EU-CIRCLE

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

D4.1 EU-CIRCLE RESILIENCE FRAMEWORK – INITIAL VERSION

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Statement	
This report is a background report for the Deliverables 4.1 and 4,3, which is EU-CIRCLE Resilience Framework. In developing the resilience framework this report attempts to develop a comprehensive definition for CI resilience based on the EU-CIRCLE taxonomy (D1.1) and other literature. This report also assesses existing resilience frameworks through a systematic review of literature in order to propose the format and potential components of the EU-CIRCLE resilience framework.	

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Executive Summary

The main purposes of D4.1 is to define the term resilience of critical infrastructure in the context of EU-CIRCLE and to develop a resilience framework for critical infrastructure. D4.1 is a technical report, which provides the scientific background for the development of both the definition and the framework. As such, D4.1 in its initial version provides a comprehensive review and synthesis of literature associated with disaster resilience and critical infrastructure.

Several existing resilience definitions have been reviewed to develop a comprehensive definition for critical infrastructure resilience, which will be used across the EU-CIRCLE consortium. This definition, once approved by the reviewers will form part of the EU-CICLE taxonomy. This report presents an analysis of 16 resilience frameworks, with either a national or local focus and with either a community, city, organisational or infrastructure context to resilience. The factors influencing critical infrastructure are also reviewed.

Based on the analysis, this deliverable proposes an EU-CIRCLE resilience framework for critical infrastructure. The proposed framework has 4 layers that are independent and interdependent. Climatic hazards, including current and future climate change; critical infrastructure, their networks and interdependencies; disaster risks and impacts; and capacity of critical infrastructure are the four layers that form the resilience framework. All the layers are further detailed in several different work packages as follows:

1. Climatic hazards and climate change (WP2)
2. Critical Infrastructure (WP3)
3. Risks and impacts (WP3)
4. Capacities (WP4)

As such, the further development of the initial framework will have back and forth contributions from other work packages and deliverables of the EU-CIRLCE project. The initial framework presented in this deliverable has been validated with the stakeholders of the framework and the feedback received from the stakeholders has been incorporated. The final version of the framework will be available in June 2017.

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1 Introduction

It is presently acknowledged and scientifically proven that climate related hazards have the potential to substantially affect the lifespan and effectiveness or even destroy European Critical Infrastructures (CI), particularly the energy, transportation, buildings, marine and water management infrastructure, with devastating impacts. The main strategic objective of EU-CIRCLE is to move towards an infrastructure network(s) that is resilient to today's natural hazards and prepared for the future changing climate.

EU-CIRCLE intends to derive a holistic resilience framework, the purpose of which is to explain what constitutes resilience in the context of critical infrastructure. The EU resilience framework will be delivered in two stages:

- Stage 1: Initial Framework (Technical Report) in M12
- Stage 2: Final Framework (Operational framework supplemented by a report) in M24

This report, which is related to the initial framework, is the technical report for the purpose of establishing the theoretical background for the EU resilience framework. As such, the objectives of this report are to:

- develop a comprehensive definition of resilience;
- review existing resilience frameworks;
- investigate the factors influencing Critical Infrastructure (CI) resilience;
- discuss and synthesise a pragmatic approach for a workable framework;
- propose components for the EU-CIRCLE resilience framework.

This report will be further developed during its second phase by incorporating the contributions from other work packages and deliverable in order to produce the final version of the resilience framework for critical infrastructure.

1.1 The approach

Deliverable 4.1 is very important in the scope and framework of the project, as it essentially constitutes the establishment of the resilience framework. Thus the consortium proceeded in two "open reviews" in order to allow every partner to provide inputs and suggestions and accommodate them in the report. As "resilience" is still a fuzzily defined concept, several interactions with the consortium where necessary in order to reach a common understanding introduced herein.

Several steps have been followed in the development of the initial resilience framework. The first step was to define the term resilience from the EU-CIRCLE point of view. The main approach used for this purpose was to analyse several existing definitions for resilience, most of which have been gathered from the EU-CIRCLE taxonomy (D1.1). The key terms were identified within each definition and have been combined under four main classifications. The terminologies associated with resilience and their interconnections were also reviewed. Based on this analysis the term resilience for EU-CIRCLE has been defined. The second step was to review existing resilience frameworks. The main purpose was to analyse the purpose and components of existing resilience models in order to identify the appropriate components that can be used for the EU-CIRCLE resilience framework. 16 different frameworks were analysed and compared, with the frameworks analysed having either a national, regional or international focus. The factors influencing critical infrastructure were thus identified. Both the resilience framework analysis together with the factors influencing critical infrastructure helped to develop the necessary components for the EU-CIRCLE resilience framework. The initial framework was presented to potential stakeholders at the EU CIRCLE Consolidated Workshop in Milan, in order to obtain their feedback and has been incorporated within the model.

1.2 The role of Infrastructure

Infrastructure systems, commonly referred to as the energy production & distribution systems, the chemical industry, water system, transportation, ICT Networks and public sectors, are one of the defining features of modern societies. We rely heavily upon them and their smooth operation to carry out our day to day activities. For example, roads and rail take us to our places of employment whilst transporting raw materials to production facilities and the subsequent final goods to retail stores and consumers. Electricity and energy allow us to use our buildings (i.e., lighting, heating, and cooling) as well as to operate equipment, appliances, and technology. Water networks transport water for drinking, cooking, cleaning, cooling, for the production of raw materials and goods, for irrigation, whilst wastewater systems eliminate personal and manufacturing waste (NIST vol 2). Infrastructures thus facilitate economic growth, protect human health and the environment and promote welfare and prosperity.

When infrastructure systems are damaged or fail, the smooth functioning of society is disrupted, with negative impacts on our ability to continue in our daily activities; well-being; and security. Damage or failure may result in severe economic losses and interruption of many services that we rely on (NIST vol 1). To further complicate matters, modern infrastructures operate as a ‘system of systems’ with many interactions and interdependencies among these systems. Thus damage in one infrastructure system can cascade and result in failures and cascading effects onto all related and dependent infrastructures. For example, loss of an electricity substation may stop a water treatment plant from functioning; which may stop a hospital from functioning. This is a failure cascade chain that spans energy, water and healthcare systems. (UNISDR)

Such failures are made worse because of the nature of our modern societies which are characterised by high density urban centres, high levels of material wealth, and rapid, immediate and interconnected lifestyles (Rogers et al). The societal disruption caused by infrastructure failures can frequently be disproportionately higher in relation to the actual physical damage (Chang, 2009). It is for these reasons that the ability of systems to cope and bounce back from shocks, their resilience, is so important (Rogers et al).

Various disasters over the past few decades, including man-made and natural disasters, have highlighted that avoidance of all threats at all times for all infrastructures is practically impossible (Sandia report, 2014). This realisation, combined with the disruptive societal impacts of infrastructure damage or failure, has led to the wide recognition in recent years for the need for resilience– for example, ICE’s state of the nation report: ‘Defending critical infrastructure’ (ICE, 2009); the European Commission’s policy on the prevention of natural and man-made disasters (EC, 2009), the national response framework (NRF) (DHS, 2008), prepared by the USA’s Federal Emergency Management Agency (FEMA) and globally by the Hyogo Framework for Action 2005- 2015: Building the Resilience of Nations and Communities to Disasters and its successor the Sendai Framework for Disaster Risk Reduction 2015 - 2030 .

1.3 The Sendai Framework for Disaster Risk Reduction 2015-2030

The Sendai Framework for Disaster Risk Reduction 2015-2030 (Sendai Framework) is a voluntary and non-binding agreement, which coordinates work on disaster risk management and maps the global course in this field over the next 15 years. It was adopted by UN Member States on 18 March 2015 at the Third UN World Conference on Disaster Risk Reduction in Sendai City, Miyagi Prefecture, Japan.

The Sendai Framework is the successor to the Hyogo Framework for Action 2005- 2015: *Building the Resilience of Nations and Communities to Disasters* and previous global efforts in the field of disaster management[1]. It is notable for representing a shift in emphasis from disaster management to *disaster*

[1] Including the International Framework for Action for the International Decade for Natural Disaster Reduction of 1989, and the Yokohama Strategy for a Safer World: Guidelines for Natural Disaster Prevention, Preparedness and Mitigation and its Plan of

risk management and its goal is to prevent new disaster risks, reduce existing disaster risks and ultimately increase resilience globally. It advocates actions on tackling underlying risk drivers as a tool for achieving its goal, and recognises that climate change is one such risk driver. The Sendai Framework thus strongly promotes taking into account of climate change and climate change adaptation in disaster risk management activities and policies across the globe.

The Framework is underpinned by seven global targets, which relate to the reduction of: 1) global disaster mortality; 2) the number of people affected by disasters; 3) direct disaster economic loss; 4) disaster damage to critical infrastructure and disruption of basic services; whilst increasing: 5) the number of countries with disaster risk strategies; 6) international cooperation to developing countries; and 7) the availability of and access to multi-hazard early warning systems (see Annex 1 for the targets in detail).

Of particular relevance to EU-CIRCLE is target four of the framework: *Substantially reduce disaster damage to critical infrastructure and disruption of basic services, among them health and educational facilities, including through developing their resilience by 2030*. This target (and the other six) are underpinned by four priority areas for action:

Priority 1: Understanding disaster risk.

Priority 2: Strengthening disaster risk governance to manage disaster risk.

Priority 3: Investing in disaster risk reduction for resilience.

Priority 4: Enhancing disaster preparedness for effective response and to “Build Back Better” in recovery, rehabilitation and reconstruction

Through these priority areas the Framework proposes the following actions in relation to critical infrastructure:

- integration of disaster risk reduction in laws and regulations that apply to publically owned, managed or regulated services and infrastructures;
- investment in structural, non-structural and functional disaster risk prevention and reduction measures in critical infrastructures;
- **promotion of resilience of new and existing critical infrastructure**, including water, transportation and telecommunications and health infrastructure, to ensure that they remain safe, effective and operational during and after disasters in order to provide live-saving and critical services.

In order to monitor the implementation and effectiveness of the seven global targets, a set of indicators is currently being developed and will be finalised by December 2016. The preliminary indicators include several indicators on critical infrastructure which are relevant to EU-CIRCLE, as set out below:

C-3 - Direct economic loss due to industrial facilities damaged or destroyed by hazardous events

C-7 - Direct economic loss due to damage to [critical infrastructure / public infrastructure] caused by hazardous events.

D-1 - Damage to critical infrastructure due to hazardous events.

D-2 – [Number / percentage] of health facilities destroyed or damaged by hazardous events

D-3 - [Number / percentage] of educational facilities destroyed or damaged by hazardous events

D-4 - [Number / percentage] of [major] transportation [units and] infrastructures destroyed or damaged by hazardous event

Action, adopted in 1994 and the International Strategy for Disaster Reduction of 1999.

D-5 – [Number / Length / Percentage] of [time / days / person days] basic services have been disrupted due to hazardous events

D-10 – Number of communication infrastructure destroyed or damaged by hazardous events.

D-14 – Number of water and sanitation infrastructures destroyed or damaged by hazardous events.

Resilience of critical infrastructure is thus recognised in the Sendai Framework as of vital importance; as their continuing operation and provision of critical services is crucial, both during and after a disaster.

2 Expanded definition of resilience

2.1 Defining resilience

Resilience has multiple meanings and is a term increasingly employed throughout a number of sciences: psychology, ecology, disaster planning, urban planning, political science, business administration and international development. It is a term that originally emerged from the field of ecology in the 1970s to describe the capacity of a system to function in the face of disturbance (Holling, 1973; Rockefeller Foundation and Arup, 2014). The shared use of the term does not, however, signify unified concepts or definitions of resilience. In fact, 'resilience' has been defined in a number of different ways by various authors and organisations.

This section reviews the definitions provided for the term resilience within the EU-CIRCLE Taxonomy (D1.1) and other scientific literature in order to arrive at a comprehensive definition for use in the development of the resilience framework. The following table provides an overview of the definitions analysed.

Table 2-1 Resilience definitions

Definitions of resilience	**Source**
Capacity to resist, absorb, accommodate to and recover from the effects of hazards in timely and efficient manner through preservation and restoration of structure and functions	D1.1-EU-CIRCLE Taxonomy –V1.0 EU-ADAPT
Ability to anticipate, absorb, accommodate or recover from hazards in a timely and efficient manner through preservation, restoration or improvement of structure and functions	D1.1-EU-CIRCLE Taxonomy –V1.0 IPCC, 2012 UNISDR, 2009
Capacity to anticipate, prepare for, respond to and recover from the effects of hazards with minimum damage to the social-wellbeing, the economy and environment	D1.1-EU-CIRCLE Taxonomy –V1.0 US EPA
The capacity of a system, community or society potentially exposed to hazards to adapt, by resisting or changing in order to reach and maintain an acceptable level of functioning and structure	D1.1-EU-CIRCLE Taxonomy –V1.0 UNISDR, 2004
Resilience is a tendency to maintain integrity when subject to disturbance	D1.1-EU-CIRCLE Taxonomy –V1.0 UNDP, 2005 Levina and Tirpak, 2006
The ability of a system to recover from the effect of an extreme load that may have caused harm.	D1.1-EU-CIRCLE Taxonomy –V1.0 Levina and Tirpak, 2006 UKCIP, 2003
Capacity of a community, its members and the systems that facilitate its normal activities to adapt in ways that maintain functional relationships in the presence of significant disturbances	Paton, 2007
Ability to prevent, withstand, recover from and learn from the impacts of extreme weather hazards	Hallet, 2013
The amount of disturbance a system can absorb and still remain within the same state or domain of attraction; the degree to which the system is capable of self-organisation; the ability to build and increase the capacity for learning and adaptation	Carpenter et al., 2001
Robustness (the extent of system function that is maintained) /Redundancy (system properties that allow for alternate options, choices, and substitutions under stress) /Resourcefulness (the capacity to mobilize needed resources and services in emergencies)/ Rapidity (the time required to return to full	McDaniels et. al. 2008 Bruneau et al., 2003

system operations and productivity)	
Ability of an asset, or system of assets, to continue to provide essential services when threatened by an unusual event and its speed of recovery and ability to return to normal operation after the threat has receded.	D1.1-EU-CIRCLE Taxonomy –V1.0 McBain et. al., 2010

A close look at the above definitions indicates that the interpretation of resilience implies four concepts, though the boundaries between them are blurred.

- PREVENT - ability to predict and resist the impact – prepare for / anticipate / resist / prevent / preservation
- WITHSTAND - ability to sustain the damage – absorb / withstand / accommodate / robustness
- RECOVER - damage can occur but the system will be able to recover – respond to / recover / rapidity
- ADAPT - modifications to system – change / adapt / restoration / improvement / learn

As such our definition of resilience will include the capacity of a system to prevent, withstand, recover and adapt from the effects of climate hazards and climate change. The resilience framework's goal is to measure the present capacity of CI "to cope and bounce back from shocks" (Rogers et al., 2012); in other words, to assess if CI resilience level is acceptable or not to face climate hazards in a climate change context.

Critical Infrastructure systems do not act alone as they are interdependent on many other systems at multiple levels and are deeply embedded within social systems in cities. Therefore, a disruption in one system will create cascading impacts and consequences to the networked infrastructure system. This nature of interdependency of infrastructure demands a focus also on the resilience of networks when defining critical infrastructure resilience. Previous research on infrastructure networks (Zio and Kroger, 2009; Murray et al., 2007; Turnquist and Vugrin, 2013) focused mainly on elements such as vulnerability, reliability and recovery. Vulnerability assessment focused on identifying the network links whose failure would cause the most disruption in the functioning of the network; reliability-based analyses typically focused on the degree to which a network can withstand certain types of disruptions; and recovery analysis was about system recovery in infrastructure networks following a disruptive event.

According to Turnquist and Vugrin (2013, p.104), increasing network resilience involves three related capabilities—providing absorptive capacity so that the network can withstand disruptions; providing adaptive capacity so that flows through the network can be accommodated via alternate paths; and providing restorative capacity so that the recovery of the network from a disruptive event can be accomplished quickly and at minimum cost. It is clearly evident that these three capabilities (withstand, recover and adapt) are also the essential elements in defining resilience, as per Table 2.1.

2.2 Correlation of resilience related terminologies

The correlations of terminologies associated with resilience are established in this section to understand the positive and negative linkages they have with each other.

Hazard: A potentially dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage (UNISDR, 2009). However mere existence of a hazard is not considered dangerous unless it is exposed to a vulnerable environment or system. Therefore to minimise the impact of hazards, it is vital to reduce the exposure of hazards, reduce vulnerabilities and to improve the capacity of the associated community or system (I2UD, 2014).

Mitigation: The lessening or limitation of the adverse impacts of hazards and related disasters (UNISDR, 2009). The adverse impacts of hazards often can be substantially lessened by taking appropriate measures, though the impact cannot be fully prevented. The knowledge and awareness on disaster risk reduction will help to develop mitigation strategies and mitigation will also improve public awareness, as such we can see a two-way positive contribution between knowledge, awareness and mitigation. In climate change policy, “mitigation” is defined differently, being the term used for the reduction of greenhouse gas emissions that are the source of climate change (UNISDR, 2009). As such mitigation will also positively contribute to climatic hazards in the long run.

Preparedness: The knowledge and capacities developed by governments, professional response and recovery organizations, communities and individuals to effectively anticipate, respond to, and recover from, the impacts of likely, imminent or current hazard events or conditions (UNISDR, 2009). As per this definition, one of the crucial inputs for effective preparedness is knowledge and awareness. Preparedness can also lead to prevention, with the help of anticipatory capacity.

Prevention: The avoidance of the adverse impacts of hazards and related disasters. Prevention is closely associated with anticipatory capacity, which anticipates and reduces the impacts of climate change through preparedness and planning. If prevention is possible, it will minimise disaster risks and impacts by reducing the level of vulnerability.

Recovery: The restoration, and improvement where appropriate, of facilities, livelihoods and living conditions of disaster-affected communities, including efforts to reduce disaster risk factors.

Resilience: The ability of a system, community or society to resist, absorb, cope with and recover from the effects of hazards and to adapt to longer term changes in a timely and efficient manner without enduring detriment to food security or wellbeing (UNISDR, 2009). As such the term resilience is associated with anticipative capacity, absorptive capacity, coping capacity, restorative capacity and adaptive capacity. Contradicting Biringer et al., 2013, UNISDR sees the adaptation as the longer-term defence in comparison to recovery. We agree with this. A close look at the definition of recovery reveals that restoration is only a part of the recovery process. As such it is possible that recovery can also happen within a short term. The key differences are that adaptive capacity reflects the ability of a system to be changed whereas restorative capacity reflects the ability to be repaired. This implies after a restoration, the system will return to something near its original structure whereas after an adaptation the structure of the system may have radically changed (Biringer et al., 2013).

Risks: The combination of the probability of an event and its negative consequences. Climatic hazard and future climate change will increase the risks, especially when the society and system are exposed to such uncertainty conditions of climate change and climatic hazards. Risk reduction is one of the main ingredients for achieving resilience.

Vulnerability: The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard. Vulnerability is associated with the uncertainty nature of climate change, lack of capacity and lack of knowledge about disaster risks. Reducing vulnerability will help to improve the level of resilience.

2.3 The EU-CIRCLE definition for Critical Infrastructure (CI) resilience

Based on the above analysis, the short form of the definition of resilience in the context of critical infrastructure is the **ability of a CI system to prevent, withstand, recover and adapt from the effects of climate hazards and climate change**.

In line within that, this definition further clarifies that CI resilience is the ability of the critical infrastructure system to:

1. Prevent the impacts from climatic hazards by minimising the exposure of critical infrastructure to hazards;
2. Withstand the impacts from climatic hazards and climate change by reducing the magnitude and number of impacts;
3. Recover from the effects of climate hazards and climate change; and
4. Adapt through modification and improvements to the CI system.

3 Development of the EU-CIRCLE resilience framework

This section reviews and analyses existing resilience frameworks developed by various scholars and organisations in order to understand the components used in such frameworks. In addition, the factors affecting critical infrastructure protection are investigated. Based on the analysed information, the components for incorporation within the EU-CIRCLE framework are identified.

3.1 Analysis of existing resilience frameworks

This section presents a general description of different frameworks and analyses the components incorporated within these frameworks.

NB: Because resilience and adaptation are closely related concepts, some frameworks presented below combine both resilience and adaptation approaches.

The resilience frameworks can in general be categorised according to their aims and audience. Some frameworks have a policy-maker focus hence are more relevant to National level or Government actions at a strategic level and as such can be classified as high level. Other frameworks are aimed at a local level or are more stakeholder focussed and as such can be categorised as operational level. The resilience approaches below can be categorised under the basis of the above taxonomies.

In addition, resilience has two main time frames:

i. Short term, linked to business continuity (how to optimize flows in the CI nets), especially under disruptive events, how to sustain the supply chain of the infrastructure (D4.2),

ii. Long term, linked to adaptation ability that would result in the CI being able to cope with climate change over the longer time horizon (~ years, decades, etc.) (Task 4.4).

3.1.1 National Infrastructure System Model family (NISMOD)

The UK Infrastructure Transitions Research Consortium (ITRC, 2015) delivers research, models and decision support tools which enable analysis and planning of national infrastructure systems. As part of this, ITRC has tackled four major challenges as detailed below (ITRC, 2015, P.3):

- How infrastructure capacity and demand can be balanced in an uncertain future – by developing methods for modelling capacity, demand and interdependence in national infrastructure systems in a compatible way under a wide range of technological, socio-economic and climate futures.
- What the risks of infrastructure failure are and how to adapt national infrastructure to make it more resilient - by analysing the risks, vulnerability and consequences of interdependent infrastructure failure and by identifying ways of adapting infrastructure systems to reduce risks in the future.
- How infrastructure systems evolve and interact with society and the economy, by examining the complex relationship between infrastructure, the economy and society.
- What the UK strategy should be for integrated provision of national infrastructure in the long term by using new methods to develop and test alternative strategies for Britain’s national infrastructure.

The National Infrastructure System Model (NISMOD) family contains four components including a model for long-term performance, a model of risk and vulnerability, a model for regional development and a national database of infrastructure networks. The long-term performance model, which is presented in Figure 3.1, is the focus, as it constitutes infrastructure resilience.

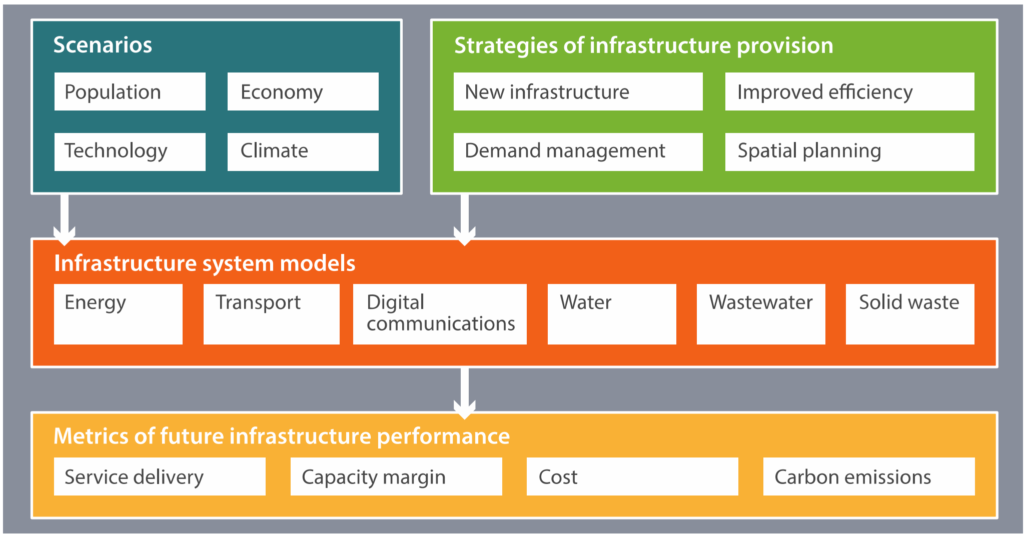

Figure 3-1 National Infrastructure System Model - Long-term Performance - NISMOD-LP (Source: ITRC, 2015)

The factors that influence demand for infrastructure services in the future are combined with alternative strategies for infrastructure provision. Combinations of scenarios and strategies are input into the modules that compute demand for various infrastructure system models such as energy, transport, digital communications, water, wastewater and solid waste, now and in the future. The model then outputs sets of metrics for future infrastructure performance.

3.1.2 The model of area-picture of potential threats from/to CI in the Baltic Sea Region

Another layered approach has been proposed concerning the vulnerability assessment of critical infrastructures and their networks in the Baltic Sea Region as illustrated in Figure 3.2.

The elements of critical infrastructures and their networks, on the one hand, may be vulnerable to damage caused by external factors and on the other hand, may pose actual or potential threats to other critical infrastructures and networks. The expected threats associated with the critical infrastructures located in the Baltic Sea area have been divided into the following 3 layers:

- Layer of dynamic threats,
- Layer of static threats,
- Layer of natural hazards associated with weather and climate change.

As critical infrastructures are often interconnected and interdependent, the combination of these three layers can help to indicate critical infrastructures, which can be affected and can affect other critical infrastructures in a fixed area of the Baltic Sea Region. This in turn will help to determine the critical infrastructures based on their level of vulnerability.

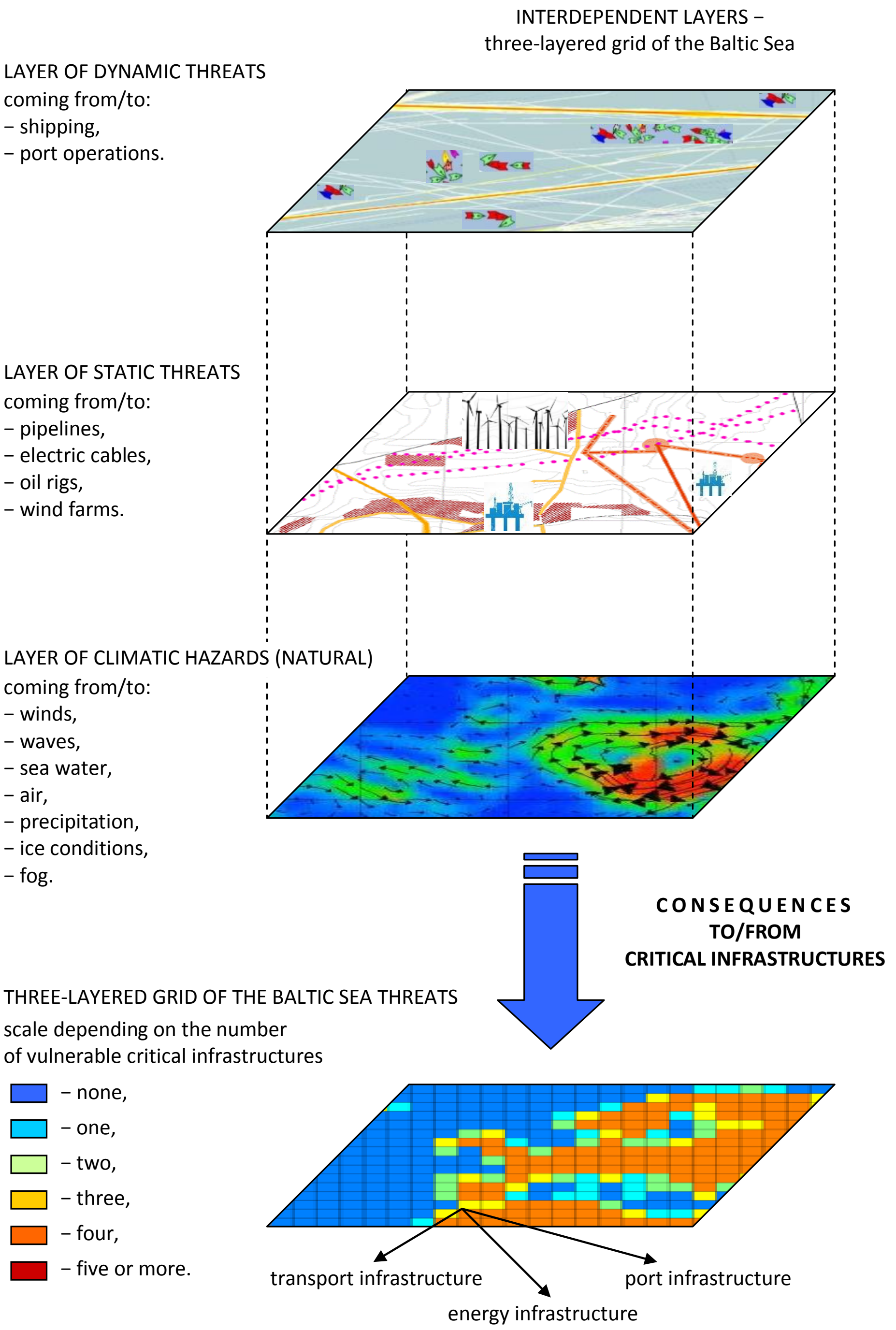

Figure 3-2 The model of area-picture of potential threats from/to critical infrastructures in the Baltic Sea Region (Source: GMU, 2016)

3.1.3 UNISDR Disaster Resilience Scorecard for Cities

The Disaster Resilience Scorecard has been prepared by the United Nations Office for Disaster Risk Reduction (UNISDR) and provides a set of assessments that allow cities to gauge how resilient they are to natural disasters. The aim of the scorecard is to: aid cities to establish a baseline measurement of their current level of disaster resilience, to identify priorities for investment and action, and to track their progress in increasing their disaster resilience over time. It is made up of 85 disaster resilience evaluation criteria which focus on the following features:

- **Research**, including evidence-based compilation and communication of threats and needed responses.
- **Organisation**, including policy, planning, coordination and financing.
- **Infrastructure**, including critical and social infrastructure and systems and appropriate development.
- **Response capability**, including information provision and enhancing capacity.
- **Environment**, including maintaining and enhancing ecosystem services.
- **Recovery**, including triage, support services and scenario planning.

The scorecard is based on the UN's ten essentials and of particular relevance to this report is essential four: *Invest in and maintain critical infrastructure that reduces risk, such as flood drainage, adjusted where needed to cope with climate change.* The scorecard treats the topic of resilient infrastructure by subdividing it into issues, and offering measurement indicators and measurement scales. For example:

Subject/Issue	Item measured	Indicative Measurement	Indicative Measurement Scale	Comments
Electricity	Customer service days at risk of loss.	"Electrical energy loss factor". If a = estimated # of days to restore regular service area-wide b = % of user accounts affected … then electrical energy loss factor = a x b (Example – 1.5 day's loss of service for 10% of user accounts in city = loss factor of 15%; 3 days' loss of service for 50% of user accounts in city = loss factor of 150%)	5 – No loss of service even from "most severe" scenario 4 – No loss of service even from "most probable" scenario 3 – Loss factor of 1-25% from most probable" scenario 2 – Loss factor of 25-100% from "most probable" scenario 1 – Loss factor of 100-200% from "most probable" scenario 0 – Loss factor >200% from "most probable" scenario	Loss of service should be assessed relative to the "normal" state: - If "normal" service is electricity 24 hours a day then loss of service is anything that reduces this; - If "normal" service is electricity for less than 24 hours per day, then loss of service is anything that reduces this still further.
	Designated critical asset service days at risk of loss from energy failure.	"Electricity critical asset (ECA) loss factor". If a = estimated # of days to restore regular service area-wide b = % of critical assets affected … then ECA loss	5 – No loss of service even from "most severe" scenario 4 – No loss of service even from "most probable" scenario 3 – Loss factor of 1-25% from most probable" scenario 2 – Loss factor of 25-	Critical electrical assets are those that are either: - Essential for the operation of some part of the energy grid for the city; - Essential for the functioning of some other critical asset (say, a water

		factor = a x b (Example – 1.5 day's loss of service for 10% of critical assets in city = loss factor of 15%; 3 days' loss of service for 50% of critical assets in city = loss factor of 150%)	100% from "most probable" scenario 1 – Loss factor of 100-200% from "most probable" scenario 0 – Loss factor >200% from "most probable" scenario	treatment plant or a rail line). Loss of service refers to service from the main electricity supply. Service may be provided either from the asset itself or via a designated alternative/back-up.

3.1.4 I2UD's Climate Change Adaptation and Resiliency Framework

The Institute for International Urban Development (I2UD) has developed a climate change adaptation and resiliency framework mainly focusing on low-income urban populations who tend to live on exposed sites that are prone to environmental and weather related risks. Urban policies related to climate change have largely been focused on mitigation, but I2UD (2014) claims that there has recently been a shift toward the development of resilient cities that can respond and adapt to climate related disruptions. The I2UD framework, which is shown in Figure 3.3, reflects this shift.

Figure 3-3 I2UD's Climate Change Adaptation and Resiliency Framework (Source: Institute for International Urban Development (I2UD)

The I2UD framework is different from other frameworks due to its focus on the local level, whereas most climate change policies are often developed on a national scale. The framework provides an approach for local authorities to conceptualize climate change adaptation in a manner that recognizes their particular circumstances; organize policies around this issue; and affect change (I2UD, 2014).

Based on the documentation of climate change effects and adaptation approaches developed by the International Panel on Climate Change (IPCC), this integrated framework focuses on the specific risks faced by informal and lower-income settlements and offers a way to both understand and address the underlying causes of risks. I2UD views risk as a combination of three components such as exposure to natural hazards due to geographic location; vulnerability to small- and large-scale weather events due to socioeconomic conditions; and lack of institutional capacity to adapt due to inadequate infrastructure systems, inefficient land management, and a lack of inclusive development policies. These three components provide the basis of the framework

3.1.5 Vulnerability to Resilience (V2R) Framework

Practical Action, which is an international non-governmental organisation (NGO) that uses technology to challenge poverty in developing countries, has developed a resilience framework entitled 'from vulnerability to resilience (V2R)' (Pasteur, 2011) as shown in Figure 3.4.

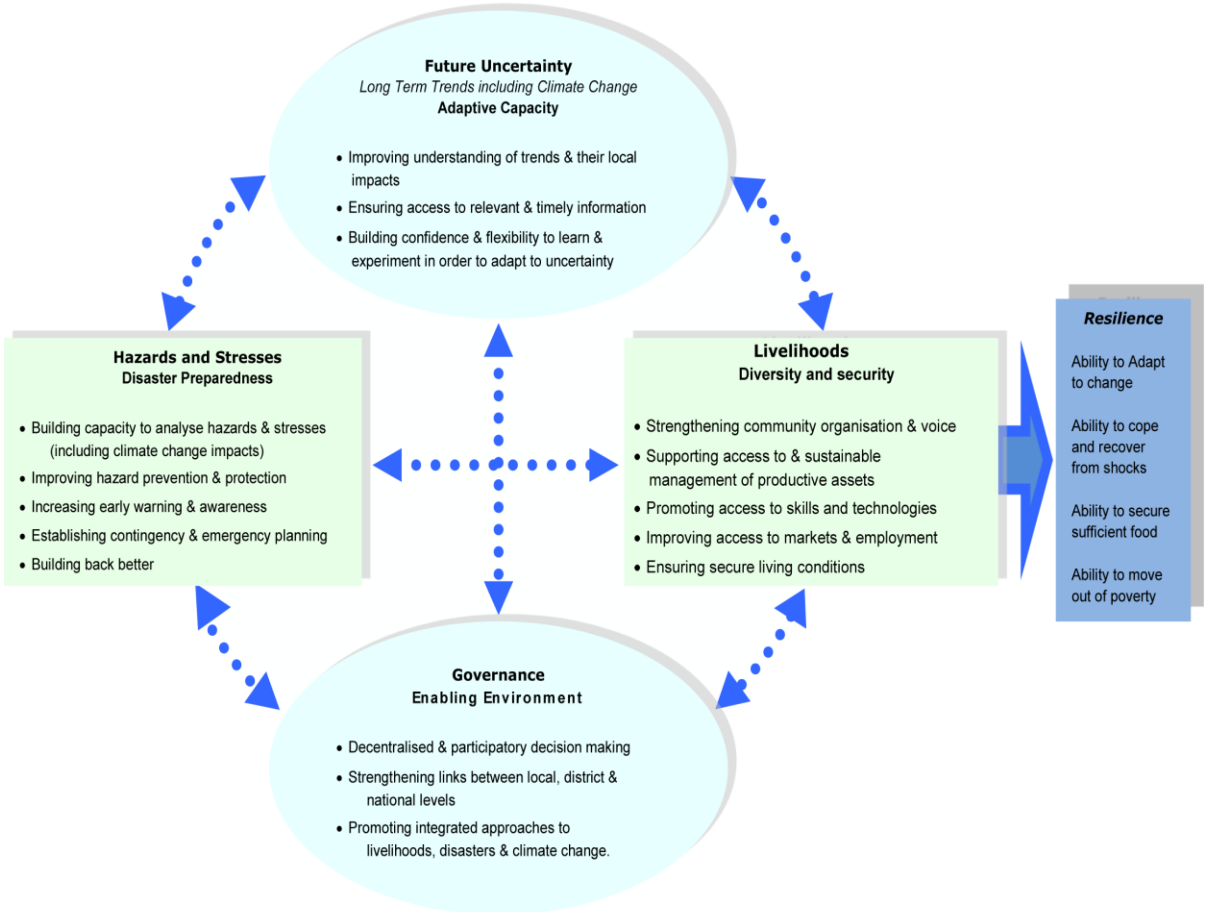

Figure 3-4 V2R Framework (SOURCE: Practical Action, Bangladesh)

Vulnerability is the degree to which a population or system is susceptible to, and unable to cope with, hazards and stresses, including the adverse effects of climate change (Pasteur, 2011). The causes of vulnerability are based on the extent of exposure to hazards and the social and economic conditions of the people or the system. Vulnerability is further increased by a situation of uncertainty such as climate change. This coupled with a lack of knowledge, understanding and accessibility to information and resources increase vulnerability. The V2R framework was therefore developed to tackle the causes and consequences of vulnerability. As such V2R considers four key components for incorporation within the framework. They are exposure to hazards and stresses; fragile livelihoods; future uncertainty; and weak governance as shown in Figure 3.4.

The V2R framework mainly aims to improve the livelihoods of poor people in relation to multiple hazards and an uncertain future and thus could be used in the context of community resilience.

The above framework, which is not specific to infrastructure though, seems to be a Governance mechanism for high-level resilience management in developing countries.

3.1.6 The Climate Resilience Framework

The Climate Resilience Framework (CRF) provides a conceptual framework for assessing vulnerabilities and risks, identifying resilience strategies—and creating an open, inclusive learning process to identify specific measures and processes that can address the uncertainties of climate change through action and implementation (Friend and MacClune, 2013, p.9).

The Climate Resilience Framework that has been developed by the Institute for Social and Environmental Transition-International (ISET-International), has a combination of two loops as indicated in Figure 3.5. One loop is about understanding vulnerability and the other is about building resilience. The vulnerability loop helps clarify factors that need to be included in the diagnosis of climate vulnerability, and structures the systematic analysis of vulnerability in ways that clearly identify the entry points for responding. The resilience loop supports strategic planning to build resilience to climate change, prompting new and practical ways of thinking about the challenges of adapting to climate change. Combining these two loops will lead to a shared learning dialogue process to achieve the integration of vulnerability and resilience elements.

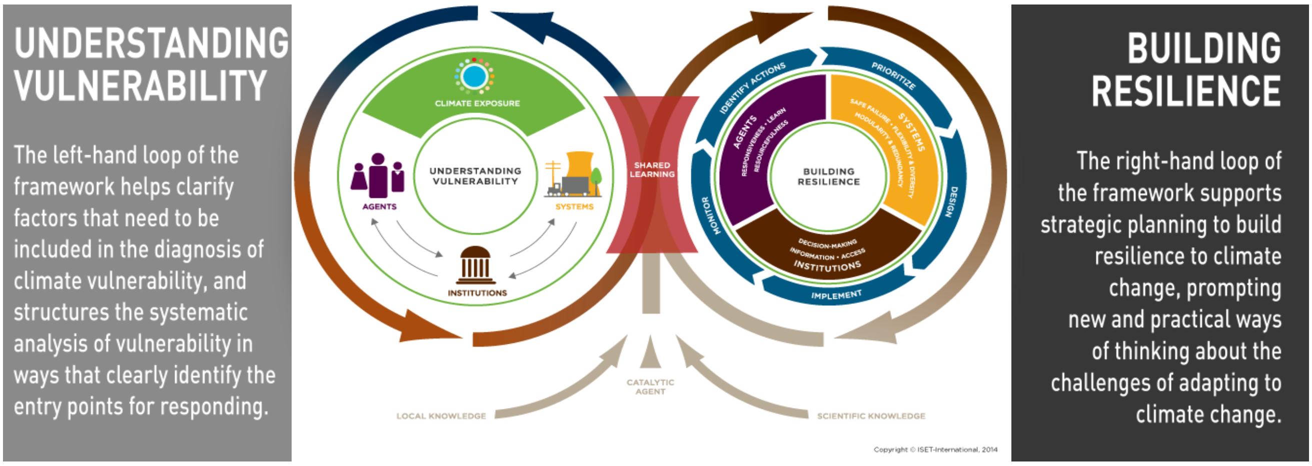

Figure 3-5 Climate Resilience Framework (CRF) – (Source: The Institute for Social and Environmental Transition-International - ISET-International)

The resilience framework has three core components: systems, agents and institutions. The framework further identifies the factors and characteristics of each of these components that are important to enhance and to identify the indicators to measure the success which are presented below (Friend and MacClune, 2013):

- Systems: are considered the combination of ecosystems and infrastructure systems. The characteristics of systems are flexibility and diversity; redundancy, modularity; and safe failure.
- Agent: refers to people and their organizations, whether as individuals, households, communities, private and public sector organizations, or companies. The characteristics of agents are responsiveness, resourcefulness and capacity to learn.

- Institution refers to the rules, norms, beliefs or conventions that shape or guide human relations and interactions, access to and control over resources, goods or services, assets, information and influence. The characteristics of institutions are access rights and entitlements; decision-making processes, information flows and application of new knowledge.

3.1.7 DFID's resilience framework

The Department for International Development (DFID, 2011, P.6) defines resilience as the ability of countries, communities and households to manage change, by maintaining or transforming living standards in the face of shocks or stresses without compromising their long-term prospects. The resilience framework built upon this definition has used four elements such as context; disturbance; capacity to deal with disturbance; and reaction to disturbance as shown in Figure 3.6.

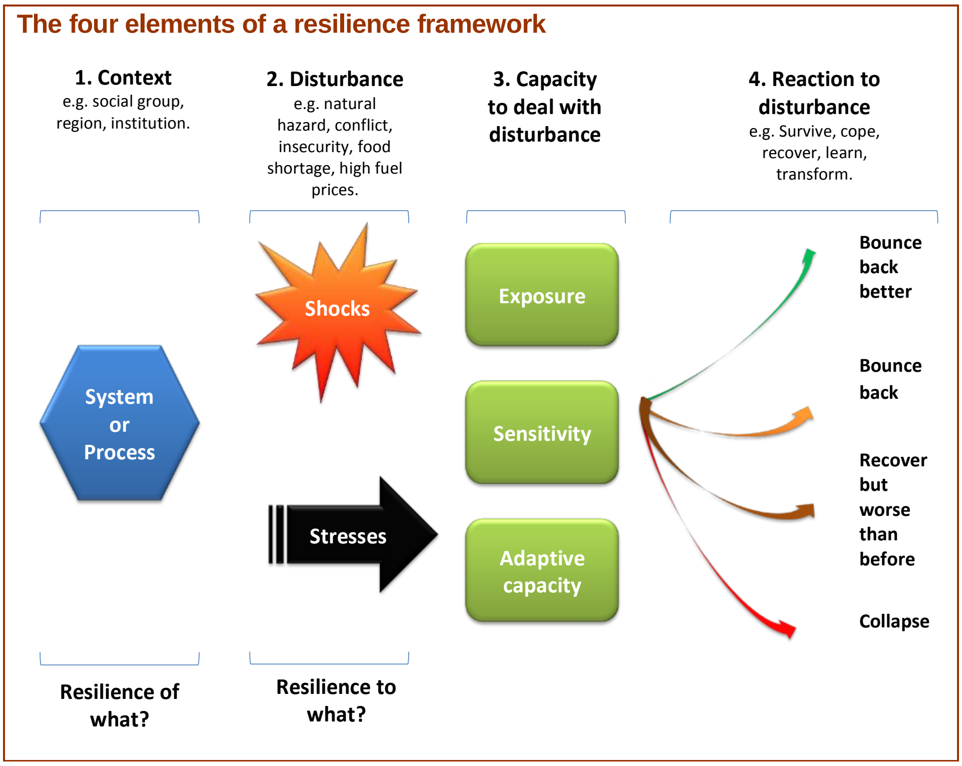

Figure 3-6 DFID's Resilience Framework (Source: Department for International Development)

The framework emphasises that resilience should always be contextualized in order to answer the question of 'resilience of what', as the significance of resilience differs across a range of different contexts. The next stage is to understand the disturbance to address the question 'resilience to what' where they have considered the immediate shocks and the long-term stresses as the main forms of disturbances. The third step is about the ability of the system or process to deal with the shock or stress based on the levels of exposure, the levels of sensitivity and adaptive capacities. And the final step is the reaction to disturbance, which might be 'bounce back better' for the system or process concerned in the best case (DIFD, 2011).

3.1.8 The City Resilience Framework

The City Resilience Framework developed by the Rockefeller Foundation and Arup International Development provides a framework for conveying a common understanding of resilience in the context of cities (see Figure 3.7). Through the framework resilience is defined as: '*The capacity of cities to* *function, so that the people living and working in cities – particularly the poor and vulnerable – survive and thrive no matter what stresses or shocks they encounter'*. The framework defines resilient systems as having the following seven qualities:

1. **Reflective**: Reflective systems use mechanisms to continuously evolve, and will modify standards or norms based on emerging evidence, rather than seeking permanent solutions based on the status quo.
2. **Robust**: Robust design anticipates potential failures in systems, making provisions to ensure failure is predictable, safe, and not disproportionate to the cause.
3. **Redundant**: Redundancy refers to spare capacity purposely created within systems so that they can accommodate disruption, extreme pressures or surges in demand. It includes diversity: the presence of multiple ways to achieve a given need or fulfil a particular function. Examples include distributed infrastructure networks and resource reserves.
4. **Flexible**: Flexibility implies that systems can change, evolve and adapt in response to changing circumstances.
5. **Resourceful**: Resourcefulness implies that people and institutions are able to rapidly find different ways to achieve their goals or meet their needs during a shock or when under stress.
6. **Inclusive**: Inclusion emphasises the need for broad consultation and engagement of communities, including the most vulnerable groups. Addressing the shocks or stresses faced by one sector, location, or community in isolation of others is an anathema to the notion of resilience
7. **Integrated**: Integration and alignment between city systems promotes consistency in decision making and ensures that all investments are mutually supportive to a common outcome. Integration is evident within and between resilient systems, and across different scales of their operation. Exchange of information between systems enables them to function collectively and respond rapidly through shorter feedback loops throughout the city.

The framework has 12 indicators under the four categories of: 1) health and wellbeing of individuals; 2) infrastructure and environment; 3) economy and society; and 4) leadership and strategy. Its indicators were defined in terms of a city's ability to fulfil and sustain its core functions, which in turn rely on a combination of assets, systems, practices and actions undertaken by multiple actors.

Health & Wellbeing of Individuals	Infrastructure & Environment	Economy & Society	Leadership & Strategy
1.Minimal human vulnerability	4.Reduced physical exposure and vulnerability	7.Collective identity and mutual support	10.Effective leadership and management
2.Diverse livelihoods and employment	5.Continuity of critical services	8.Social stability and security	11.Empowered stakeholders
3.Adequate safeguards to human life and health	6.Reliable communications and mobility	9.Availability of financial resources and contingency funds	12.Integrated development planning

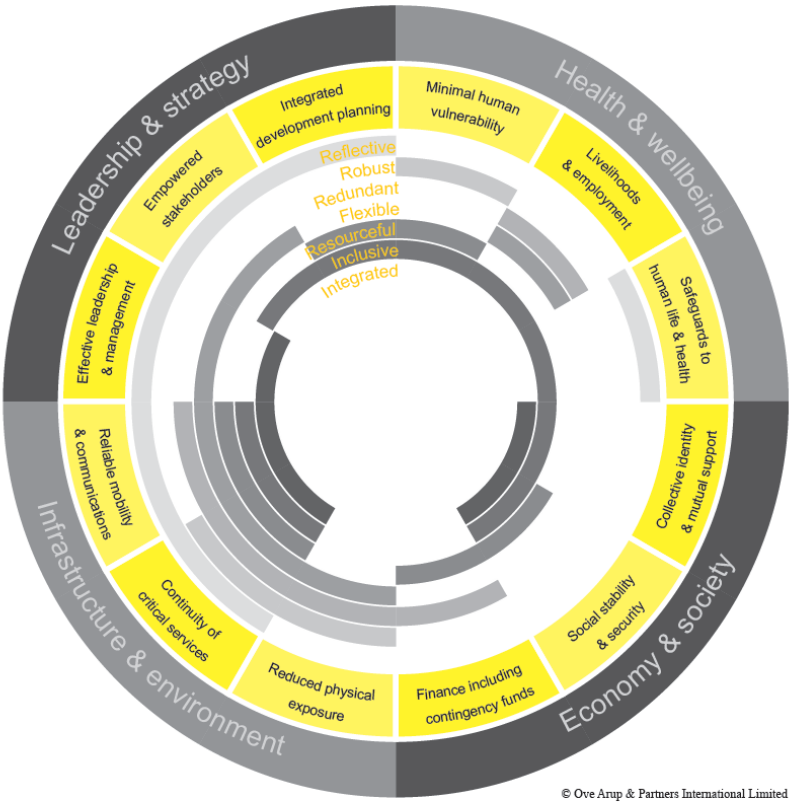

Figure 3-7 City Resilience Framework (Source: Arup and the Rockefeller Foundation, 2014)

3.1.9 City Strength Diagnostic: Resilient Cities Programme

The CityStrength Diagnostic was developed by the World Bank and the Global Facility for Disaster Reduction and Recovery (GFDRR) to facilitate a dialogue among stakeholders (e.g. government, civil society, residents, and the private sector) about risks, resilience, and the performance of urban systems. Because cities depend on a complex network of infrastructures, institutions, and information – the CityStrength Diagnostic first evaluates resilience on a sectoral basis and then brings together the findings to holistically assess a city's resilience.

The CityStrength Diagnostic consists of 5 stages, book-ended by leadership commitment for resilience on the front-end and a longer-term engagement with development partners through financing or technical assistance at the back-end, as illustrated in Figure 3.8.

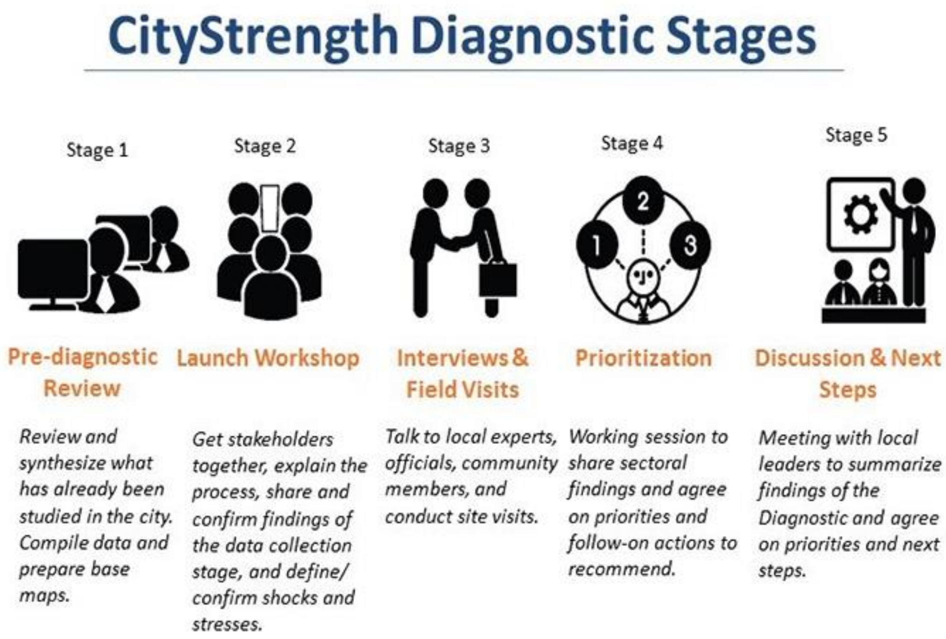

Figure 3-8 CityStrength Diagnostic Stages

This model is an implementation method involving diagnostics and resilience building.

3.1.10 Singapore's Adaptation Approach

The National Climate Change Secretariat (NCCS, 2012) Singapore emphasises that adaptation measures, which require time to implement, have to be taken into consideration early. As such identifying and understanding the risks and impacts of climate change on public health, energy demand and biodiversity are crucial to help developing adaptive measure to address these risks. The Singapore Government has therefore devised a resilience framework to guide their efforts towards safeguarding Singapore against projected climate change effects over the next 50 to 100 years. The framework is presented in Figure 3.9 and this belongs to the category of a national framework.

Figure 3-9 Singapore's Adaptation Approach (SOURCE: The National Climate Change Secretariat (NCCS), Singapore)

The framework presents the steps of an adaptation approach to climate change for the Government of Singapore. It involves understanding the local climate and identifying the vulnerabilities, risks and impacts of climate change in order to formulate adaptation options. The options are then assessed and prioritised for implementation as adaptation measures. The implementation must be monitored and the options evaluated for their effectiveness. This feeds into the review strategy, which will further feed towards a better understanding of the local climate. There is an on-going development of this at the Future Resilient Systems (FRS) Research Group at Nanyang Technological University in Singapore where a new approach that views resilience as a dynamic process involving physical infrastructures, organizational/institutional structures and social behaviour, is being currently explored in a new 3 year project.

3.1.11 The PEOPLES Resilience Framework

The PEOPLES resilience framework has been established for defining and measuring disaster resilience for a community at various scales. Seven dimensions characterizing community functionality have been identified and are represented by the acronym PEOPLES: **P**opulation and Demographics, **E**nvironmental/Ecosystem, **O**rganized Governmental Services, **P**hysical Infrastructure, **L**ifestyle and Community Competence, **E**conomic Development, and **S**ocial-Cultural Capital as depicted in Figure 3.10. The proposed PEOPLES Resilience Framework provides the basis for development of quantitative and qualitative models that measure continuously the functionality and resilience of communities against extreme events or disasters in any or a combination of the above-mentioned dimensions (Renschler et al., 2010).

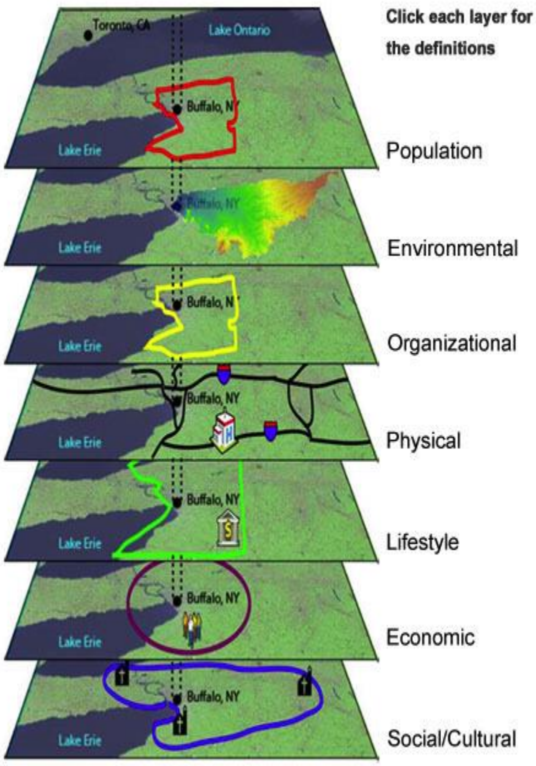

Figure 3-10 PEOPLES Resilience Framework (Source: U.S. Department of Commerce, National Institute of Standards and Technology, Office of Applied Economics Engineering Laboratory)

The framework has seven layers, where interdependencies between and among these layers are key to determine the resilience of communities. The disaster resilience of communities is measured at different scales ranging from individual to groups, local, regional, state level, national level and global level. Further the framework has established a comprehensive list of components and subcomponents of each dimension of the framework (refer Renschler et al., 2010 for the complete list). A software (Personal BrainTM) platform is used which is capable of linking and dynamically visualizing all seven PEOPLES dimensions in multiple layers of components and properties of functionality and resilience as well as pointing to information about quantitative and qualitative concepts, algorithms or models in various databases. This model also provides the flexibility to overlay the layers or even to add layers depending on the context.

3.1.12 Gibson and Tarrant (2010) on various conceptual models on organisational resilience

a) The 'integrated functions model' of resilience

Integrated models that are based around a robust risk management programme can be a major contributor to organisational resilience. In such models, risk management provides the foundation that links different organisational capabilities such as emergency, business continuity, security and crisis management. Risk management provides a common understanding of how uncertainty arising from highly volatile environments can affect the organisation's objectives and provides the means by which these specialised capabilities can then address that uncertainty. However, while this may be a significant contributor to resilience it is not a complete picture.

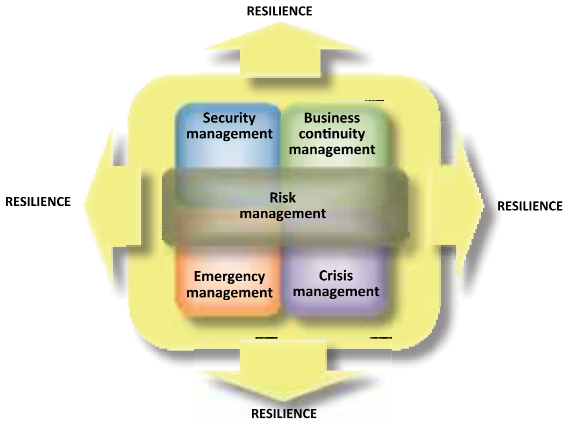

Figure 3-11 Integrated functions model of resilience

b) Attributional resilience model

In this 'attributional model' the key drivers for creating resilience are:

- The organisational values - establishing commitment, trust and strong internal alignment and creating a common purpose.
- Leadership - establishing a clear strategic direction based upon an understanding of risk, empowering others to implement the strategic vision, and engendering trust.

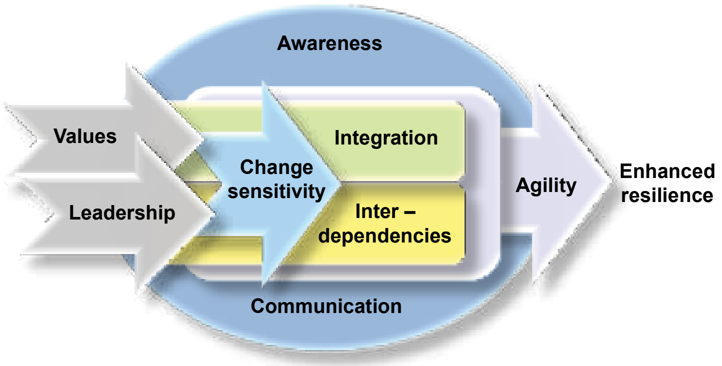

Figure 3-12 Attributional resilience model

c) Composite resilience model

A drawback of the attributional models is the lack of attention paid to the 'harder' elements that contribute to resilience. The composite resilience model provides a different viewpoint that considers both soft and hard elements' operation: processes, infrastructure, technology, resources, information and knowledge. Key to the model is the central importance of strategy and policy in establishing an operational duality, the capability to operate in both routine and non-routine environments.

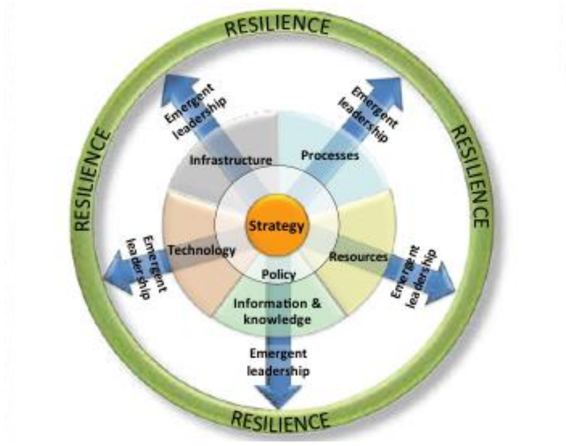

Figure 3-13 Composite resilience model

d) Herringbone model of resilience

To try and provide more of a one-stop shop model, the herringbone model was developed to encapsulate the concepts of the other three models provided above and to fill in some of the gaps.

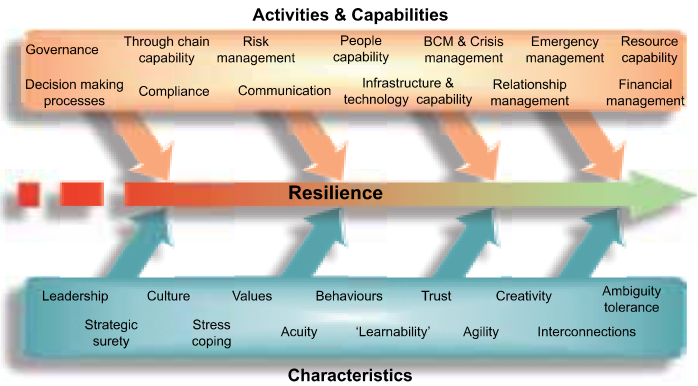

Figure 3-14 Herringbone model of resilience

The 'herringbone' recognises that an organisation possesses a substantial range of capabilities and undertakes a range of activities (collectively what the organisation 'does') that will contribute towards improved resilience. Furthermore, the organisation also exhibits a number of characteristics ('how' the organisation operates) that will affect the effectiveness of the capabilities and activities and help to enhance the organisation's resilience.

Some of the critically important factors in helping to create a resilient state by helping all aspects of the organisation to better operate in a non-routine environment are listed below.

- Acuity – the ability to recognise precedence - what has occurred in the past; situational awareness - what is happening now and foresight - understand what could happen in the future. Acuity provides the ability to take this information and identify early warning indicators of dramatic change and provides an understanding of possible options for dealing with it.
- Ambiguity tolerance – the ability to continue making decisions and taking action at times of high uncertainty.
- Creativity and agility – operating in novel ways to work around problems at a speed that matches volatility.
- Stress coping – that people, processes and infrastructure continue to operate under increasing demands and uncertainty.
- Learnability – the ability of the organisation to use the lessons of their own and others' experiences to better manage the prevailing circumstances, including using lessons in real time as they emerge.

e) The resilience triangle model

Collectively, the previous models demonstrate that resilience arises out of a complex interplay of organisational elements or capabilities that contribute to resilience when they adapt to a significant change. The challenge now is to encapsulate this complexity in a simple model construct. The resilience triangle model attempts to show that all three types of capabilities: process capabilities; resources and infrastructure capabilities; and leadership, people and knowledge capabilities, that are essential for organisational resilience.

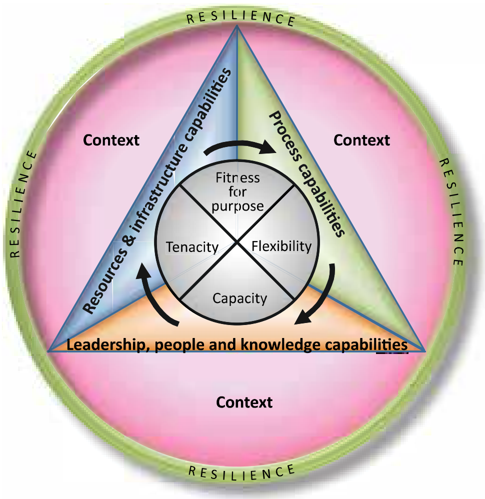

Figure 3-15 Resilience Triangle Model

3.1.13 Comparative analysis of Resilience Frameworks

The following Table presents a comparison of the frameworks against some main features including time horizon, level of applicability (local, regional, national etc.), the main components, and the context for which the frameworks were designed. The final column of Table 3.1 indicates which features were taken into consideration in the development of the EU-CIRCLE resilience framework.

Table 3-1 Comparative analysis of resilience frameworks

Type of framework / emphasis	Short term operational Local / regional	Long term strategic City / country	Components	Context	Features considered for the Framework
1.NISMOD –long term performance model		To tackle major challenges on - Balancing infrastructure capacity and demand in an uncertain future - Risks of infrastructure failure and how to adapt national infrastructure to make it more resilient - How do infrastructure system evolve and interact with society and the economy - What should the UK strategy be for integrated provision of national infrastructure in the long term	Scenarios, strategies of infrastructure provision, infrastructure system models, metrics of future infrastructure performance	National Infrastructure	Infrastructure capacity Uncertain future Risks to infrastructure
2. Model area-picture of potential threats from/to CI	Focused to CI and networks at Baltic Sea Region		Dynamic threats, Static threats, Natural hazards associated with weather and climate	CI and their networks	Layered approach
3. UNISDR Disaster Resilient Scorecard		To assess the level of cities' resilience to natural disasters	85 disaster resilience evaluation criteria focusing on 6	City resilience	Feature related to infrastructure

			features one of which is infrastructure		
4. I2UD's Climate Change Adaptation and Resiliency Framework	To understand and address the causes of risks faced by low-income population (local level policy)		Exposure to hazards, vulnerability to small to large scale weather events and lack of institutional capacity	Local community (low-income) resilience	Hazards and vulnerability Lack of capacity
5. Vulnerability to resilience framework (V2R)		To tackle causes and consequences of vulnerability	hazards and stresses; fragile livelihoods; future uncertainty; and weak governance	Community resilience	Hazards, Vulnerability, future uncertainties
6.CRF (Climate Resilience Framework)		To create inclusive learning process to identify measures to address uncertainties of climate change	Systems, agents, institutions	Understanding vulnerability and building resilience to climate change	Vulnerability uncertainties of climate change
7. DFID's resilience framework		Emphasise that contextualising is importance to react to disturbance	Context, Disturbance, Capacity to deal with disturbance, Reaction to disturbance	Context is to be defined (resilience of what)	Resilience of what (CI) Resilience for what (Climate Hazard) Capacity
8. City Resilience Framework		To convey common understanding of resilience in terms of cities	7 qualities , 12 indicators one of which is related to infrastructure and environment	City resilience	Indicator related to infrastructure
9. City Strength Diagnostic:		to facilitate a dialogue among	Resilience building	Cities (which	Concept of diagnostic

Resilient Cities Programme		stakeholders about risks, resilience, and the performance of urban systems	through 5 stages (Diagnostic model)	depend on complex network of infrastructure, institutions, and information) resilience	model
10. PEOPLES Resilience Framework		To define and measure disaster resilience for a community at various scales considering the interdependencies of the components	**P**opulation & Demographics, **E**nvironmental /Ecosystem, **O**rganized Governmental Services, **P**hysical Infrastructure, **L**ifestyle and Community Competence, **E**conomic Development, and **S**ocial-Cultural Capital	Community resilience	Layered approach
11. Integrated functions model of resilience	Robust risk management programme		Emergency, business continuity, security and crisis management	Organisational resilience	Business continuity
12. Composite Resilience model	strategy and policy in establishing an operational duality, the capability to operate in both routine and non-routine environments		Processes, infrastructure, technology, resources, information and knowledge.	Organisational resilience	Hard and soft elements to consider
13. Herringbone model	to encapsulate the concepts of the other		Activities, capabilities and	Organisational resilience	The concept of combining activities,

	three models (11, 12, 13) and to fill in some of the gaps		characteristics were combined to achieve resilience		capabilities and characteristics
14. Resilience Triangle model	To encapsulate complexity into a simple structure		process capabilities; resources and infrastructure capabilities; and leadership, people and knowledge capabilities	Organisational resilience	Capabilities

The table represents an eclectic bundle of features and perspectives of resilience frameworks and has informed the preparation of the layered resilience model under this task.

3.1.14 Synthesis

The review of several existing resilience frameworks indicates noticeably that hazards, risks and vulnerability should essentially be part of the resilience framework. The other component is the capacity of the system to deal with the disaster in order to improve its resilience. As illustrated in the DFID (2011) framework it is important to focus on the 'resilience of what' and 'resilience for what' questions, as we intend to develop the resilience framework for a particular system. As such, the focus of the proposed framework should be specifically given for the resilience of critical infrastructures (resilience of what) for climate hazards (resilience for what). The frameworks on city resilience all have infrastructure as one of their components. Another observation noted within some of the frameworks is the multi-dimensional approach. The critical infrastructure system could involve more than one resilience parameter and therefore the framework could possibly take a multi-dimensional form. Taking into account the nature and incorporation of multidimensional components within a resilience framework, a layered approach is preferable as it has the flexibility to modify each layer (each component) independently and yet the collective output will be based on the interconnection between the layers. Particularly as the framework is to be used within the Critical Infrastructure Resilience Platform (CIRP) under EU-CIRCLE, a layered system is easier to debug and modify as the changes might affect only limited portions of the code, and a programmer does not have to know the details of the other layers (Goldstein and Bobrow, 1980; Mohammed, n.d). In summary, the EU CIRCLE resilience framework will have multi-dimensional components, incorporating risks and capacities with the focus on critical infrastructure and climate hazards.

The next section reviews the literature on critical infrastructure protection. The analysis of the factors influencing critical infrastructure coupled with that of the resilience frameworks will contribute to provide necessary input into the EU-CIRCLE resilience framework.

3.2 Factors influencing critical infrastructure protection/resilience

This section reviews the factors affecting or influencing critical infrastructure protection or resilience.

3.2.1 Nature of interdependency

Modern societies are becoming increasingly dependent on critical infrastructure systems to provide essential services that support daily life within cities. These systems do not act alone as they are interdependent on many other systems at multiple levels for smooth operation. Further, infrastructure facilities such as transportation, telecommunications, healthcare, water supply and electricity are deeply embedded within social systems in cities. City infrastructure managers and emergency planners therefore require a more holistic approach in order to understand the complex and cascading impacts and consequences of the networked infrastructure systems rather than considering them as individual systems.

For example, when considering flooding, the impacts may arise either directly from the flooding of an asset, or indirectly because of the asset's role within an infrastructure network. For instant, the flooding of a pumping station, an access road, an electricity substation or a chemical supply depot may affect the normal operation of dependent treatment works. While frameworks are in place for assessing flood risk, including systems of flood defence assets (DEFRA/EA, 2004; Dawson et al., 2005; Dawson and Hall, 2006; Flikweert and Simm, 2008), these methods cannot be easily extended to cases where the physical interdependency of assets is the essence of the problem. The potential importance of considering risk arising from the dependencies within asset networks has been recognized by the water industry (Halcrow, 2008; Water UK 2008); however, there are no detailed publications of how this might be done in practice as little has been done to address the challenge of evaluating flood risk within networks of interdependent assets, hence there is much potential in such research.

As such, infrastructure resilience includes both the physical systems themselves and their dependence and interdependence on other infrastructure. Cutter et al. (2008) highlight that the high degree of interdependency among infrastructure will reduce their resilience as a disruption to one-sector cascades into impacts onto another (McDaniels et. al. 2008). This point has to be seriously considered, as the majority of critical infrastructures are tightly interconnected. This nature of interdependencies poses a challenge in achieving overall resilience.

3.2.2 Climate change

Infrastructures are generally designed and constructed in accordance to national building codes and infrastructure standards (Auld and Maclver, 2007; Connor et al., 2013). These codes and standards set out climatic design values which aim to build resilience to climate in infrastructures (Ruth et al., 2007; Auld, 2008). These include environmental loads such as wind, rain intensities, water level, waves, cold and hot temperatures and humidity as well as calculated return periods for extreme weather (Connor et al., 2013).

Climatic design values are calculated through analyses of historical climate data and trends, with the assumption that the average and extreme weather conditions of the past will represent conditions over the lifetime of a given infrastructure (Ruth et al., 2007; Auld, 2008, Connor et al., 2013; Auld and Maclver, 2005; Auld and Maclver, 2007; Infrastructure Canada, 2006; Means et al., 2010). Existing infrastructure has thus been designed using climatic design values which assume that climate exhibits stationarity and stationary return levels i.e. no change to the frequency of extreme climate events over time (Klein et al. 2009; Means et al., 2010). In fact, most infrastructure continues to be designed on the basis of historical climate data, extrapolating from historical trends to forecast future trends and conditions (NRCNA, 2008; Boyle et al., 2014).

However, climate change predictions indicate that future climate patterns will not be consistent with those of the past. According to the IPCC (2014) the frequency of climate extremes has been changing and is likely to continue changing in the future. Under climate change, climate conditions are expected to change considerably over the life of long-lived infrastructure, such as bridges (100 years), rail tracks

(60+ years) and water supply networks (50 years) etc. (Thom et al., 2010; Infrastructure Canada, 2006). Climate change will initiate a new climate regime with increases in extremes, the impact of which will be a reduction in the “effective” return period of extreme events that existing structures were built to withstand (Auld and Maclver, 2007). For example, Hennessy et al. (2007) report that design values for extreme events are very likely to be exceeded regularly by 2030 whilst an analysis by Kharin and Zwiers (2000) concluded that the return period of extreme rainfall events may, on average, be reduced by a factor of two. This means that, under a changed climate, a current 20-year rainfall event could occur every 10 years.

As the effective return periods of extreme events change with the climate, weather extremes will tend to exceed the design specifications for structures more frequently and earlier during the expected service life of an infrastructure, decreasing the durability and resilience of the structure, possibly imposing reconstruction, retrofit or relocation (NRCNA, 2008, Infrastructure Canada, 2006). The changing climate will, in effect, shorten the lifespan of existing structures in many regions (Auld and Maclver, 2007). Climate change will further interact with existing risks (e.g. ageing infrastructure, rising demand etc.) and act as a multiplier potentially altering infrastructure ‘tipping points’ (Lal et al., 2012).

As a result, there is a growing argument that current design standards may not be sufficient to accommodate the impacts of climate change (NRCNA, 2008; Regmi and Hanaoka, 2014). Current planning and design of new infrastructure may be inadequate to handle climate change as historical data used to predict statistical events can no longer be assumed to represent the conditions expected over the life of a an infrastructure (Connor et al., 2013). The assumption of climate stationarity during the design, maintenance and retrofit of infrastructures is no longer sufficient (Lal et al., 2012). Climate change thus impacts on the resilience of critical infrastructure. How resilient a particular infrastructure is, depends on its adaptive capacity which in turn depends on several factors. The main factor affecting the adaptive capacity to climate change of a particular infrastructure is its lifetime, for example short lived infrastructure such as telecommunications which are updated every 20 years are better able to take into account of the changing climate regime than water networks which may have a lifetime of 50 years. Furthermore, factors such as age, location (e.g. coastal infrastructure) and maintenance levels will also impact on the adaptive capacity of a particular infrastructure and thus its resilience to climate change (Auld and Maclver, 2007; Thom et al., 2010).

It must be noted that consideration of climate change in the resilience framework is complicated by the inherent uncertainties of climate change predictions. Climate change predictions thus far are based on global climate models which have the greatest accuracy but which provide future projections at the global or continental scale and not at the regional scale required by infrastructure owners and operators. In addition, there are uncertainties in future socioeconomic developments as well as any future response to climate change which will also affect the extent and risks of the climate change experienced (NRCNA, 2008; Infrastructure Canada, 2006; Sanders and Phillipson, 2003).

Another factor is sea level rise, linked to climate change temperature rise, which affects flood risk and related damage to critical infrastructure.

Further factors influencing critical infrastructure resilience include:

- Age of infrastructure
- Location of infrastructure e.g. coastal, in a floodplain etc.
- Status of Maintenance e.g. most infrastructure in Europe and the US is in serious need of maintenance for example see National Report Card of America’s Infrastructure (American Society of civil engineers , 2013)

4 The proposed EU-CIRCLE resilience framework

4.1 Components of the resilience framework

The EU-CIRCLE resilience framework will help to determine what constitutes resilience. The framework has incorporated several components, which are listed below. These components are further expanded in the subsequent sections.

1. Resilience of what – the context which is Critical Infrastructure (CI), their networks and interdependencies (Layer 1)
2. Resilience for what – the disturbance which is Climatic Hazard (CH), including current and future climate change (Layer 2)
3. Risks and Impacts (Layer 3)
4. Parameters associated to CI and CH (contributes to Layer 1, Layer 2 and in turn Layer 3)
5. Capacities of critical infrastructure (Layer 4)
6. Resilience parameters and indicators (Contributes to Layer 4)

4.1.1 Resilience of what

The CI and assets provided in this section are obtained from EU-CIRCLE D1.2: State of the art review and Taxonomy. To ensure consistency across the project section 4.1.1 will be derived from D3.1 – Registry of CI assets and interconnections (M22).

The framework will focus on the resilience of critical infrastructure and their assets also taking into account the interdependencies of their networks. The main sectors of critical infrastructure and assets addressed by EU-CRICLE are set out below.

- Energy production & distribution systems
  - Electric power generation & transmission
  - Thermal power generation & transmission
  - Oil plants
  - Natural gas
  - Renewable energy plants (EUC)
  - Underground mining and open pits
- Chemical Industry
  - Basic Chemical manufacturing facilities
  - Petrochemical manufacturing facilities
  - Pharmaceutical manufacturing facilities
  - Consumer product manufacturing facilities
  - Agricultural manufacturing facilities
  - Chemical storage and warehousing facilities
- Water Systems
  - Groundwater
  - Surface water
  - Sea water
  - Drinking water
  - Technical water (industry and maintenance)
  - Water for agriculture (irrigation)
  - Wastewater
  - Storm water
  - Dams

  - Water works
- Transportation
  - Road network
  - Railway network
  - Aviation
  - Maritime
  - Inland waterway transport (river transport)
  - Space transport
- ICT Networks
  - Telecommunication network
  - SCADA
  - Information Systems
- Public Sector
  - Civil Protection-Emergency responders
  - Public Health Protection

4.1.2 Resilience for what

The climate hazards identified in this section are obtained from EU-CIRCLE D1.3: Report on EU-CIRCLE strategic Context. To ensure consistency across the project section 4.1.2 will be derived from WP2 (Climatic Data capture and processing).

The framework will address resilience of critical infrastructure to the climate hazards listed below and how climate change will affect the frequency and severity of these hazards.

Climate drivers	Climate hazards
Temperature	Heat waves, cold snaps
Precipitation (rain / snowfall) - humidity	Floods / costal floods
Winds	Forest Fires
Cloud / fog	Droughts
Solar radiation	Earth movement caused by climate drivers such as rain (landslide, erosion, avalanches, rock fall, soil subsidence, liquefaction, etc.)
Sea level rise	
Ice, frost, permafrost	
Storm surges, waves	
Lightning / thunderstorm	

4.1.3 Disaster risks and impacts

The broadly accepted definition of “risk” is that risk is a product (or another mathematic operator such as the maximum) of two aspects: The first are the consequences of a hazard, the second is the likelihood of the occurrence. AS/NZS 4360 defines “consequences” as “the outcome of an event expressed qualitatively or quantitatively, being a loss, injury, disadvantage or gain. There may be a range of possible outcomes associated with an event". Likelihood is defined as used as a "qualitative description of probability or frequency".

Climate hazards, including the nature of uncertainty of current and future climate change, will increase the disaster risks and impacts on critical infrastructure, especially when they are exposed to such climatic conditions. As such, the level of vulnerability of critical infrastructure to climate hazards and climate change will positively correlate with the level of risk of the climate hazard and its impact(s) on critical infrastructure. The level of risk and its impacts are also influenced by the various capacities of critical infrastructure. Hence, in order to achieve resilience the risk level and the various capacity levels must be maintained at an optimum level. Risks and impacts are discussed in detail in WP3, and in particular deliverables 3.4 and 3.5.

4.1.4 Parameters associated with Critical Infrastructure and Climate Hazards

The establishment of a threshold level of risks and vulnerability for each critical infrastructure can be achieved through coupling each asset against each type of climate hazard. This determination can be based on the Critical Infrastructure (CI) parameters, which were discussed in Section 3.2, and the Climatic Hazard (CH), both current and future, parameters. These CI and CH parameters will feed the EU-CIRCLE resilience framework.

Some of the features that can be built within the resilience framework are summarised below

- Critical Infrastructure parameters
  - Lifecycle
  - Age of infrastructure
  - Location of infrastructure
  - State of maintenance
  - Level of Exposure to climatic hazards
  - Level of interdependencies

- Climatic hazards parameters
  - Frequency of the event (historically)
  - Magnitude of the event
  - Anticipated level of impact on CI
  - Future climate change projections (for X time periods e.g. for the next 50 years and X regions etc.) (WP2)
  - Nature of uncertainties

4.1.5 Capacities of Critical Infrastructure

The capacity of critical infrastructure is one of the main ingredients for infrastructure resilience. An improved capacity will reduce the risks and impacts. This section presents the different types of capacities. At any one point the critical infrastructure can either have one or a combination of more than one type of capacity. The level of each type of capacity can vary even within a single critical infrastructure against a particular type of hazard. For example, a railway network along the coast can have a good level of anticipative capacity through an early warning system for tsunami, but might have a poor level of absorptive and coping capacity. In such an instance, it can minimise the damages only by avoiding the disasters rather than facing it. Therefore, it is crucial to determine the level of each type of capacity for an infrastructure in order to understand its level of resilience against climatic hazards. The different types of capacity are discussed below.

Anticipatory capacity: is the ability of a system to anticipate and reduce the impact of climate variability and extremes through preparedness and planning (Bahadur et al., 2015). This is considered as a proactive action before a foreseen event to avoid disturbance, either by avoiding or reducing exposure or by minimising vulnerability to specific hazards (Kellett and Peters, 2014). As such it has close links to vulnerability, hazards and prevention.

Absorptive capacity: is the ability of a system to buffer, bear and endure the impacts of climate extremes in the short term and avoid collapse (death, debilitation and destruction of livelihoods) (Blaikie et al., 2003; Folke et al., 2010, Bene, 2012). This is the first line of defence (Biringer et al., 2013).

Coping capacity: is the ability of people, organizations and systems, using available skills and resources, to face and manage adverse conditions, emergencies or disasters (UNISDR, 2009). This is similar to absorptive capacity. The absorptive is immediately after a disaster whereas coping can be for a comparatively longer period.

Restorative capacity: is the ability of a system to be repaired easily and efficiently (Biringer et al., 2013). This capacity is associated with recovery too. In the context of critical infrastructure, system repair is the distinguishing feature of restorative capacity and it has been claimed as the final line of defence that requires the greatest amount of effort. Biringer et al., 2013 state that restorative capacity is not usually used unless either the absorptive and adaptive capacities are not able maintain an acceptable level of performance or the system is completely broken and unable to perform.

Adaptive capacity: is the combination of assets, skills, technologies and confidence to make changes and adapt effectively to the challenges posed by long term trends, such as future climate change (UNISDR, 2009). One of the distinguishing features of this capacity is the reorganisation and change of standard operating procedures where Biringer et al., 2013 claim this as the second line of defence.

All these different types of capacities discussed above are included within the EU-CIRCLE resilience framework as depicted in Figure 4.2.

4.1.6 Resilience parameters

In order to put resilience into practice, we want to know what properties indicate resilience, how to measure or assess their resilience, and how to manage for resilience. There are several dimensions to resilience that need to be taken into consideration when trying to achieve a holistic approach for infrastructure resilience. One of the components of EU-CIRCLE resilience framework will be the resilience parameters that are related to critical infrastructures and their capacities.

The EU-CIRCLE resilience framework recognises five types of generic resilience parameters. These parameters correspond to the critical infrastructure capacities outlined in section *4.1.5. Capacities of Critical Infrastructure* above and are a way of quantifying these capacities. These parameters are as follows:

1. Anticipation,
2. Absorption,
3. Coping,
4. Restoration, and
5. Adaptation.

Resilience indicators will be expanded and further analysed/developed for each parameter and each type of critical infrastructure as a part of *D4.5 Resilience Indicators*. Possible generic indicators are shown in Table 4-1. The list of generic indicators is not final and will be changed in accordance with the results of further research. These generic indicators will be further developed in a several levels, e.g. specific indicators, sub-indicators, indicator variables, etc.

The resilience indicators can be qualitative, quantitative or binary according to the type of data they utilize and may be absolute (e.g., speed of critical infrastructure failure) or relative (e.g., recovery/loss ratio) (Ellis, 2014; Prior, 2014).

Quantitative indicators (e.g. the average annual temperature, the number of projects developed in response to a policy, or the number of bridges constructed) are often preferred for monitoring and evaluation. Quantitative resilience indicators might be most appropriate for technical features of infrastructure. Where quantitative data is not available, and the issue is still considered important for monitoring purposes, qualitative or binary indicators may be utilized.

Qualitative indicators provide narrative or summary information regarding an item of concern. Qualitative indicators may be most appropriate when examining the quality of infrastructure organisation, operation, maintenance or management, or when assessing users interactions with infrastructure. Adaptation indicators, because they relate to processes, are more likely to be qualitative than climate change or climate impact indicators.

Binary indicators have a yes/no answer. Several indicators appropriate for climate adaptation could be binary, e.g. early warning systems in place (yes/no).

In principle, the strategy for measuring resilience is to quantify the difference between the ability of a critical infrastructure to provide services prior to the occurrence of an event and the expected ability of that infrastructure to perform after an event (Bruneau at al., 2003).

Good metrics are (Phillips and Tompkins, 2014):
- Comprehensive,
- Understandable,
- Practical,
- Non-redundant, and
- Minimal.

The above create defensible, transparent and repeatable metrics.

Table 4-1 Proposal of generic resilience indicators

Resilience parameters	**Generic resilience indicators**
Anticipation	1. Probability of failure 2. Quality of infrastructure 3. Pre-event functionality of the infrastructure 4. Quality/extent of mitigating features 5. Quality of disturbance planning/response 6. Quality of crisis communication/information sharing 7. Learnability
Absorption	1. Systems failure (Unavailability of assets) 2. Severity of failure 3. Just in time delivery - Reliability 4. Post-event functionality 5. Resistance 6. Robustness

Coping	1. Withstanding 2. Redundancy 3. Resourcefulness 4. Response 5. Economic sustainability 6. Interoperability
Restoration	1. Post-event damage assessment 2. Recovery time post-event 3. Recovery/loss ratio 4. Cost of reinstating functionality post-event
Adaptation	1. Substitutability (replacement of service) 2. Adaptability / flexibility 3. Impact reducing availability 4. Consequences reducing availability

A short description of the generic resilience indicators that are listed in Table 4.1 is provided below.

Probability of failure: Probability of failure is an estimation of the expected impact and degradation of an infrastructure following a disturbance or shock (Prior, 2014). This probability will vary depending on the nature of the disturbance or shock, but also on the nature of the critical infrastructure itself.

Quality of infrastructure: Quality of infrastructure indicated by how well an infrastructure performs (Prior, 2014). Performance is influenced by design, materials, age, service life, and the quality of management and maintenance. Infrastructures with lower quality are likely to be less operable after disturbance, and this indicator can be used to describe performance over time.

Pre-event functionality of the infrastructure: Assessing pre-event functionality is an important benchmarking exercise that can be used to inform how rapidly critical infrastructure function returns after disturbance (Prior, 2014). Knowing the baseline level of functionality of a critical infrastructure is fundamental to assessing and quantifying functionality change both in normal operational circumstances, but especially after a disruption.

Quality/extent of mitigating features: Assessing the quality and extent of features associated with an infrastructure that can mitigate the consequences of disturbance or shock is an important a-priori resilience indicator (Prior, 2014). Mitigating features add to the robustness of the infrastructure, and an early assessment of their quality and extent can be useful in improving these features where the necessity exists. Mitigating features will be specific both to the type of infrastructure and the nature of disturbance the infrastructure is likely to be subject to.

Quality of disturbance planning/response: Technical assessments of infrastructure are perhaps the most obvious when considering resilience, yet considering organisational planning for preparedness and response are also important (Prior, 2014). Assessing the value of pre-determined policies that increase or maintain the quality and functionality of infrastructure can be a useful indicator of resilience. In addition, the nature and availability of repair facilities, resources or personnel can also increase the speed of recovery.

Quality of crisis communication/information sharing: The quality and nature of crisis communication structures, and organisational information sharing between managers of CI and government agencies can be a useful indicator of the CI resilience (Prior, 2014). Where crisis communication methodologies and technologies are of high functionality, their deployment at times of disturbance or shock may limit loss of functionality, and speed up the recovery of infrastructure function. Making either qualitative or quantitative assessments of information sharing processes and practices can be particularly good indicators of the strength of relationships of the managers of infrastructure systems that are characterised by significant interdependencies.

Learnability: Learnability is the ability of organisation to use the lessons of their own and others' experiences to better manage the prevailing circumstances, including using lessons in real time as they emerge (Gibson and Tarrant, 2010).

Systems failure (unavailability of assets): Observing an actual failure in an infrastructure can provide a clear indication of its resilience, and specifically what characteristic of the infrastructure, or its relationship to the disturbance, may have led to the failure (Prior, 2014). Many factors may influence the likelihood that a system fails completely, but also interdependencies, lack of security, poor management and disturbance planning, poor communications, etc. Systems failure can be measured in a binary fashion: fail, or not fail.

Severity of failure: For instance, old or poorly maintained infrastructures are likely to fail such that they lose functionality completely following disturbance, and consequently require a complete rebuild during recovery (Prior, 2014). By contrast, well-managed, newer infrastructure that is designed to cope with disturbance (the most likely to occur in any given location) is likely to suffer less as a result of disturbance, and some functionality may persist.

Just in time delivery – Reliability: Reliability is concerned with ensuring that the infrastructure components are inherently designed to operate under a range of conditions and hence mitigate damage or loss from an event (Cabinet Office, 2011; Watson at al., 2014; Fisher at al., 2010). The tendency of a reliability strategy is to focus only on the events within the specified range, and not events that exceed the range. Reliability cannot therefore be guaranteed, but deterioration can sometimes be managed at a tolerable level until full services can be restored after the event.

Post-event functionality: Measuring functionality of an infrastructure following a disturbance or shock, and comparing this level to the pre event assessment of functionality will provide an excellent indication of CI resilience (Prior, 2014). The closer the level of post-event functionality to the assessed pre-event functionality, the more likely the infrastructure is to be resilient (in relation to a consequential disturbance).

Resistance: Resistance is focused on providing protection (Cabinet Office, 2011; Fisher at al., 2010; Watson at al., 2014). The objective is to prevent damage or disruption by providing the strength or protection to resist the hazard or its primary impact. Resistance has significant weaknesses as protection is often developed against the kind of events that have been previously experienced, or those predicted to occur based on historic records.

Robustness: The robustness component of resilience is the ability to maintain critical operations and functions in the face of a crisis (Bush at al., 2009; Fisher at al., 2010; Watson at al., 2014; IEA, 2015). It is directly related to the ability of the system to absorb the impacts of a hazard and to avoid or decrease the importance of the event that could be generated by this hazard. This can be reflected in physical building and infrastructure design (office buildings, power generation and distribution structures, bridges, dams, levees), or in system redundancy and substitution (transportation, power grid, communications networks).

Withstanding: Withstanding is ability to sustain the damage. This includes available dispatchable capacity, available demand response capacity, available link capacity, continuity of critical services, etc. (ARUP, 2014).

Redundancy: Redundancy is concerned with the design and capacity of the network or system (Cabinet Office, 2011; Watson at al., 2014; Fisher at al., 2010; IEA, 2015). The availability of backup installations or spare capacity will enable operations to be switched or diverted to alternative parts of the network in the event of disruptions to ensure continuity of services.

Resourcefulness: Resourcefulness is the ability to skillfully prepare for, respond to and manage a crisis or disruption as it unfolds (Bush at al., 2009; Fisher at al., 2010; Watson at al., 2014; IEA, 2015). Resourcefulness begins prior to an event and continues into the response phase. It comprises the steps taken prior to an event to prepare employees and management for possible threats and the application of the training and planning once an event occurs. This includes identifying courses of action, business continuity planning, training, supply chain management, prioritizing actions to control and mitigate damage, and effectively communicating decisions.

Response: Response aims to enable a fast and effective response to disruptive events (Cabinet Office, 2011; Watson at al., 2014). The effectiveness of this element is determined by the thoroughness of efforts to plan, prepare and exercise in advance of events. Some owners of critical infrastructure understand the weaknesses in their networks and systems and have arrangements in place to respond quickly to restore services.

Post-event damage assessment: Geographic information systems (GIS) and remote sensing technologies can, and have been used in post disaster damage assessments (Prior, 2014). Such technologies can be used to yield quantitative measures of damage to many forms of infrastructure, and therefore give a direct idea of the robustness of infrastructure affected by the disturbance.

Interoperability: Interoperability is the ability to cooperate at all levels with neighboring cities/states and other levels of government of critical systems and procedures. Interoperability needs to be assessed at multiple levels (UNISDR, 2014).

Recovery time post-event: Possibly the most well-known indicator of resilience in CI, the recovery time post-event is a measure of the amount of time it takes for an infrastructure to be brought back to its pre-event level of functionality (Prior, 2014).

Recovery/loss ratio: Closely related to ‘recovery time post-event’, the recovery/loss ratio is a calculation of speed of recovery based on the severity of loss (Prior, 2014). The more severe a loss, or a decrease in functionality, the longer the recovery time. However, for CI that is rated as having a high level of resilience, the speed at which recovery occurs may be higher than similar infrastructure with lower rated resilience.

Cost of reinstating functionality post-event: The cost of returning infrastructure to pre-event functionality can be used as an indirect measure of an infrastructure’s resilience (Prior, 2014). This measure assumes that a greater expense (relative to the value of the infrastructure alone, not the value of the service the infrastructure provides to society) equates to more damage, and therefore lower resilience in the infrastructure.

Substitutability: Substitutability is an aspect of a CI system’s redundancy, and a key characteristic associated with resilience in infrastructure (Prior, 2014). Substitutability reflects the possibility that the functional aspects of an infrastructure or infrastructure system can be replaced by back-up infrastructure or by other components in the system.

Adaptability and flexibility: Adaptability and flexibility are capacity or ability to change while maintaining or improving functionality, adopting alternative strategies quickly, responding to changing conditions in time, designing open and flexible structures (RAMSES, 2016).

Impact reducing availability: Impact reducing availability is availability of adaptive processes that reduce the impacts of climate change, e.g. re-allocation of facilities, building new facilities according to climate-ready standards, protection of existing critical infrastructures, etc. (Barami, 2013).

Consequences reducing availability: Consequences reducing availability is availability of adaptive processes that reduce consequences of climate change, e.g. re-routing transportation flows, developing flexibility of networks, etc. (Barami, 2013).

Economic sustainability: Local communities are interested in ensuring they develop and maintain a vibrant and thriving economy, even amid hazard events (NIST, (2), 2015). Factors that might affect a community's economic sustainability after hazard events include the degree to which the local economy depends on a single industry.

4.2 The operational structure of the framework

Based on the analysis of: existing resilience frameworks; the factors influencing critical infrastructure; and resilience terminologies; the operational structure of the proposed framework has a layered approach. The layers inbuilt within this model will be: 1) climatic hazard/ climate change; 2) critical infrastructure, their networks and interdependencies; 3) risks and impacts from climate change; and 4) capacities of critical infrastructure. Critical Infrastructure resilience will be achieved by combining the features from each of these layers. The operational structure of the EU-CIRCLE resilience framework is presented below in Figure 4.1. Figure 4.2 presents the relationships between the layers and the potential input to each layer from other work packages and tasks.

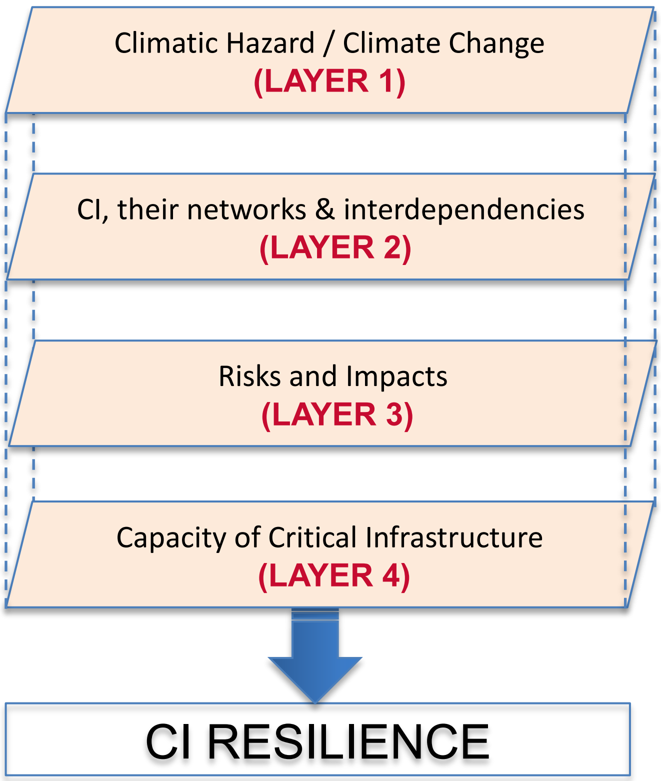

Figure 4-1 EU-CIRCLE Resilience Framework

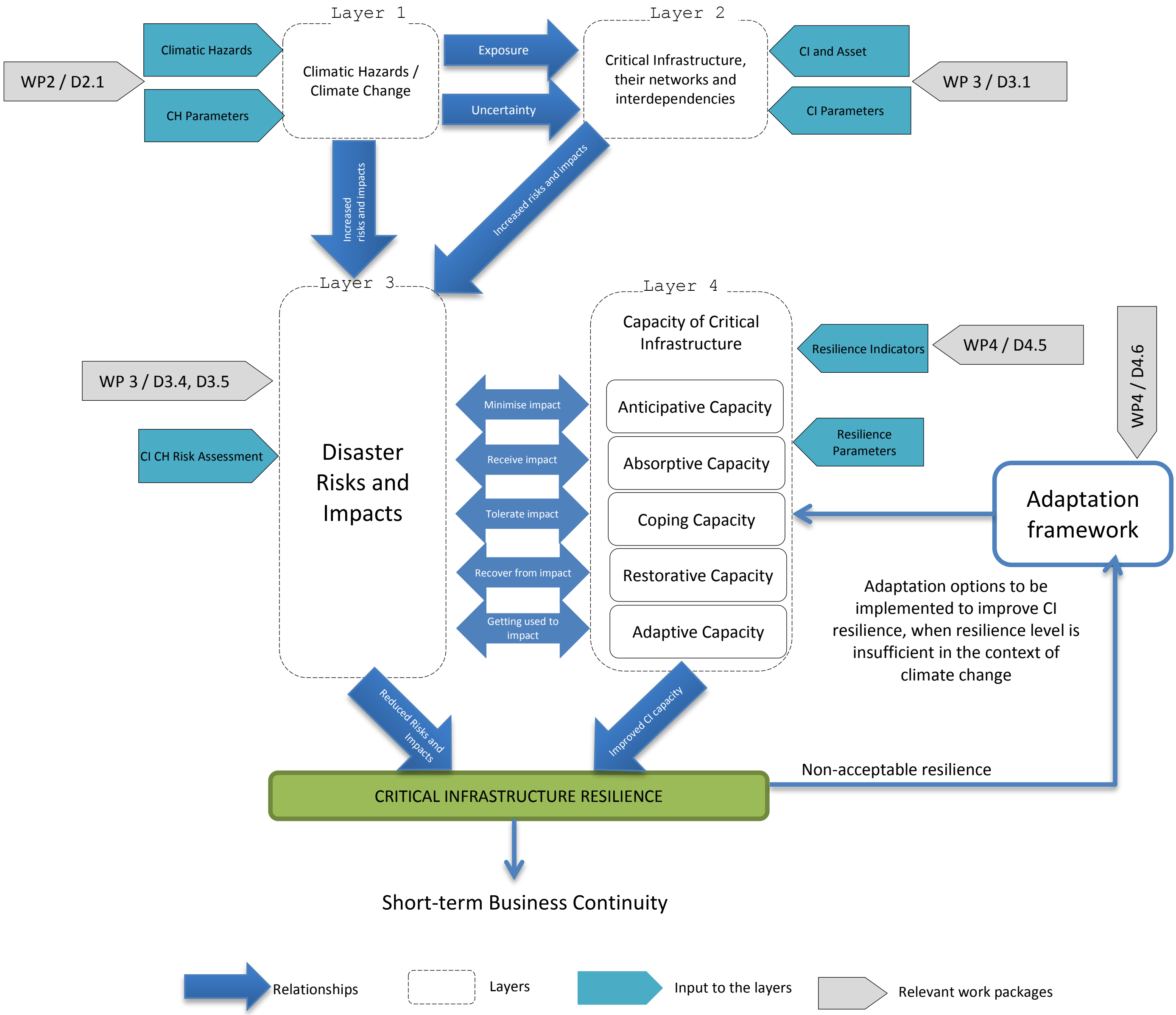

Figure 4-2 EU-CIRCLE Resilience Framework with input and relationships

4.3 Feedback from stakeholders on the initial model

The workings of the Resilience framework and its 4 layer approach were presented to the stakeholders present at the Consolidation Workshop held in Milan on the 18th of May 2016. The approach of treating resilience as a combination of anticipative, absorptive, coping, restorative, and adaptive capacities elicited favour in the workshop discussions. However, the specific points that can be fed into the EU resilience framework are as follows:

1. One of the stakeholders (from the insurance sector) mentioned that business continuity issues have not been covered sufficiently, and emphasised its importance in the context of critical infrastructure. In responding to this, the resilience model presented in Figure 4.2 leads to business continuity and adaptation which have been identified as the two main time frames of resilience i.e. as short-term and long-term resilience respectively (refer to section 3.1).
2. The stakeholders' perspective on the terms resilience are associated with the following key words
   - Safe lives, safe valuables, return to service
   - Strength, elasticity, insight (awareness)
   - Interruption of all sources of flooding, risk acceptance, building the capacity
   - Adaptation, how to absorb the impact, recover

   All these key concepts are either directly or indirectly associated with the anticipative, absorptive, coping, restorative and adaptive capacities that have been incorporated within the resilience model.

5 Conclusions

This report is one of the main deliverables of Task 4.1 (resilience framework) of the EU-CIRCLE project. The term resilience carries a number of different definitions. One of the purposes of this deliverable is to define the term resilience that can be used by the project partners and stakeholders throughout the project. As a result, a comprehensive definition for resilience has been established having analysed most of the existing definitions for the term resilience. Hence, the definition of resilience in the context of critical infrastructure (CI) is the ability of a CI system to prevent, withstand, recover and adapt from the effects of climate hazards and climate change. The other main purpose of this deliverable is to develop a resilience framework for critical infrastructure in Europe. 16 existing resilience frameworks have been analysed and this analysis provided a sound basis for identifying the necessary components for the EU-CIRCLE resilience framework. In addition, to the existing frameworks the factors influencing critical infrastructure have also been studied, as they are an essential part of the resilience framework . This initial version of the resilience framework has a layered approach with 4 layers : 1) Climatic hazard, climate change; 2) Critical infrastructure, their networks and interdependencies; 3) Disaster risks and impacts; and 4) capacity of critical infrastructure. Each layer is fed with different data and parameters to determine the resilience of critical infrastructure and to further improve the level of resilience. The initial model was presented to stakeholders of the framework and further improvements were made based on their feedback. The initial version of this framework will be further developed by incorporating the necessary data about climate hazards, climate change, critical infrastructure and its assets and including the parameters associated with climate hazard, critical infrastructure and resilience in contributing towards the development of the final version of the resilience framework, which will be made available in a further 12 months' time.

6 ANNEX 1 The Global Targets of the Sendai Framework for Disaster Risk Reduction 2015-2030

The seven global targets are:

1. Substantially reduce global disaster mortality by 2030, aiming to lower the average per 100,000 global mortality rate in the decade 2020–2030 compared to the period 2005–2015;
2. Substantially reduce the number of affected people globally by 2030, aiming to lower the average global figure per 100,000 in the decade 2020–2030 compared to the period 2005–2015;9
3. Reduce direct disaster economic loss in relation to global gross domestic product (GDP) by 2030;
4. Substantially reduce disaster damage to critical infrastructure and disruption of basic services, among them health and educational facilities, including through developing their resilience by 2030;
5. Substantially increase the number of countries with national and local disaster risk reduction strategies by 2020;
6. Substantially enhance international cooperation to developing countries through adequate and sustainable support to complement their national actions for implementation of the present Framework by 2030;
7. Substantially increase the availability of and access to multi-hazard early warning systems and disaster risk information and assessments to people by 2030.

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