster planning and preparedness (11.7); city-level plans (8.3.3.3 and 27.3.5.2; Boxes 26-3 and 27-1), district-level plans (26.3.3), sector plans (26.5.4), which may include integrated water resource management (3.6.1 and 23.7.2), landscape and watershed management (4.4.2.3), integrated coastal zone management (2.4.3, 5.5.4.1, and 23.7.1), adaptive management (2.2.1.3 and 5.5.1.4; Box 5-2), ecosystem-based management (6.4.2.1), sustainable forest management (2.3.4), fisheries management (7.5.1.1.3 and 30.6.2.1), and community-based adaptation (5.5.4.1, 8.4, 15.2.2, 21.3.2, 22.4.4.5, 24.5.2, 29.6.2.2, and 29.6.2.3; Tables 5-4 and 8-4; FAQ 15.1)

Notes: These adaptation options should be considered overlapping rather than discrete, and are often pursued simultaneously as part of adaptation plans. Examples given can be relevant to more than one category.

[a] A number of these would fall under the term "green infrastructure" in some European Commission documents (European Commission, 2009).
*WGII AR5 sections containing representative sample of adaptation options.

Besides, some adaptation actions can be considered as maladaptive actions. Maladaptation is defined when “intervention in one location or sector could increase the vulnerability of another location or sector, or increase the vulnerability of the target group to future climate change” [9], [10].

Table 3. Example of maladaptive actions from the IPCC WGII AR5 report [9], [10]

Table 14-4 | A selection of examples of actual or potential maladaptive actions from this report.

Broad type of maladaptive action	Examples in AR5
Failure to anticipate future climates. Large engineering projects that are inadequate for future climates. Intensive use of non-renewable resources (e.g., groundwater) to solve immediate adaptation problem	22.3, 22.4.8.5
Engineered defenses that preclude alternative approaches such as EBA	Box CC-EA; 15.2.2
Adaptation actions not taking wider impacts into account	22.4.5.8, 25.4.2, and 26.9.4
Awaiting more information, or not doing so, and eventually acting either too early or too late. Awaiting better “projections” rather than using scenario planning and adaptive management approaches	7.5.1.2.2, 8.5.2, and 16.5.2
Forgoing longer term benefits in favor of immediate adaptive actions; depletion of natural capital leading to greater vulnerability	13.2.1.3; 22.4.5.8; 25.9.1
Locking into a path dependence, making path correction difficult and often too late	16.3.2; FAQ 25.1
Unavoidable ex post maladaptation, e.g., expanding irrigation that eventually will have to be replaced in the distant future	17.5; see also 5 and 6 above
Moral hazard, i.e., encouraging inappropriate risk taking based, e.g., on insurance, social security net, or aid backup	17.5 and 29.8
Adopting actions that ignore local relationships, traditions, traditional knowledge, or property rights, leading to eventual failure	12.3, 12.5.2; 26.9.4
Adopting actions that favor directly or indirectly one group over others leading to breakdown and possibly conflict	13.1.1 and 13.1.4
Retaining traditional responses that are no longer appropriate	21.3.2 and 22.4.5.8
Migration may be adaptive or maladaptive or both depending on context and the individuals involved	26.2.1, 26.8.3, 29.3.3, 29.6.2.4

Note: These examples of maladaptation represent a set of cases found in the report that might help the readers to understand the rich range of circumstances in which maladaptive actions might arise. They do not represent a formal categorization of type of maladaptation.

Based on the analysis of the above typologies and the purposes of EU-CIRCLE, the adaptation model will look at the following typologies of adaptation actions

- **Type of action:** Soft and structural measures
- **Object of the action:** Action to be implemented at CI level or in its operating environment (which implies multiple stakeholders, not only the CI operators or owners)
- **Purpose of the action:** Planned adaptation only, including in response to regional policy objectives (i.e. induced by policy measures, regulations or norms) and excluding autonomous and anticipatory adaptation options.
- **Time horizon:** various time horizons are concerned regarding the implementation phase (action to be implemented in the short/medium/long term) and the lifetime of the action (one-off isolated action / long-lasting or permanent action), etc.

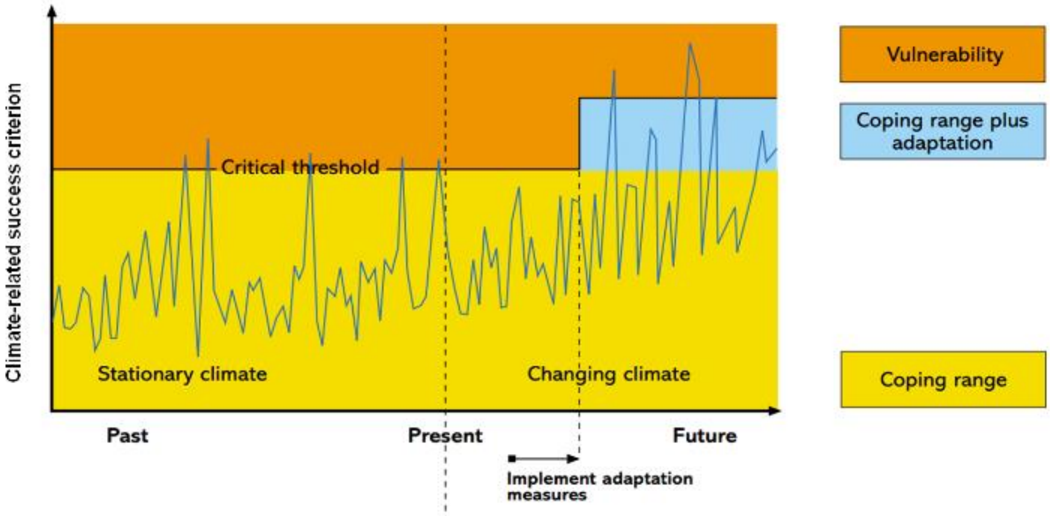


Figure 4. The relationship between coping range, critical threshold, vulnerability, and a climate-related success criterion for a project [9], [10]

Adaptation of CI structures to climate change

CI, as large scale structures with both loading and structural properties, follow strict and comprehensive Building Regulations and building codes, both on national (NEN standards) and on European basis (CEN standards; the so-called Eurocodes). The structural properties are treated in separate, material dependent standards [37]–[39]. The loads are given in a series of standards under number [40]. In these codes, methods to determine a design load are given. The design load and design resistance must have values which are chosen so to obtain a structure that is safe enough during its lifetime. This implies that the design load has a very small probability of exceedance of about 10^{-4} or 10^{-5}. To establish these design loads, statistical distributions are needed of the extreme loads having very long returns periods. Traditionally, design codes have used past climatic load data to help forecast future loads on buildings. Since this extrapolation to the future is based on historic records of meteorological observations, as fundamental assumption, the possible existence of long term trends with a period of some decades or so is not taken into account. When climate change influences structural risks, the distribution of the load, from which the design load results, can probably no longer be based only on measurements from the past, since the future development of the load under climate change has to be included.

The climatic data on which the current generation of the Eurocodes is based are mostly 10-15 years old, with some exceptions of recent updates of national data, e.g. the case of the new maps for climatic actions of the Czech Republic. The Structural Eurocodes which deal with the design of buildings, infrastructures and civil engineering structures are already implemented within most of the CEN Members CEN/TC 250 “Structural Eurocodes” has just started the works on the evolution of the Eurocodes under the Mandate M/515, and the second generation of the Eurocodes is expected by 2020. The standardisation works relevant to the climate change encompass:

- revision and update of EN 1991-1-3 on snow loads, EN 1991-1-4 on wind actions, and EN 1991-1-5 on thermal actions, preparation of background documents;
- conversion of ISO standards on actions from waves and currents, and on atmospheric icing to ISO-EN standards;

- preparing a document with the probabilistic basis for determination of partial safety factors and load combination factors, taking into account the variability and interdependence of climatic actions;
- technical report (TR) by Project Team (PT) on SC1.T5 analysing and providing guidance for potential amendments for Eurocodes with regard to structural design addressing relevant impacts of future climate change (general and material specific).

The above documents highlight the need to estimate of expected changes, made in terms of the Eurocodes concept for the characteristic values of the variable climatic actions as the upper value of a random variable with annual probability of exceedance of 2% (i.e. a “reference period” of 50 years) for future time windows (typically of 30-40 years) up to the end of the available modelled data time period.

Four highly important case studies on an EU wide level were selected in view of a EU-wide analysis about future exposure vulnerability and adaptation (Table), covering different aspects of climate change (extreme precipitation and floods, heat stress, sea level rise), infrastructure types (roads, rail track, bridges) and involved life spans[11] (7 years to more than 100 years) [41].

Table 4. A focus on road and rail transport infrastructures

				Area for cost quantification		
Climate change effect	**Mode**	**Transport system component**	**Typical infrastructure life**	**Asset at risk**	**Adaptation**	**Avoided impacts**
Change in temperature	road	infrastructure	7-10 years maintenance cycle	Mapping future changing risk for road pavemet cracking	changing asphalt binder	- reduce road pavement degradation- avoid accidents (vehicle damages, injuries, fatalities)
	rail	infrastructure and operation	50-100 years track life	Mapping future changing risk for rail bucklings	speed limitationschanging track conditions	- reduce rail track buckling damage- avoid accidents (vehicle damages, injuries, fatalities)
Change in precipitation and river floods	road rail	infrastructure (bridges)	> 100 yr life	Mapping future risk for river bridge scour	- rip rap, - strenghtening of bridge foundations with concrete	concrete- damages to bridges due to scour- accidents, fatalitiesSea
Sea level rise and sea storm surges	Road	infrastructure	> 100 yr life	Value of infrastructure at risk of permanent or temporary inundation	-	-

[11] https://ec.europa.eu/jrc/en/research-topic/transport-sector-economic-analysis

The level of uncertainty and availability regarding projected changes varies significantly among the different climate change stressors. The two main climate parameters which can be derived from climate model scenario and their regional downscaling concern **temperature and precipitation**. Several severe events are associated with precipitation, although the causal relation can hardly be quantitatively assessed.

- ✓ The analysis of **River floods** in the framework of PESETAII [42] have been used as an input for the transport study (bridge scour case).
- ✓ **Flash floods**, as associated with heavy rainfalls (in case of thunderstorms for instance) are expected to become more frequent in certain regions of Europe. Extreme precipitation (~>50 mm/day) can be a proxy indicator for future trends in flash flood event frequencies.
- ✓ **Landslides** are the consequences of multi-factors, including soil moisture – as influenced by rainfalls intensity, soil types and slopes. As in the case of flash floods, heavy precipitations (e.g. precipitations more than 150-200 mm/24h) could only be used as a very rough proxy indicator to identify potential risks, in the case of mountainous regions.
- ✓ So far, **wind gusts** are not properly simulated and for the purpose of this study, only few and regional studies could be referred to assess the vulnerability of transport.
- ✓ Regarding **sea level rise**, The 2007 Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) [8] projected that global mean sea levels would rise by **18–59 cm** above 1990 levels by the 2090s (where the lower bound corresponds to the lower estimate for the lowest emissions scenario.

Infrastructures are traditionally designed to cope with various stresses along their life, including extreme weather events as historically and currently experienced. Regular maintenance is normally performed to maintain sufficient resilience to the weather conditions. Design codes are usually defined to achieve a high level of resilience to extreme events for which the occurrences (return period) is set in accordance to the typical design life spans.

Table 5. Infrastructures typical lifetime

Bridges	Roads	Road pavement	Culverts	Causeways in low-lying coastal zones	Drainage (surface):
100 yrs	30-40 yrs	10-25 yrs	20-100 yrs	20-100	20 yrs

Each mechanism by which weather-induced deteriorations occur is specific to the infrastructure and, the level of deterioration, depends on a multiplicity of environmental parameters (e.g. locations, soil, traffic load,…).

4 Interaction with EU-CIRCLE stakeholders

The stakeholders of EU-CIRCLE have been a substantial collocutor of the consortium for defining and detailing the methodological framework of the project. The EU-CIRCLE community comprises CI owners and operators, CIP National Authorities, International and European Associations of CI operators, NCPs of EPCIP, Civil Protection Organizations, Emergency responders, Health Emergency Agencies, Urban planners, Industrial and Environmental Engineers, Climate and Climate change community, as identified in D8.1. The Insurance sector, as a critical partner for risk sharing, is also considered as a significant stakeholder of EU-CIRCLE and the methodological framework of the project has been discussed with relevant representatives. Weather coverage is an emerging insurance product, with payouts based on measurable weather events and not on individual loss assessments. Complementarities between government-guaranteed and private insurance products could be supported by the EU-CIRCLE methodological framework and can be mutually beneficial to both parts.

The EU-CIRCLE consortium has already been engaged in interaction with representatives of the above groups in order to discuss eventual climate change impacts to CIs, the methodological framework of the project and to familiarize end users with the approach adopted by the consortium for assessing climate change related risks to essential services as well as for considering resilience concepts and indicators within the operators security plans.

4.1 Collecting information from stakeholders

There are several problems related to information security and building trust when interacting with security end users, owners and operators of critical infrastructures.

A number of data collection means and techniques have been used in context of EU-CIRCLE in order to investigate and understand the current situation of managing security issues and protecting critical infrastructures. A properly prepared questionnaire was distributed in context of project workshops and relative events such as the “Critical Infrastructure Protection” stakeholders training event held in Athens (Greece), organized in December 2015 by KEMEA in cooperation with DG Home and JRC Ispra. A related online questionnaire[12] was also created and was asked to be filled by EU-CIRCLE stakeholders. The feedback provided by the EU-CIRCLE stakeholders community to these questionnaire is presented in the following statistics gallery. A total of 76 questionnaires was completed in this way, mainly by representatives from the transportation, energy and ICT sector (Thumb a). Most of the respondents replied positively to the question of having already in place an Operator Security Plan (OSP), which consider mostly intentional and accidental threats as well as natural hazards (Thumb b). The OSP includes risk analysis, identify critical assets for the CI operation, as well as interconnection and interdependency information (Thumb c). Flooding, forest fires and extreme rainfall are the more important hazards challenging CIs (Thumb d). The analysis of the information collected has shown that climate change aspects aren’t included in the OSP and risk assessment practices of the CI operators (Thumb e). Business continuity plan is considered part of the OSP documentation (Thumb f), while operators and technical personnel are not very familiar with concepts such as resilience and resilience indicators (Thumb g). The respondents linked though resilience with climate change through risk mitigation and impact/consequences analysis (Thumb i). Finally the feedback to the questionnaire has shown that end users are normally (67%) addressing internally climate related risks for the facility that they operate (Thumb j).

[12] http://eu-circle.kemea-research.gr/index.php/survey/index/sid/154347/newtest/Y/lang/en

The cooperation between the consortium and the EU-CIRCLE stakeholders led to a better understanding of what CI perceive as resilience, how they work as regards their preparedness to address threats and manage natural hazards, in particular related to climate change as well as how they believe that relevant information should to be delivered to them to improve their mitigation and adaptation plans. The importance of existing Operator Security Plans linked to extreme climate phenomena and natural disasters was highlighted. For example, it was proposed that a comprehensive risk mapping exercise needs to be undertaken to determine not only what worked in the past and the gaps and challenges that needs to be addressed in the future, but also to determine what are actually being planned disaster management in the years to come.

The interaction with the users included also interviews and focused discussions concerning impact and analysis of harsh climate elements to the various sectors of essential services. During these meetings the methodological framework of EU-CIRCLE was tested to be consistent with the mindset, expertise and experience of the CI stakeholders. Results collected during these meetings formed the starting point for the definition of relevant scenarios of climate change impact to the various critical sectors of the economy. The following tables summarize these conclusions for the Water (Table 6), Energy (Table 7), Transport-Rail (Table 8), Transport-Road (Table 9) and Transport-Maritime (Table 10) sector [19], [35], [43]–[46].

Table 6. Climate impact scenarios on the Water sector CI elements

	WATER*	WASTEWATER**
HAZARD	IMPACTS	IMPACTS
# of days with Tmax(heat stress): Tmax≥ 32 °C, Daily mean(TG), max (TX), min(TX), Drought, drier summers	*Increased water demands and pressure on infrastructure, socioeconomic drought, loss of potable water, availability of hydropower supply, dam failure: inadequate spillway design, geological instability, internal erosion*	*Increased demand for water delivery and collection systems*
Cold waves: Tmean≤ 0 °C, Tmean≤ -7 °C, Tmean≤ -20 °C, permafrost	*Rupture of drinking water lines, Rupture of water storage tanks*	*Potential rupture of drinking water and sewage lines, sewage storage tanks, Failure of frozen-core dams on tailing ponds due to thawing and differential settlement*
Extreme precipitation - flood # of days R≥30- 50mm/day, average annual precipitation Rmax_7day, Evapotranspiration, runoff, Total daily precipitation	*poor maintenance or landslides to the reservoir, flooding*	*Stormwater infrastructure more frequently exceeded, Urban drainage systems could fail, causing problems such as sewer backups and basement flooding, require increased capacity on wastewater treatment facilities, potential impact on the strength in wastewater systems, pipeline ruptures, buildings, tankage, housed process equipment affected by flooding*
Landslides (R≥ 150-200 mm/24h)		
Duration and extent of snowcover	*water storage capacity*	*(Dams, Reservoirs, Aquifers, Hydroelectric Generators)
Sea level rise, sea storm	*Saltwater intrusion in groundwater aquifers*	**(Treatment Facilities, Culverts, Sewers, Storm Drains, Pipes)
extreme winds, wind gusts(6h): WG ≥ 17 m/s , WG ≥ 25 m/s	*movement of trees and roots*	

Table 7. Climate impact scenarios on the Energy sector CI elements

	COAL	NATURAL GAS	RES
HAZARD	**IMPACTS**	**IMPACTS**	**IMPACTS**
# of days with Tmax(heat stress): Tmax≥ 25 °C, Tmax≥ 32 °C, Tmax≥ 43 °C	*increased electricity demand for cooling/heating increased resistance of overhead lines increased sag of overhead lines damage to underground cables(drought) reduced capacity to underground cables Increased incidence of wildfire*	*increased electricity demand for cooling/heating, affection in generation, transmission, and transformer substations increased resistance of overhead lines increased sag of overhead lines Increased incidence of wildfire*	*cooling water issues for thermal power plants reduced generation efficiency for thermal power plants, availability of the hydropower supply Increased incidence of wildfire*
Cold waves: Tmean≤ 0 °C, Tmean≤ -7 °C, Tmean≤ -20 °C			
Extreme precipitation - floods: # of days R≥30-50mm/day, 100mm/day Total daily precipitation	*inundation of infrastructure components*	*inundation of infrastructure components, disruption and damage of vessels and pipelines*	*inundation of infrastructure components*
cloud cover, solar radiation			*increased resource availability*
Snowfall Rs ≥ 1 cm/d, Rs ≥ 10 cm/d, Blizzard: Rs ≥ 10 cm/d, Tmean≤ 0 °C, WG ≥ 17 m/s	*reduced ice accretion on overhead power lines*		*reduced icing problems for wind turbines*
Sea level rise, sea storm	*erosion of coastal structures*	*affect in generation, transmission, and transformer substations*	*erosion of coastal structures*
extreme winds, wind gusts(6h): WG ≥ 17 m/s , WG ≥ 25 m/s	*toppled pylons and downed overhead lines*		*forced wind turbine shut down*
average summer precipitation, soil moisture			*availability of the hydropower supply*

Table 8. Climate impact scenarios on the Transport (Rail) sector CI elements

HAZARD	IMPACTS	HAZARD	IMPACTS
# of days with Tmax(heat stress): Tmax≥ 25 °C, Tmax≥ 32 °C, Tmax≥ 43 °C	*Rail buckling risk Disturbance to transport electronic infrastructures, signaling, shortened life expectancy of rail, increase wildfires can damage infrastructure*	**Snowfall Rs ≥ 1 cm/d, Rs ≥ 10 cm/d, Blizzard: Rs ≥ 10 cm/d, Tmean≤ 0 °C, WG ≥ 17 m/s**	*increased propability of incidents, soil instability, ground movement and slope instability, Ice on trains and catenary*
Cold waves: Tmean≤ 0 °C, Tmean≤ -7 °C, Tmean≤ -20 °C		**Sea level rise, sea storm**	*bridge washouts, underpass and basement flooding, disturbance to transport electronic infrastructures, signaling, erosion of coastal structures*
Extreme precipitation - floods: # of days R≥30- 50mm/day, 100mm/day Total daily precipitation	*flooding of underground transist systems, ushflow avalanches, trees and branches, landslides and associated risks,destabilization of embankment*	**extreme winds, wind gusts(6h): WG ≥ 17 m/s , WG ≥ 25 m/s**	*Disturbance to transport electronic infrastructures, signaling, trees and branches*
Humidity, dew-point, fog	*reduced visibility*	**Landslides (R≥ 150-200 mm/24h)**	*ushflow avalanches, landslides and associated risks*

Table 9. Climate impact scenarios on the Transport (Road) sector CI elements

HAZARD	IMPACTS	HAZARD	IMPACTS
# of days with Tmax(heat stress): Tmax≥ 25 °C, Tmax≥ 32 °C, Tmax≥ 43 °C	*Reduced safety for vehicles driving, Railroad track deformities, instability of road substructure, melting asphalt and rutting, roadside fires, road asphalt cracking, problems on steel bridges, buckling risk, reduced safety for vehicles driving, fatigue among drivers, augmentation of Urban Heat Island Effect*	**Snowfall Rs ≥ 1 cm/d, Rs ≥ 10 cm/d, Blizzard: Rs ≥ 10 cm/d, Tmean≤ 0 °C, WG ≥ 17 m/s**	*reduced visibility, ice on the roads increased propability of incidents, reduced safety for vehicles driving, Damage to roadway integity due to thawing of permafrost, soil instability, ground movement and slope instability*
Cold waves: Tmean≤ 0 °C, Tmean≤ -7 °C, Tmean≤ -20 °C	*fatigue among drivers, Damage to roadway integity due to thawing of permafrosts*	**Sea level rise, sea storm**	*floods, coastal infrastructure at risk of inundation, erosion of coastal structures, buckling risk, reduced safety for vehicles driving*
Extreme precipitation - floods: # of days R≥30- 50mm/day, 100mm/day Total daily precipitation	*evacuation flooded roads/tunnels, bridges exposed to 20%-40% increase in 100-yr river discharge, reduced safety for vehicles driving*	**extreme winds, wind gusts(6h): WG ≥ 17 m/s , WG ≥ 25 m/s**	*trees and branches overturned trucks etc increased noise reduced road speed*
Humidity, dew-point, fog	*Reduced safety for vehicles driving, reduced visibility FMI Road Weather Model*	**Landslides (R≥ 150-200 mm/24h)**	*landslides, lushflow avalanches, landslides and associated risks, reduced safety for vehicles driving*

Table 10. Climate impact scenarios on the Transport (Maritime) sector CI elements

HAZARD	IMPACTS	HAZARD	IMPACTS
# of days with Tmax(heat stress): Tmax≥ 25 °C, Tmax≥ 32 °C, Tmax≥ 43 °C	*overheating and fatigue, hazardous for certain groups of workers*	**Snowfall Rs ≥ 1 cm/d, Rs ≥ 10 cm/d, Blizzard: Rs ≥ 10 cm/d, Tmean≤ 0 °C, WG ≥ 17 m/s**	*snow cover, high humidity at harbour*
Cold waves: Tmean≤ 0 °C, Tmean≤ -7 °C, Tmean≤ -20 °C	*cold waves: freazing sea and structures*	**Sea level rise, sea storm**	*flooding, erosion of coastal structures, affection of chemical structure of buildings, and structural fatigue, Degradation of wharves through increased corrosion*
Extreme precipitation - floods: # of days R≥30- 50mm/day, 100mm/day Total daily precipitation	*seaport flooding,thunderrstorms, electricity breakdown at port, reduced visibility, degradation of wharves through increased corrosion, delays and cancelations for airline traffic*	**extreme winds, wind gusts(6h): WG ≥ 17 m/s , WG ≥ 25 m/s**	*wind effect on ships ' performance and harbour structure, delays to berthing and cargo-handling operations, waves, increased problems on ship navigation Damage to infrastructure on seaports.*
fog	*reduced visibility, high humidity on harbour*		

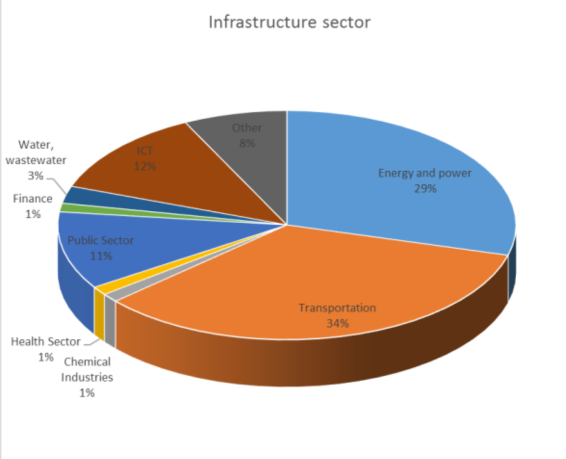
In order to build the trust with the CIP stakeholders the EU-CIRCLE partners organized personal interviews with representatives of the project user groups. Climate change scenarios considered in EU-CIRCLE and having interest for the user group included persisting temperatures, extreme rainfall, prolonged drought, high intensity forest fires, extended flooding, rapid snow melt and sea level rise.

The main questions that the interviewed project stakeholders mentioned that they would be interested to be answered using the EU-CIRCLE methodological framework are the following:

1. Identify time periods within the next years/decades when predefined climate risk scenarios may occur
2. Assess the intensity/strength/size/extent of such risk scenarios
3. Assess the impact of climate change risk scenarios to the performance and the operationality of CI functioning
4. Estimate the consequences of risk scenarios in terms of time needed for recovery
5. Simulate the CI functioning status during an expected climate scenario related to climate change (e.g. extreme weather)
6. Plan mitigation and adaptation counter-measures in advance

Despite the good faith and mood developed and the personal relations that have been developed with the CI stakeholders and representatives of the EU-CIRCLE user group, a number of question remained unanswered. The kind of questions that was hard to be answered in a way to generalize their use included the following:

- What is/are the **reference time period** for your operational plans?
- Can you decompose the network of your CI down to physical **assets** (units) and links?
- What IPCC **scenario** of climate conditions may create problems to CI asset?
- What is the climate modelling spatial **resolution** that you wish to be offered to you
- What assets will be influenced (**impact**) by the scenario
- What you can do to **mitigate** the impact
- What will be the **downtime** of the asset before return to full operation
- Can you describe **interdependencies** among assets of your CI and other CIs



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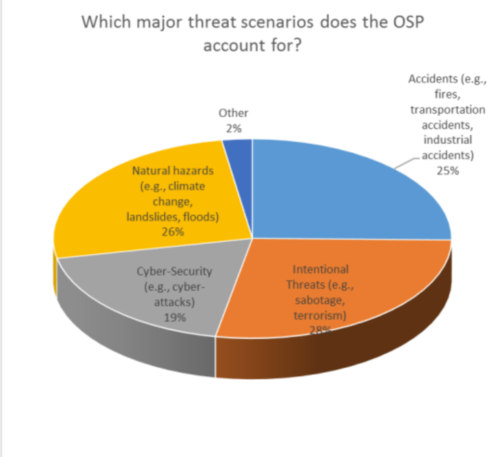

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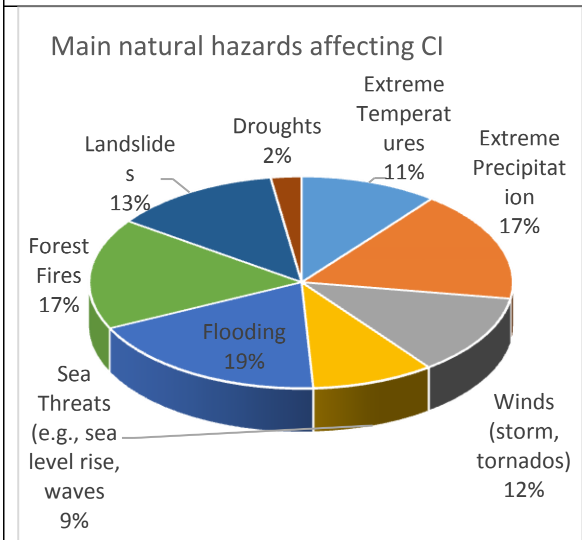

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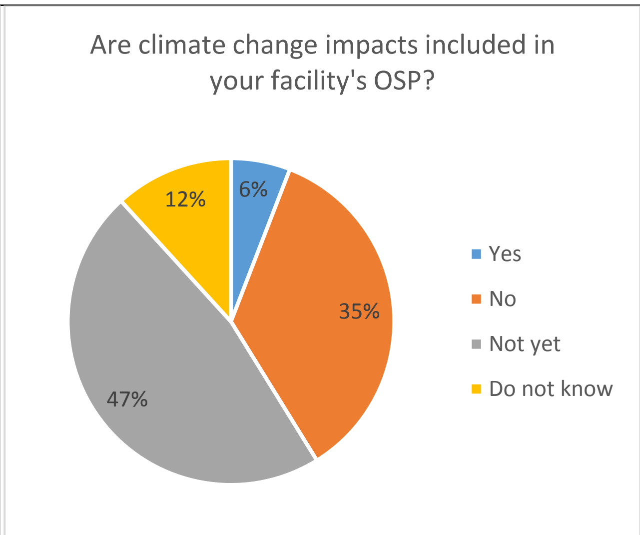

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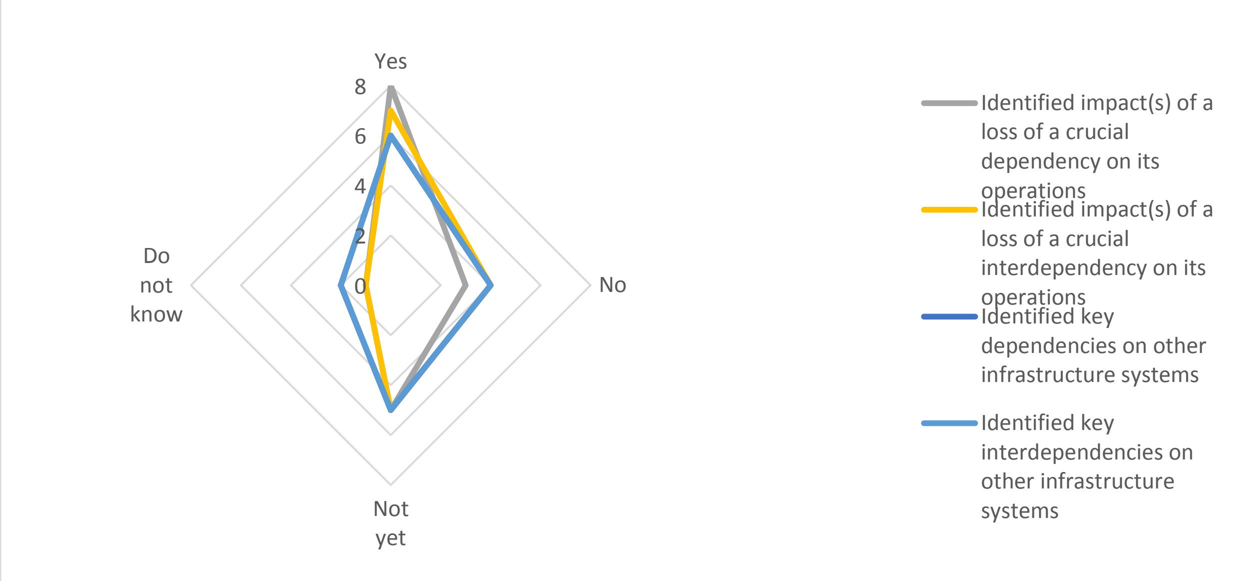

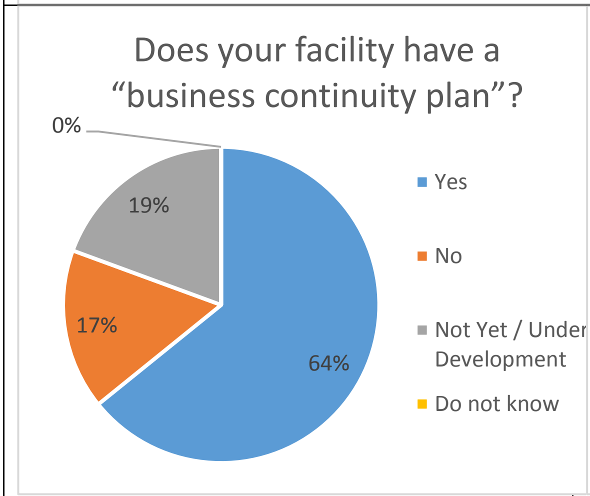

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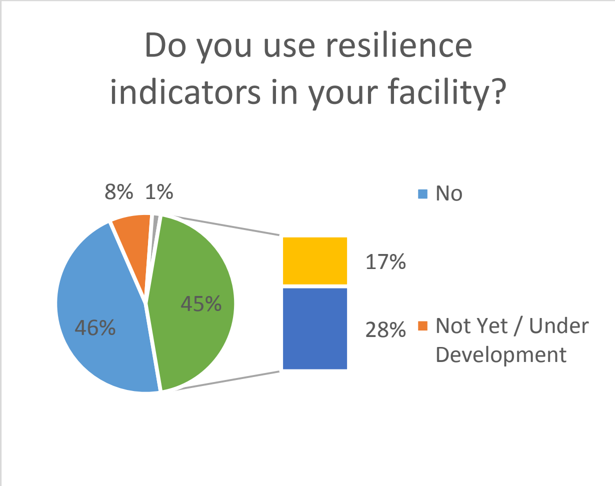

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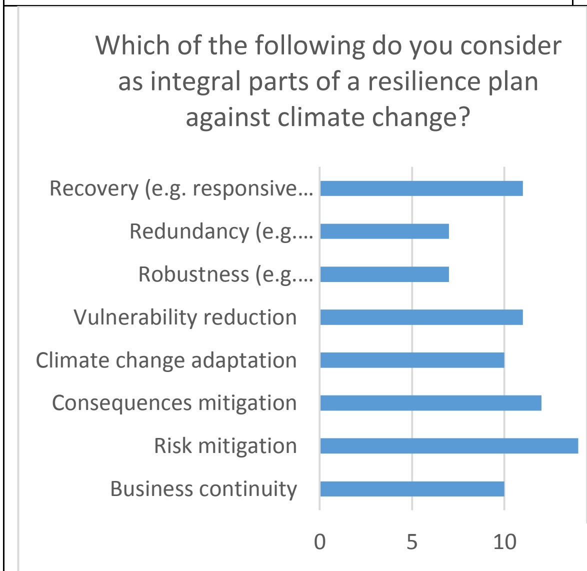

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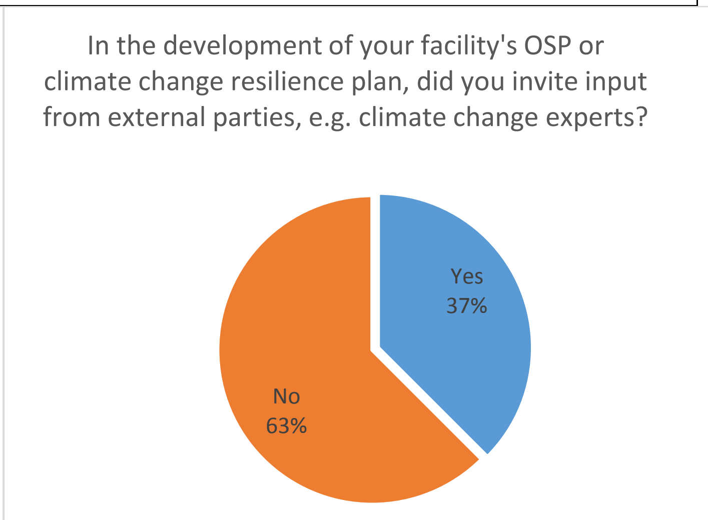

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5 How to implement the EU-CIRCLE process

Use of the EU-CIRCLE conceptual framework has the objective to involve all stakeholders including the climate research community, the hazard and risk modelers and the CIP community in resilience planning for critical services in order to address climate changing impacts. This is proposed to be organized within a concrete and structured context (Figure 1), which shall follow a process comprising the next methodological steps:

1. Define the settings i.e. Area of interest, time period, CI types & network by CI community
2. Identify CC drivers to CI challenges and climate hazard precursors (use EU-CIRCLE results)
3. Compare climate related engineering design standards (e.g. return period) in place with relevant EU-CIRCLE CC assessments (by CC and DRM in cooperation)
4. Use CC modeling and project climate data to identify risk periods of climate change scenarios per CI type by the CC community (based on EU-CIRCLE defined scenarios)
5. For each risk period use CC modeling and project climate data to Identify risk areas of climate change scenarios for all CI types by the CC community (based on EU-CIRCLE defined scenarios)
6. Run disaster management spatial modeling
7. Identify and define damage/consequence curve per CI element (sector, service and/or asset)
8. Identify and define resilient indicators per CI element (downtime, minimum performance level, time to complete recovery, cost of repair ..)
9. Adapt all information in the EU-CIRCLE risk assessment framework
10. Run CIRP to define for each use case (incl. settings, CC model, time period and area of influence)
    a. Which CI elements are at risk to fail (resilient vs non resilient) as individual assets, interconnected units (network or service) or interdependent services (cascading effects)
    b. What will be the expected impact (population, cost, environment)
    c. Foresight of required measures to ensure resilience
11. Simulate and visualize results depicting risk levels, network islanding, resilient/non resilient CI elements, adaptation priority areas, engineering standards failure, adaptation measures ..

In order to end up with a foresight analysis to assess the impact and formulate relative policy recommendations using the EU-CIRCLE conceptual framework the process model of Figure 1 is adopted, applying specific methodological approaches briefed in Section 6

Scenarios can be thought of as stories of possible futures states of the interconnected network of CIs. They allow the description of factors that are difficult to quantify. In the context of climate change scenarios are used for the future development of factors such as governance, social structures, future population growth, technical development and agriculture. These descriptions are essential to model the future climate.

A scenario is plausible and often simplified description of how the future may develop, based on a coherent and internally consistent set of assumptions about driving forces and key relationships. Often a set of scenarios are developed to span out many alternatives. An important application of ***scenarios is in what-if analyses***, in which case the question of whether these assumptions are actually realised or not in the future is not necessarily the key question. For example, what happens to the future climate of Europe if the greenhouse gas concentration increases to 600 ppm? Or, what might happen if the mean sea-level rises by one meter and there is a storm surge of one meter on top of that? In the context of climate change and its impacts there is a chain of scenarios from global socio-economic scenarios via climate scenarios to regional impact scenarios.

Each line of Figure 5 represents a step further in a modular approach aiming to come up with eventual scenarios and foresight of the potential impacts of climate change to the operation, performance and resilience of elements backing essential services for the EU MS and the European societies including critical assets, sectoral services and interdependent lifelines. These steps include: (a) Scenario selection, (b) Scenario elaboration, (c) Data collection, (d) Scenario execution and on the spot analysis, (e) Assessment of results and policy suggestions.

Different methods comprising brainstorming [47], scenario building [48], [49], general morphological analysis [50] and future wheel [51] are considered (Fig.5) for implementing these consecutive methodological steps.

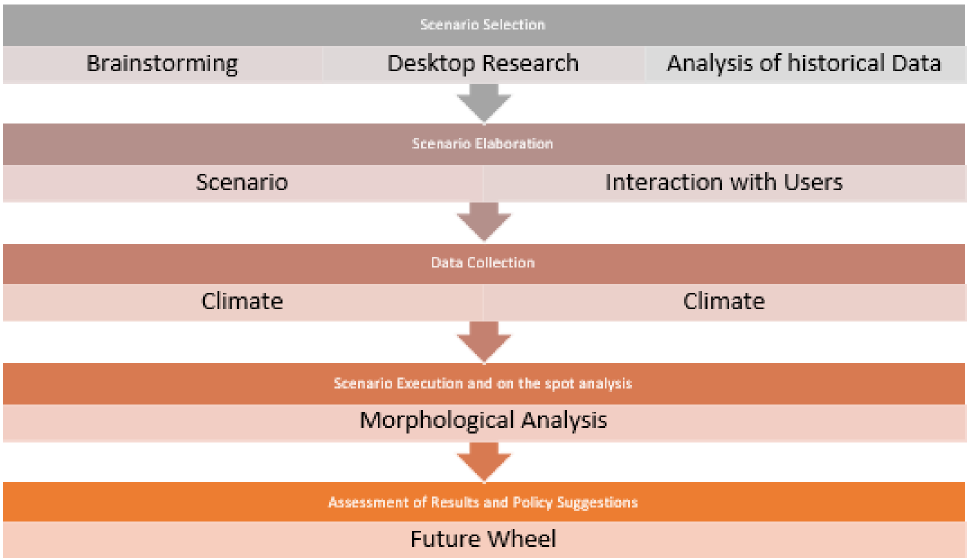

Figure 5. Flow process model of the EU-CIRCLE foresight analysis

Basic information, weaknesses and strengths of the methods and techniques mentioned are briefly presented in Table 11 here next.

Table 11: Foresight methods strengths and weaknesses

Method's name	Short description	Strengths	Weaknesses
Brainstorming	Creative and interactive used in face-to-face and online group working sessions to generate new ideas around a specific area of interest	It is fast, collaborative, cheap, commonly known and proven. It may produce out-of-the-box thinking.	It is insufficiently robust underlying thinking if no other foresight tools are used.
Scenarios	Systematic and internally consistent visions of plausible future states of affairs	Help in developing plans that are viable over the wide range of possible futures. Open up the mind to hitherto unimaginable possibilities.	Can be mistakenly assumed as official possible futures. Can fail to be useful when their authors either fear criticism for saying too many things that seem too "far out". Can be very time-consuming.
Future Wheel	Structural brainstorming where a certain event or trend is analysed by imagining its primary impacts and secondary impacts	It gets people thinking about the future quickly. Can help identify positive and negative feedback loops. It moves the mind from linear, hierarchical, and simplistic thinking to more network-oriented, and complex thinking.	The complexity of the overview can become overwhelming. It can also yield contradictory impacts. It is no better than the collective judgments of those involved.
Morphological Analysis	A method for rigorously structuring and investigating the internal relationships of inherently non-quantifiable socio-technical problem complexes	It defines structured variables and creates a real dynamic world. It can help discover new relationships that were overlooked before and encourage the identification of boundary conditions.	It requires strong and experienced facilitation. It takes relatively long time to complete. The outputs of the process are no better than the quality of its inputs.

5.1 Specific Elements of the described process

The process described in the previous paragraph inherently introduces certain elements that need specific attention during the implementation phase. The use of stakeholders/ subject matter /expert opinions is essential for the sufficient dependability, robustness and detail of the development of a scenario, the determination of risk (e.g. categorization of the impact and likelihood) and resilience, to generate an inventory of adaptation / mitigation options and capacities. Most importantly the introduction of the existing concept of operations (CONOPS) and existing operating practices on the operation (and business continuity practices) of CI that deviate of the mathematical formulations of related models is critical in obtaining meaningful results of this process.

In order to guarantee that experts are smoothly and effectively introduced in this process the following elements should be accounted for:

- ✓ Decide which group of experts takes part in the scenario development process, who determines risk (number and ranges of likelihood categories, weights and importance of impact(s) categories, hierarchical structure of impacts, range and number of impact categories, risk matrix) and resilience parameters (which resilience indicators to employ).

- ✓ Decide which group to identify the mitigation / adaptation options and capabilities. Also decide on prioritization factors and their relative importance and type of cost-benefit analysis to be used.
    - o It is desirable that the expert group that determines the risk components should be totally different from the group that writes the scenario or the group that performs the adaptation/mitigation assessment.
- ✓ Allow for a proper balance between experts on scenario building, and representatives from policymaking and the scientific community. The presence of IT experts could also be helpful in case demanding use of the modelling tools is required.
- ✓ The participants should cover all specialist fields that are relevant to the developed scenario.
- ✓ Always consider continuation of the work. At the stage of scenario development, ensure that there is sufficient dependable information that is relevant (or could be obtained with reasonable effort/cost) for the determination of risk factors and resilience assessment. Also provide sufficient information about relevant adaptation/mitigation options and capabilities, so that the established scenario offers points of departure for producing the inventory of capabilities that result in reinforcement of CI assets.
- ✓ Elaborate in the process uncertainties and differences of opinion between experts, which are inevitable in the type of scenarios used in complex interconnected CI systems. Account in the process well-argued differences in views as an enhancement of the usability of the results of analyses and a key element to determine the uncertainty of the final scenario. Make a clear distinction between uncertainties due to lack of knowledge and data, and differences of views between experts.
- ✓ Define with the experts the chain of events that determine the scenario, what the causal connection is and which line of reasoning will be followed. Consensus on these topics is critical for reliable determination of the risk and resilience analysis and selection of most suitable adaptation/mitigation options pertinent to the examined scenario.
- ✓ Source of experts' know-how (empirical data, model calculations) and assumptions and should be double-checked against the latest circumstances or developments that influence (the likelihood of) the occurrence of future related scenarios.
- ✓ The use of correction factors (or climate change allowances as is the case of UK flooding assessments[13]) could also be used.
- ✓ A priori determine how to achieve the greatest possible convergence between the various expert, while maintaining individual views and to a 'best' outcome, and how the best can be reported, including the uncertainties and differences of views.
- ✓ Experts should engage in posterior evaluation of the scenario building process , e.g. as described in [51]. Such evaluations should take into consideration include the most pertinent of the following criteria: Relevance - Effectiveness - Efficiency - Appropriateness - Utility - Impact Complementarity - Complexity - Sustainability

[13] https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances

6 The EU-CIRCLE methodological framework approach and its elements

The main idea behind the EU-CIRCLE conceptual framework is that any essential service used for the maintenance of vital functions of modern societies may suffer significant impact due to climate changes, which are associated to exacerbation of extreme weather events as well as to the increase of the frequency of occurrence of such events. A major problem is that most of the critical infrastructures already in place have been designed using engineering standards related to past climate data, which are expected to change following the IPCC scenarios. Therefore the overall framework has to consider a redefinition of such engineering standards for new developments and a revision in critical infrastructures where they have been already applied would be necessary to determine eventual needs of mitigation measures or investments for adaptation. This would be comprised in a climate security by design approach that EU-CIRCLE aims to suggest and which all critical infrastructures would require in the coming decades.

Furthermore the planned CIRP platform, described in D5.1 [52], would support planners, operators and authorities assessing the impact of alternate climate change scenarios linked to the operation and performance of critical infrastructures in order to assess the direct impact and the potential cascading effects due to interdependencies of the CIs. Such assessment may prioritize the planning of mitigation and adaptation measures to both the critical infrastructures as well as to the society at the local, regional or even national scale depending on the scenario, the climate change driver pattern and the associated geo-hydrological hazard. This potential use of CIRP is aligned with the EU-CIRCLE methodological framework, which aims to guide end users to understand the climate change impact to the CI and to help them to make informed decisions.

The EU-CIRCLE methodological framework considers that values of climate parameters exceeding certain thresholds and climate change patterns (distribution of climate parameters values in space and time declining from current normality) can greatly influence the performance of assets within a CI, causing diverse (and probably unexpected) impacts to operations, affecting also other interconnected assets or networks. The result may be loss of operational performance of the asset/CI, downtime of the asset or the facility and reduction or loss of the service provided. In case the level of provided service is below the respective demand the envisaged essential service is disrupted. The project has built a methodology that integrates the use of the CIRP platform in order to support decision making to prevent or mitigate relative situations in a structured and organized fashion.

Basically the applied modelling and simulation tools of the project can estimate the state of a CI (or its assets) depending upon its previous state and/or the states of its interconnected assets. The state of an interconnected asset is thus a result of its nature, the strength of the climatic pressure affecting the originating asset to which it is connected, the coping capacity or resilience potential of the envisaged asset or network (risk mitigation, means of immediate response, safety equipment) and the type of connection with other assets. Based on this driving concept, a consequence-based risk analysis framework is defined, which will be developed in context of the relative project work packages, respectively WP2, WP3 and WP4 (Fig. 1). This figure depicts clearly the conceptual blocks that define the climate security management framework for CIs as it is addressed by EU-CIRCLE.

As already mentioned above, the EU-CIRCLE methodological framework will be implemented on the CIRP platform, an innovative modular and expandable software platform that will allow assessing potential impacts to CIs due to climate hazards; will provide risk monitoring through adequate resilience indicators, and will support planning of cost-efficient adaptation measures. The CIRP platform is defined as an end-to-end collaborative modeling environment where new analyses can be added anywhere along the analysis workflow and present findings in a unified manner, providing an efficient solution that integrates existing modeling tools and data into a standardized fashion.

As it can be deduced from the EU-CIRCLE conceptual diagram (Fig.1), the EU-CIRCLE climate resilience management framework is mainly based on a. the identification of the critical assets/processes that provide essential services to the society; b. the determination of the critical values and/or patterns of climate parameters that define a change of state for these assets (in terms of performance or functionality); c. the analysis of the relative impact, determined using appropriate consequence or damage curves; d. consequence analysis to determine cascading effects and related impact; and e. Analysis of coping capacity of the asset/network/society and their respective adaptive capacity (resilience) and identification of adaptation potential and investment needs. The approach is scalable and modular and can be applied from a single critical infrastructure facility to a network of infrastructures spanning across regions and countries, covering thus also the needs of applying the EC Directive 114/2008 concerning the CIs of European Interest.

A breakthrough in the envisaged methodology is the proposal to move towards a standardized modeling of the capabilities (coping and adaptive capacity) and challenges (vulnerability, exposure) of critical infrastructures placing emphasis on their type, constituent assets, the flow of the relevant commodity to connected and dependent network nodes aiming to support the provision of uninterruptible essential services to the European citizens. Critical infrastructure assets/units are defined as nodes of a network that can communicate with one another as they operate in a particular environment. Each node receives inputs from others and sends outputs to them. These “inputs” and “outputs” need not be resources used in, or products made by, an infrastructure or process. Metrics that describe the state of an asset can also be viewed as outputs that other asset can sense (use as input) and act upon. A major issue in the modelling approach is the influence of interdependencies among networks of assets. Interdependencies increase dramatically the overall complexity of the “system of systems” made from the interconnected networks of critical assets.

They are comprised of technical, economic, business, social/political, legal/regulatory, public policy, health and safety, and security concerns that affect infrastructure operations. These complex relationships are characterized by multiple connections among infrastructures, feedback and feedforward paths, and intricate, branching topologies. Apart from their type, interdependencies are described mathematically as an input-output relation between the connected assets. The environment comprising these concerns influences normal system operations, emergency operations during disruptions and periods of high stress, and repair and recovery operations.

In EU-CIRCLE, four principal classes of interdependencies: physical, cyber, geographic, and logical [53] (Rinaldi et al, 2001) are considered. Therefore the EU-CIRCLE methodological framework allows to approach multiple interconnected infrastructures and their interdependencies in a holistic manner. Interdependency classes and relevant implications to risk assessment are shown in Table 12.

Table 12. Type of interdependency and implications to infrastructures

Interdependency type	Relevant themes	Implications for risk assessment
Physical Interdependency	[53] state the it "*arises from the physical linkage between the inputs and output of two agents (where the) commodity produced or modified by one infrastructure (an output)is required by another infrastructure for it to operate (an input)*" (e.g., drinking water and electricity).	Risks in one infrastructure directly influence operations (i.e., outputs, product, goods and services) of physical interdependent systems. For example, the availability of clean drinking water physically depends on electrical systems that must purify water. The operator of a water treatment system is concerned with the risks on the electricity system.
Cyber Interdependency	Related to risks associated with the omnipresence of information and communications technologies. [54] states that "*computerisation and automation of modern infrastructures and the widespread use of SCADA systems have led to the pervasive cyber interdependencies*".	Management must consider the risks associated with outputs, products, goods and services that depend on information and communications systems (e.g., SCADA systems). The use of data and information provides connections to other systems that might not exist.
Geographical Interdependency	[55] state that geographical interdependency exists when different infrastructure systems share the same environment (e.g., power lines share the same corridor with a bridge).	A common environment is needed for coupling infrastructure systems and their components. However, this poses a threat to all infrastructures in the same corridor (e.g., an explosion threat to a bridge affects the bridge and power line).
Logical healthcare Interdependency	Infrastructure systems can have logical interdependencies if the state of one infrastructure depends on the state of another infrastructure via a mechanism that is neither physical, cyber nor geographical [54]. An example is the linkage between the 1996 power deregulation policy and the energy crisis in California in the 2000s [56].	Interconnections between infrastructures must be analysed beyond time and space with respect to physical, cyber and geographic mechanisms. For example, the consideration of policy and its possible influence on operations regardless of space on time between infrastructures and the point of origin.
Policy and/or Procedural Interdependency	Interdependence becomes apparent only after changes take place so that functioning of one infrastructure is impacted by changes in policies/procedures in another infrastructure (e.g., after the 9/11 attacks, U.S. Congress issued regulations affecting all air transportation [57].	It is necessary to analyse how changes in national, state, regional and local policies influence infrastructure operations, including the quality of goods and services across time and space.
Societal Interdependency	[58] state that societal interdependencies arise when infrastructure operations are affected by public opinion (e.g., after the 9/11 attacks, air traffic was reduced due to the public's evaluation of travel safety, resulting in job cuts and bankruptcies).	It is necessary to analyse the action of the public and relate the actions to popular opinion regarding critical infrastructure operations. The result may be used to inform understanding about the possible influence on goods and services that the infrastructure of interest provides to the public.

In context of CIRP the diverse CI networks are shown as parallel layers representing individual sectors as shown in Figure 6, which introduces the reference simulated environment of the EU-CIRCLE testing platform.

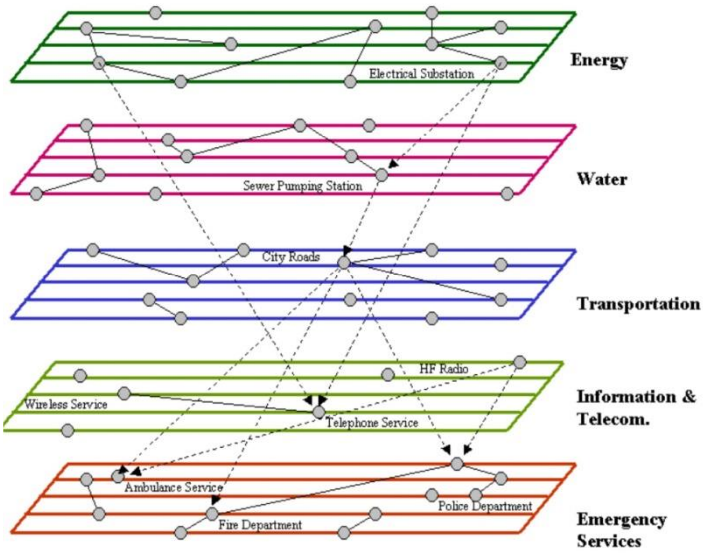

Figure 6. Infrastructure independencies for simulated environment [59]

Furthermore within CIPR each infrastructure network is represented as a set of interconnected assets (e.g. power generation stations; power distribution stations; and power lines or pumping stations; water pipelines; and pipeline junctions either bridges; roadways; etc). Each network is modeled using nodes and links. Beyond interconnectivity, interdependencies among the networks are defined. Using this approach, network flow algorithms are applied to ascertain network behavior given any climate change scenario.

According to the EU-CIRCLE approach there are two elements associated with impact i.e. the *Climate drivers*, which refer to climate parameters exceeding normal (usual) patterns and thresholds and hydro-geological *Climate hazards*, originated by Climate drivers, that can jeopardize the operation and performance of the CI. Identifying *threats* and quantifying *risks* related to such drivers and hazards is comprised in the methodological framework of the project.

The essential services that are considered in context of EU-CIRCLE include the Energy, Transportation, Water – Sewage, ICT – Information & Communication, Chemical Industry, Health and the Government Services sector.

For the purpose of strengthening CIs resilience to the climate change potential, EU-CIRCLE consortium adopted a methodological framework, which is organized in three consecutive steps:

1. Assessing the potential context of climate change and define the climate scenarios that may have impact to assets of critical infrastructures;
2. Defining the damage function that relates the *Climate drivers* and *Climate hazards* to the respective assets of the critical infrastructure; and

3. Analysing the relative consequences to the operational efficiency and the capacity of the CI to address relevant societal needs and demand, taking into consideration interdependencies and interconnections between CIs (ripple analysis).

The EU-CIRCLE methodological framework combines, in point 1, the knowledge of the climate modelling community with the expertise of the critical infrastructure security experts. In point 2 climate elements are paired with critical infrastructure assets in order to assess *vulnerable* situations, based on *critical thresholds* and predefined values, in case of relevant *exposure*. *Climate drivers* coincide with climate parameters such as temperature, precipitation, relative humidity, winds, clouds, fog, solar radiation, sea level, ice, frost, storm surges, waves etc. presenting values deviating far from (current) normality. *Climate hazards* include derivative phenomena linked with the drivers and comprised of heat waves, cold snaps, floods, forest fires, droughts, soil erosion, landslides etc.

Infrastructure sectors have direct and indirect interdependencies and are vulnerable to each other impact and disruptions, deliberate or accidental, which can be pernicious, resulting in derivative losses that can be roughly estimated. Impact due to harsh climate conditions can be direct (estimated using damage functions), cascading (estimated using consequence analysis) or indirect. Being thus infrastructures interconnected and dependent between them, it isn't sufficient to assess impact on one without considering the consequences on the dependent others. For this reason, *interdependency and consequence analysis* is a structural element of the EU-CIRCLE methodological framework. Relationships between interdependent infrastructures can be estimated using appropriate input-output methodology [60].

Since the ultimate objective of EU-CIRCLE is to *strengthen resilience*, the methodological framework includes a number of resilience indicators that can be used to identify potentially critical patterns, linked with climate changes. Such indicators refer to:

- Metrics of *Climate hazard likelihood* (e.g. return period) in relation to actual figures;
- Ratio of CI performance under current and expected critical climate change conditions;
- Impact related metrics (costs, downtime etc.);
- Uncertainty of the derived results;
- Resilience constituents estimates (*business continuity, cost effectiveness and adaptation*) and collective resilience indices; and
- Multiple metrics (combination of the above)

The EU-CIRCLE framework, which integrates all the above elements, is described in D1.3 and is depicted in the following figure:

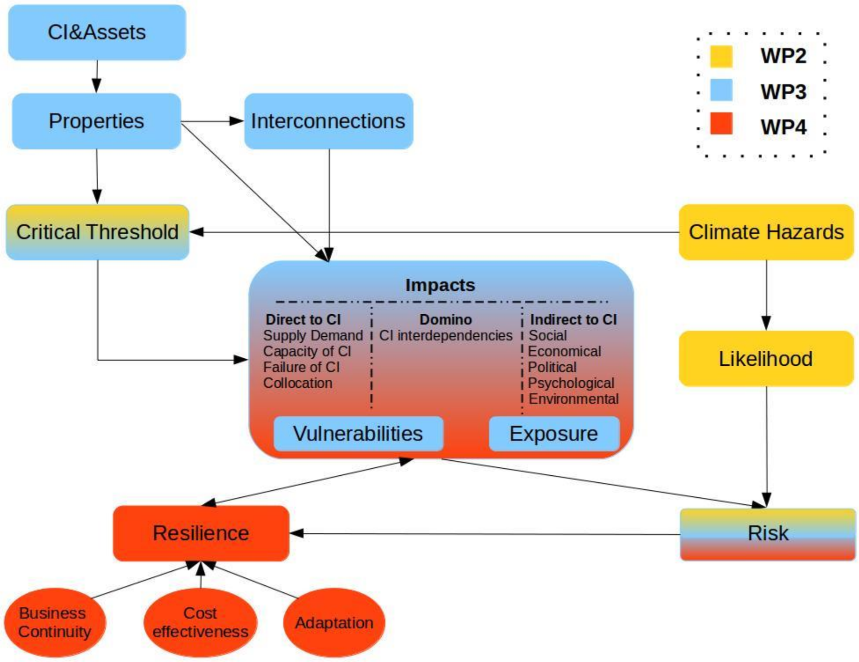

Figure 7. EU-CIRCLE methodological framework

In context of the EU-CIRCLE conceptual framework, the exposure and the vulnerability of infrastructure systems to climate hazards are understood as follows:

- A climate hazard refers to a climatic event with the potential to cause harm (e.g., fl wildfires, hurricanes) or long-term changes in climate variables that have negative consequences over time (e.g., rising temperatures, changing rainfall patterns).
- Exposure of infrastructures to climate risk refers to the presence of infrastructures in climate-hazard prone areas.
- Vulnerability of infrastructure systems to climate events is understood as the susceptibility of those infrastructures to harm from climate hazards. The vulnerability of particular infrastructures depends on the sensitivity of infrastructures to climate risk (i.e., the predisposition of infrastructures to be affected due to at least three factors: the age, the composition and the design of infrastructure) and the capacity of the sector to adapt (adaptive capacity) by minimizing negative impacts and/or maximizing positive ones.
- An assessment of how vulnerable assets to changes in local environmental and weather conditions might entail, examination of the future likelihood of hazards (related to the projected return periods) and the ability of mitigation/adaptation options to cope with the hazard. The vulnerability assessment might entail engineering analyses of the asset and the determination likelihood of different asset (or individual components) failing due to environmental factors

To address these elements of impact, which can be individualized in context of EU-CIRCLE climate change scenarios, adaptive measures can be taken to limit costs and strengthen the resiliency of infrastructure. A number of key policy, regulatory and financial tools have been identified as "enabling factors" in supporting the deeper integration of climate change considerations into infrastructure decision-making, design and maintenance.

Beyond the technical and scientific aspects of the EU-CIRCLE methodological framework there are important elements that define the potential and the perspective use of such framework. These include relevant European CIP policies and legislation across EU Member States as well as the identification of the stakeholders' community that will be invited to evaluate the project outcome. Both are described in this deliverable in details.

The EU-CIRCLE methodological framework introduces a systematic process for identifying the most critical assets, based on user defined criteria for identifying the assets, asset types, or important locations might include (1) high volume of CI related flows, (2) proximity to important locations e.g. intermodal terminals for transport, (3) serving highly vulnerable populations, (4) functioning as emergency response or evacuation routes, (5) important connectivity property in the interconnected CI networks. The use of an advanced IT tool (CIRP) allows for the examination of different options for valorising the importance of CI assets, and also account for the placement in hazard zones under different (unique) or multi-hazard environments.

Within EU-CIRCLE there are two more elements associated to the methodological framework. These are related to the definition of climate change-related risk *scenarios* for CIs and the identification of state of the art knowledge, *expertise and R&D capacity* concerning integration of risk concepts with interdependency issues using impact analysis and elaborating CI resilience and adaptation options. The former can be used for the definition of the operational and policy context and is addressed based on a methodology developed by NCTV (National Coordinator for Security and Counterterrorism), the Dutch Agency in charge of CIP, properly modified to fit the EU-CIRCLE approach. The latter could provide a relative indication of the aspects of climate change, critical infrastructure challenges and resilience options that have been scientifically covered enough so far and thus can be considered valid in context of the EU-CIRCLE methodological framework compared to others that still need to be investigated. This approach is based on network analysis of 81 keywords referred in 116 scientific papers and technical reports regarding risk management, climate change and resilience of critical infrastructures that were analyzed in context of EU-CIRCLE project. A more comprehensive elaboration of this analysis is included in D1.5.

Risk from climate variability (short-term) and climate change (long-term) defining the overall climate risk on infrastructure refers to the probability of harmful consequences or expected loss (e.g., degradation or destruction of infrastructures and associated loss of life and injury) resulting from interactions between climate drivers, induced hazards, exposure of infrastructures to these hazards and vulnerable conditions [61][14].

A schematic representation of the use framework of EU-CIRCLE is shown in the Figure 8. It shows how the drivers and hazards elements are conceptualized and depicts the steps towards the identification of risk and impacts of climate change potential to the assets, networks and interdependent services.

[14] http://www.preventionweb.net/english/hyogo/gar/2011/en/home/download.html

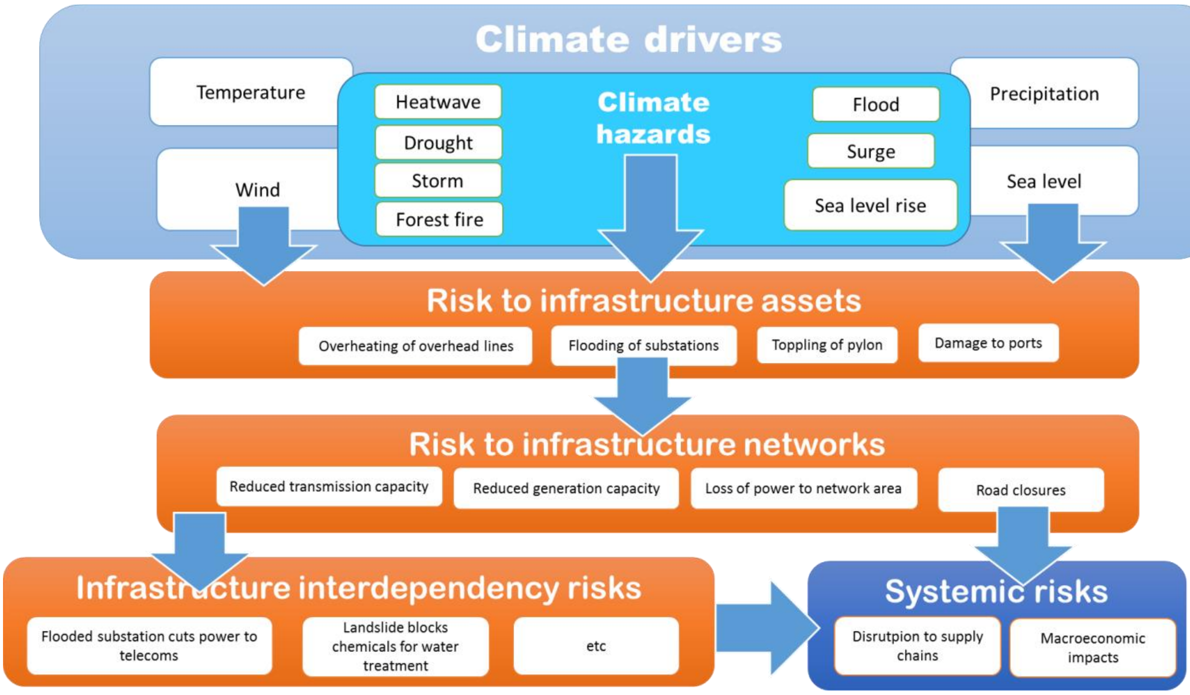

Figure 8. Framework of using EU-CIRCLE conceptual approach

The EU-CIRCLE methodological framework will be tested and validated in context of the five case studies envisaged by the project.

6.1 Basic principles of climate adaptation

Climate change adaptation is increasingly gaining importance at national and organisation levels. In particular, national level plays a key role in defining adaptation strategies. However, adaptation options are not undertaken to address climate risks or opportunities alone ([9]) but to address other goals with climate-related co-benefits (e.g. in relation to disaster risk management (DRM) or development strategies). Any adaptation framework should have as a starting point the identification of the highest elements of importance to the organization performing the assessment or scenario analysis. Depending on the level of participation this could embrace high level goals and objectives, or performance measures and metrics (such as socio-economic impacts, disruptions of CI flow, environmental impacts).

It is important that most relevant adaptation options are identified early in the process because they influence the type of information produced and data collected as part of the adaptation process. They feed directly into the next phase, defining specific adaptation policies that are more often mainstreamed into national and local policy strategies or private sector activities. We will consider a similar approach in EU-CIRCLE adaptation framework when identifying and assessing adaptation options for CI stakeholders.

In principle, adaptation options might include modifying existing operations and maintenance practices, designing extra redundancy into an asset (e.g. backup generators lasting longer), providing above-normal reserve capacity, incorporating a greater sensitivity to the protection of critical elements of the CI (such as better protection against bridge scour or high winds), designing with different design standards that reflect changing conditions, or planning for more frequent disruptions.

6.2 EU-CIRCLE resilience and adaptation framework

Resilience and adaptation are closely related concepts. In the EC guidelines of project managers [62] "the terms 'adaptation options / measures and 'resilience measures are used interchangeably". It is possible that some adaptation options are also identified as resilience measures if they answer both needs. As described in EU-CIRCLE D1.3 strategic context, the adaptation model is a component of the resilience framework, along with two related components: business continuity module (where common and accepted procedures are defined in order to maximise business continuity while minimising service disruptions under climate pressures) and cost-effectiveness analysis (allowing the comparison of different resilience strategies and adaptation measures). Adaptation actions aim at improving long-term CI resilience while resilience measures aim at increasing the coping capacity of CI. The articulation between the resilience and adaptation components will be further described in WP4 (D4.1, D4.3 and D4.6 in particular).

Different steps in the definition of an adaptation framework are identified in the literature[15] (for example in [32], [7]. Elements that will be analysed and elaborated within EU-CIRCLE are identified and will be further described in the respective deliverables.

- **Assessment of adaptation needs**
  - Identification of climate sensitivities and exposure to climate hazards *(→ WP2)*
  - Assessment of holistic risk *(→ WP3)* and resilience level *(→ D4.1 & D4.3)* of CI

Adaptation Framework

- **Identification of (a range of) adaptation options** per CI, per CH, aligned with general conditions of Member States *(→ D4.5)*
- **Appraisal of adaptation options** which includes:
  - Assessing the cost-effectiveness of adaptation options (*→ D4.6*)
  - Measuring the impact of adaptation option on CI and interconnected CI resilience level. *(→ D4.5)*
  - Possible other evaluation criteria such as risk of maladaptation, no-regret/low-regret actions, maturity of technology (e.g. using TRL scale), non-market benefits, etc. (can be verbally described) *(→ D4.5)*
  - Enabling the comparison of different adaptation scenarios *(→ D4.5)*
- **Planning and implementation of adaptation actions** *(→ not in EU CIRCLE)*
  - UKCIP : help prioritise adaptation options to define an adaptation strategy
  - EC : integrate adaptation action plan into the project development cycle
  - Mainstreaming climate change adaptation
  - Decision-making / multiple stakeholder engagement

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15 http://climate-adapt.eea.europa.eu/knowledge/tools/urban-ast

- Financing adaptation actions
- Monitoring of climate change adaptation actions

The aim of Task 4.4 is to elaborate a model that enables the identification and comparison of different adaptation options. The figure below further describes the proposed structure for the adaptation framework to be elaborated within EU-CIRCLE (green boxes) and its articulation with other EU-CIRCLE components (red boxes).

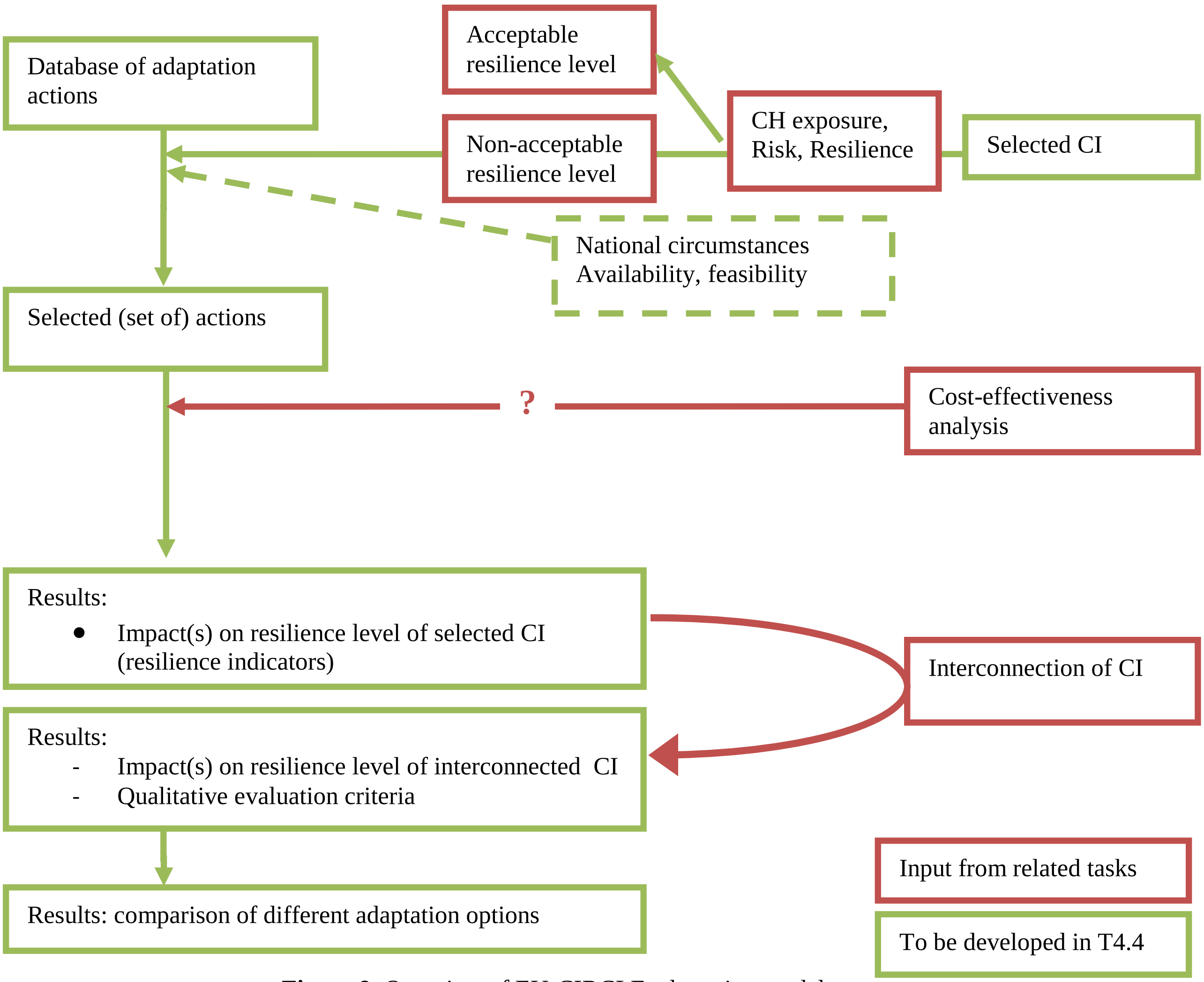

Figure 9. Overview of EU-CIRCLE adaptation model

6.3 EU-CIRCLE link to EU-Proposed Adaptation Measures

The EC guidelines of project managers [62], describe when and how Climate Resilience should be integrated into the conventional CI asset lifecycle and proposed to CI Climate Resilient Managers (or any other personnel with this role) with a toolkit on how to apply proposed set of modules. In summary the identified modules are:

Module 1: Sensitivity analysis (SA). The sensitivity of the project should be determined in relation to a range of climate variables and secondary effects / climate-related hazards.

EU-CIRCLE explicitly identifies a similar list of climate hazards

Module 2: Evaluation of exposure (EE). Once the sensitivities of a CI type have been identified, the next step is to evaluate exposure of the project and its assets to climate hazards in the location(s) where the project will be implemented.

EU-CIRCLE estimates CI's exposure to specific hazards using advanced spatial aggregation approaches for spatially extended climate hazards on a region and determines return periods or climate characteristics far exceeding design thresholds

Module 3: Vulnerability analysis (VA). Where a project is considered to have a high or medium sensitivity to a particular climate variable or hazard (Module 1), the project's location and exposure data (Module 2a) its vulnerability will be assessed, both in present and future climate conditions

Vulnerability analysis is explicitly linked to CI operational conditions and is therefore introduced into the impact assessment of EU-CIRCLE

Module 4: Risk assessment (RA). The risk assessment module provides a structured method of analysing climate hazards and their impacts to provide information for decision-making. This process works through assessing the likelihoods and severities of the impacts associated with the hazards identified in Module 2, and assessing the significance of the risk to the success of the project.

A multi-hazard risk assessment is introduced, accounting for impacts directly to the CI operation and also indirectly affecting society, the economy as a whole and the environment. Additionally, EU-CIRCLE explicitly quantifies resilience of CI through a set of related indicators

Module 5: Identification of adaptation options (IAO). This module helps to identify adaptation measures to respond to the climate vulnerabilities and risks that have been identified. The methodology first involves identification of options to respond to the vulnerabilities and risks, followed by detailed qualitative and quantitative assessment of the options.

EU-CIRCLE identifies adaptation as an important element of the CI climate resilience, on the long term, residing with the short term business continuity. Resilience Capacities constitute the backbone of the EU-CIRCLE framework, that are directly linked to the CI performance and operation levels within changing climate conditions

Module 6: Appraisal of adaptation options (AAO). Standard cost-benefit analysis (CBA) is applied to select efficient and 'optimal' options i.e. those maximising net benefits. In the context of climate change the focus widens to select not only efficient options but also those that perform robustly in the context of the uncertainties associated with future climate change.

CBA exists in EU-CIRCLE, also accounting for economic impact on the entire economic activity sectors using the Leontief's Input-Output approach

Module 7: Integration of adaptation action plan into the project (IAAP). Following the options appraisal (Module 6), decide on the modifications to the technical project design and management options, as relevant. Integrate the climate resilience measures in project design and into contracts

Not of direct relevance to EU-CIRCLE, but a potential next step of its use.

Document [62] introduces a series of Climate Resilience analyses for different stages of the CI process that are related to EU-CIRCLE potential output in the Table below:

Table 13. How EU-CIRCLE can extend required CI resilience Analysis

Decision / analysis	Main objective of climate resilience (CR) analysis	EU-CIRCLE relevant part	EU-CIRCLE related output	Additional output
Business model development	Taking into account the lifetime of the asset, consider how current and future climate conditions could affect the project's success,	WP2 WP3	Assessment of future climate hazards Risk assessment accounting for economic revenues, performance levels	Link to hazard return periods Account for social impacts, CI resilience
Pre-feasibility study	Identify and articulate the high level climate vulnerabilities and risks associated with development options covering all areas of feasibility	Entire project	Risk and resilience quantified indicators EU-CIRCLE approach expandable in accordance to international practices	Account for disruptions / damages due to interconnections. Directly applicable to non-climate risks
Conceptual designs	Consider climate risks associated with design options	WP3 – T2.2 WP3 - T3.4	Derive climate thresholds	Linked to future climate and CI design standards Account for CI operational elements (not only structural)
Site selection	Ensure assessments of changing climate vulnerabilities are incorporated into site selection decisions.	WP2, WP3-T2.3	Maps of zoning based on single and multi-hazard risks	Zoning based on asset criticality including interconnections
Technology	Identify technologies	WP4 – T4.4 & T4.3	Understand	Quantification

selection	and associated design thresholds which are most sensitive to climatic conditions so that adaptation measures	WP4 – T4.2	technologies options are affecting the resilience of CI assets to climate change	through specific indicators Introduce CI business continuity
Cost estimating & financial / economic modelling	Ensure cost estimates to appropriate estimate class is provided for climate adaptation (resilience) measures.	WP4 – T4.5	CBA analysis	Also account for impacts to rest of economy with I-O analysis
Environmental and Social Impact Assessment (ESIA) scoping and baseline	Identify environmental and social changes driven by climate change which may impact on the project and of ways that changing climate conditions could affect the environmental and social performance of the project	WP3	Risk models that include interconnectd CI numerical models feeding impact assessments that account for socio-economic impacts to the CI (direct) and the society (indirect)	CI models account for change in supply and demand due to climate conditions
Front end engineering design (FEED)	Further analysis of critical design thresholds most sensitive to climate. Analyse climate risks and test robustness of critical design components to a range of climate futures.	WP3 – T2.2	Derive climate thresholds based on return periods from climate projections from different downscaled IPCC scenarios, accounting for uncertainties.	Linked to future climate and CI design standards

7 Conclusions

This work introduces a methodological approach for assessing the resilience of European Critical Infrastructure to emerging challenges such as climate change. The work presents here the high level methodological aspects, as it is currently ongoing. All new infrastructure should be designed to cope with the future climate and especially the more severe events expected with climate change. Furthermore existing engineering design standards should be revisited and review their conformity to the climate change realm. The project framework provides a platform for collaboration between engineers and climate change researchers to identify the climate parameters that are critical to infrastructure design, and to allow applying the project results in order to enable design engineers to amend current standards.

The EU-CIRCLE methodological framework can support national authorities to establish a framework for addressing adaptation within their jurisdiction, to coordinate the risk assessment and adaptation processes, and communicate to and educate asset owners and CI operators. This approach could include targets for assessments and adaptation plans and support decisions related to the development of a roadmap of their eventual implementation. Where there is potential interaction or conflict, for example between water and power supplies, it may also be used to prioritise the adaptation measures.

The methodology developed could contribute to a diverse number of initiatives related to the Sendai Framework for DRR such as

- ✓ ***improving risk understanding - hazard characterization***: WP2 is completely devoted to the understanding of how climate parameters and secondary hazards (forest fires, floods, landslides) will change in magnitude and frequency under different future climate scenarios.
- ✓ ***exposure and vulnerability analysis***: The hazard characterization when combined with CI related data (related climate thresholds, building standards such as EUROCODES) could provide as assessment of the CI exposure to multi-hazards and links between vulnerabilities of CI and damages caused by extreme hazards (WP3)
- ✓ ***risk assessment***: The risk will be determined using a multi-hazard approach fully compatible and interoperable to existing frameworks set out in the National Risk Assessment Plans and the Directive 114/2008 on CI protection. Risk estimates will be based not only on direct impacts to the CI but also on the society.(WP3)
- ✓ ***improving institutional capacity on disaster risk reduction:*** the potential use of the EU-CIRCLE by the end-user community will allow to significantly enhance the CI capacity for enhancing CI resilience against multiple hazards, even domino ones .
- ✓ ***strengthening Early Warning Systems***: Although not within the scope of the project per se, EU-CIRCLE could be used as an early warning system for early identifying risks to interconnected CI. The substitution of climate data with seasonal prediction models or even operational numerical weather products could provide a unique service for CI operators, as presently such systems are not available.

8 Bibliography

[1] EC, “An EU Strategy on adaptation to climate change,” Brussels, COM(2013) 216 final, 2013.

[2] EC, “The EU Strategy on adaptation to climate change,” 2013.

[3] T. Wilbanks et al., “Climate change and infrastructure, urban systems, and vulnerabilities,” Technical Report for the US Department of Energy in Support of the National Climate Assessment, 2013.

[4] G. Forzieri et al., Resilience of large investments and critical infrastructures in Europe to climate change. Luxembourg: Publications Office, 2015.

[5] D. G. Huber and J. Gulledge, Extreme weather and climate change: understanding the link, managing the risk. Pew Center on Global Climate Change Arlington, 2011.

[6] R.S., R. Valentini et al., “Europe In Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)].,” Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1267-1326., 2014.

[7] IPCC, “FINAL DRAFT IPCC WGII AR5 Chapter 14,” 2014.

[8] IPCC, “The Working Group III Contribution to the IPCC Fourth Assessment Report Climate Change2007 Mitigation ofclimatechange,” Intergovernmental Panel on Climate Change, Cambridge University Press,Cambridge., a 2007.

[9] R. K. Pachauri, L. Mayer, and Intergovernmental Panel on Climate Change, Eds., Climate change 2014: synthesis report. Geneva, Switzerland: Intergovernmental Panel on Climate Change, 2015.

[10] IPCC, “Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp,” 2014.

[11] “Sendai Framework for Disaster Risk Reduction 2015-2030,” Geneva, 2015.

[12] “Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters,” Geneva, 2005.

[13] EEA, Energy and environment report 2008. Copenhagen, Denmark; Luxembourg: European Environment Agency ; Office for Official Publications of the European Communities, 2008.

[14] K. Anderson and A. Bows, “Reframing the climate change challenge in light of post-2000 emission trends,” Philos. Trans. R. Soc. Math. Phys. Eng. Sci., vol. 366, no. 1882, pp. 3863–3882, Nov. 2008.

[15] R. A. Betts, M. Collins, D. L. Hemming, C. D. Jones, J. A. Lowe, and M. G. Sanderson, “When could global warming reach 4 C?,” Philos. Trans. R. Soc. Math. Phys. Eng. Sci., vol. 369, no. 1934, pp. 67–84, Jan. 2011.

[16] M. New, D. Liverman, H. Schroder, and K. Anderson, “Four degrees and beyond: the potential for a global temperature increase of four degrees and its implications,” Philos. Trans. R. Soc. Math. Phys. Eng. Sci., vol. 369, no. 1934, pp. 6–19, Jan. 2011.

[17] D. M. Karl, L. Beversdorf, K. M. Björkman, M. J. Church, A. Martinez, and E. F. Delong, “Aerobic production of methane in the sea,” Nat. Geosci., vol. 1, no. 7, pp. 473–478, Jul. 2008.

[18] I. Burton, “Forensic Disaster Investigations in Depth: A New Case Study Model,” Environ. Sci. Policy Sustain. Dev., vol. 52, no. 5, pp. 36–41, Aug. 2010.

[19] EEA, “Climate change, impacts and vulnerability in Europe,” EEA, Copenhagen, Technical Report No. 12/2012, 2012.

[20] EC, “COMMISSION STAFF WORKING DOCUMENT - Summary of the Impact Assessment,” 2013.

[21] EC, “Adapting infrastructure to climate change,” Brussels, SWD(2013) 137 final, 2013.

[22] EC, “Overview of natural and man-made disaster risks in the EU,” SWD(2014) 134, SWD(2014) 134, 2014.

[23] EC, “Identification and designation of European critical infrastructures and the assessment of the need to improve their protection,” EC Dir 2008/114/, 2008.

[24] M. Linnenluecke and A. Griffiths, “Beyond Adaptation: Resilience for Business in Light of Climate Change and Weather Extremes,” Bus. Soc., vol. 49, no. 3, pp. 477–511, Sep. 2010.

[25] V. V. Kharin and F. W. Zwiers, “Estimating Extremes in Transient Climate Change Simulations,” J. Clim., vol. 18, no. 8, pp. 1156–1173, Apr. 2005.

[26] R. E. Morss, O. V. Wilhelmi, G. A. Meehl, and L. Dilling, “Improving Societal Outcomes of Extreme Weather in a Changing Climate: An Integrated Perspective,” Annu. Rev. Environ. Resour., vol. 36, no. 1, pp. 1–25, Nov. 2011.

[27] Michael J. Savonis, Virginia R. Burkett, and Joanne R. Potter, “Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I,” 2007.

[28] B. Lyon and D. G. DeWitt, “A recent and abrupt decline in the East African long rains: EAST AFRICAN LONG RAINS DECLINE,” Geophys. Res. Lett., vol. 39, no. 2, p. n/a-n/a, Jan. 2012.

[29] B. Lyon et al., “Baseline Probabilities for the Seasonal Prediction of Meteorological Drought,” J. Appl. Meteorol. Climatol., vol. 51, no. 7, pp. 1222–1237, Jul. 2012.

[30] Cruz, R.V.O, Lasco, R.D, Pulhin, J.M, Pulhin, F.B, and K.B. Garcia, “Assessment of Climate Change Impacts, Vulnerability and Adaptation: Water Resources of Pantabangan-Carranglan Watershed.” 2006.

[31] L. A. Bollinger et al., “Climate adaptation of interconnected infrastructures: a framework for supporting governance,” Reg. Environ. Change, Mar. 2013.

[32] UKCIP Technical Report, “Climate adaptation: Risk, uncertainty and decision-making,” Robert Willows Richenda Connell, 2003.

[33] EC, “Adapting to climate change: towards a European framework for action,” COM 0147 final, Brussels., 2009.

[34] Robert W. Kates, William R. Travis, and Thomas J. Wilbanks, “Transformational adaptation when incremental adaptations to climate change are insufficient.”

[35] O. Edenhofer and IPCC, Eds., Climate change 2014: mitigation of climate change ; Working Group III contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. New York, NY: Cambridge Univ. Press, 2014.

[36] T. R. Carter, Ed., IPCC technical guidelines for assessing climate change impacts and adaptions: part of the IPCC special report to the first session. London: ondon Department of Geography, University College London, 1994.

[37] CEN, “Eurocode-Basis of Structural Design,” 2002.

[38] CEN, “Newsletter of the European Committee for Standarization/Technical Committee 250-Structural Eurocodes,” 2007.

[39] CEN, “Business Plan, CEN/TC 250 STRUCTURAL EUROCODES, EXECUTIVE SUMMARY,” 2014.

[40] EN 1991-1-4, “Eurocode 1: Actions on structures - Part 1-4: General actions - Wind actions [Authority: The European Union Per Regulation 305/2011, Directive 98/34/EC, Directive 2004/18/EC],” 2005.

[41] EC Joint Research Centre, “The European Commission’s in-house science service Annual report,” 2012.

[42] L. Feyen, R. Dankers, K. Bódis, P. Salamon, and J. I. Barredo, “Fluvial flood risk in Europe in present and future climates,” Clim. Change, vol. 112, no. 1, pp. 47–62, May 2012.

[43] J. Hickel et al., PROVIA guidance on assessing vulnerability, impacts and adaptation to climate change: consultation document. 2013.

[44] INTACT, “Impact of extreme weather on critical infrastructure,” 2015.

[45] DOE/NETL, “Potential Impacts of Climate Change on the Energy Sector,” DOE/NETL-403/101807, 2007.

[46] Federal Highway Administration, “Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I,” 2008.

[47] P. Hawkes, Great Britain, Environment Agency, DEFRA/Environment Agency Flood and Coastal Defence R & D Programme (Great Britain), and HR Wallingford (Firm), UK Climate Impacts Programme 2002 climate change scenarios: implementation for flood and coastal defence : guidance for users. Bristol: Environment Agency, 2003.

[48] G. Ringland, Scenario planning: managing for the future, 2nd ed. Chichester, England: Wiley, 2006.

[49] K. Van der Heijden, Scenarios: the art of strategic conversation, 2nd ed. Chichester, West Sussex ; Hoboken, N.J: John Wiley & Sons, 2005.

[50] T. Ritchey, “General morphological analysis,” in 16th euro conference on operational analysis, 1998.

[51] B. Poteralska and A. Sacio-Szymańska, “Evaluation of technology foresight projects,” Eur. J. Futur. Res., vol. 2, no. 1, Dec. 2014.

[52] EU-CIRCLE, “D5.1 CIRP detail design document final version 1.0,” 2016.

[53] S. M. Rinaldi, Peerenboom J.P., and Kelly T.K, “Identifying, understanding, and analyzing critical infrastructure interdependencies,” IEEE Control Syst. Mag., vol. 21, no. 6, pp. 11–25, Dec. 2001.

[54] S. M. Rinaldi, “Modeling and simulating critical infrastructures and their interdependencies,” 2004, p. 8-.

[55] DiSera, D and Brooks, T, “The geographical dimensions of critical infrastructure and emergency response, In: Pipeline & Gas Journal, 236 (9), 1-4,” 2009.

[56] Sweeney J, Donnelly AL, McElwain L, and Jones M, “Climate Change: Indicators for Ireland, Irish Environmental Protection Agency,” Johnstown Castle Estate, Wexford, Ireland. 54 pp., 2002.

[57] D. Mendonça and W.A. Wallace, “Impacts of the 2001 World Trade Center attack on New York City critical infrastructures Journal of Infrastructure Systems,” pp. 260–270, 2006.

[58] D. D. Dudenhoeffer, M. R. Permann, and M. Manic, “CIMS: A framework for infrastructure interdependency modeling and analysis,” in Proceedings of the 38th conference on Winter simulation, 2006, pp. 478–485.

[59] Pederson, Dudenhoeffer, Hartley, and Permann, Critical Infrastucture Interdependency Modelling - A Survey of US and International Research. 2006.

[60] Owusu, A, Mohamed, S, and Anissimov, Y, “Input-output impact risk propagation in critical infrastructure interdependency,” Griffith University, Gold Coast, QLD 4222, Australia, 2010.

[61] UNISDR, “Global Assessment Report on Disaster Risk Reduction Revealing Risk, Redefining Development Summary and Main Findings,” 2011.

[62] EC, “Non-paper Guidelines for Project Managers: Making vulnerable investments climate resilient,” 2011.

[63] Koetse J. Mark and Piet Rietveld, "The impact of climate change and weather on transport: An overview of empirical findings". Elsevier Publisher: Transportation Research Part D 14 (2009) 205–221