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D2.3

Climate resilience in architecture, infrastructure and urban environments. Analysis of RAMSES case study cities

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This report addresses the state of the art in RAMSES case-study cities using document analysis (all RAMSES cities), meetings with the municipality (Bilbao and Antwerp), and comparison and analysis of results from the RAMSES case-study cities. The results contribute to a taxonomy of indicators and design guidelines for resilient architecture, infrastructure and urban environments that can be implemented by public authorities at the building, neighbourhood and catchment scales of the city, which is the subject of Deliverable 2.4.

Before introducing the case-study cities, a first part of the report examines the interplay of blue, green and grey infrastructures and soft adaptation measures, based on third party research, and highlights the necessity of a multi-scale approach to resilient infrastructure within and between sectors.

Authors: James Kallaos, Gaëll Mainguy, Georges Valentis, Ludivine Houssin, Krishna Bharathi, Pranita Shrestha, Fernanda Acre, Floriana Ferrara, Gabriele Lobaccaro, Naia Landa, and Annemie Wyckmans

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List of Abbreviations

CEN	European Committee for Standardisation
EBRD	European Bank for Reconstruction and Development
EC	European Commission
EEA	European Environment Agency
EIA	Environmental Impact Assessment
ENEA	Italian National Agency for New Technologies, Energy and Sustainable Economic Development
EPA	US Environmental Protection Agency
EU	European Union
GHG	Greenhouse Gas
ICLEI	Local Governments for Sustainability
IPCC	Intergovernmental Panel on Climate Change
PPCR	Pilot Programme for Climate Resilience
RAMSES	Reconciling Adaptation, Mitigation and Sustainable Development for Cities
SEA	Strategic Environment Assessment
UN	United Nations
UNISDR	UN Office for Disaster Risk Reduction
UK	United Kingdom
US	United States
WFD	EU Water Framework Directive
WP2	RAMSES Work Package 2

Executive Summary

This report addresses the state of the art in RAMSES case-study cities using document analysis (all RAMSES cities), meetings with the municipality (Bilbao and Antwerp), and comparison and analysis of results from the RAMSES case-study cities. The results contribute to a taxonomy of indicators and design guidelines for resilient architecture, infrastructure and urban environments that can be implemented by public authorities at the building, neighbourhood and catchment scales of the city, which is the subject of Deliverable 2.4. Before introducing the case-study cities, a first part of the report examines the interplay of blue, green and grey infrastructures and soft adaptation measures based on third party research, and highlights the necessity of a multi-scale approach to resilient infrastructure within and between sectors.

There is a considerable gap in maturity and complexity of climate resilience concepts between academic literature and the actual use of these concepts in practice. The detailed and advanced resilience frameworks and indicators found in the literature are not really used in practice. Reciprocally, operational frameworks for urban resilience are essentially self-assessment tools designed to increase the adaptive capacity of the city or business services (such as the ones from UNISDR, ICLEI, UK Cabinet, World Bank and business continuity standards). These tools consist mainly of checklists and guiding principles. They can hardly be used to directly guide investment as envisioned within the RAMSES project.

To address this challenge, we analysed current practices from the end-user perspective of 8 RAMSES case-study cities, to see where and how resilience principles and quantitative frameworks could be best introduced in a practical way.

This report addresses the state of the applied art in RAMSES case-study cities using document analysis (all RAMSES cities), meetings with the municipality (Bilbao, Antwerp), and comparison and analysis of results from the RAMSES case study cities. Finally, next steps are suggested towards development of a taxonomy of indicators and design guidelines.

For each city, we performed a systematic analysis of municipal policy and planning documents from each RAMSES case study city. These documents were assessed to ascertain the inclusion of climate resilience dimensions in architecture, infrastructure and urban planning. For each document it was evaluated[1] whether:

- Resilient architecture and infrastructure dimensions are mentioned and taken into account in the executive summary, introduction or conclusion (a sign of significance)
- Resilient architecture and infrastructure dimensions are mentioned and taken into account in goals and strategies described in the document (a sign of operationalization)
- Specific impacts and urban areas are described in detail, and the methodology for assessing and monitoring these impacts is clear
- Cost assessment of climate vulnerability and potential resilience measures has been performed, and efforts toward a more resilient city have an impact on insurance cost structure
- The proposed measures are legally binding

[1] These questions are based on the evaluation of the Norwegian Cities of the Future programme by Rambøll (Rambøll 2012)

- Resilient architecture and infrastructure dimensions are integrated in checklists for project development used by city officials (urban, neighbourhood and building scale).

Some of the key aspects lacking in many of the analysed policy documents are:

- Cost assessment. A reference to a comparison of the potential costs of the impacts of climate change versus the costs of adaptation is lacking in many of the policy documents. A cost-benefit analysis forms a key aspect for decision support related to development and evaluation of climate change policy. These assessments should be transparent in their assumptions and explicit in their treatment of uncertainty. Incorporating a detailed cost assessment for addressing vulnerabilities and the benefits of potential adaptation measures is especially relevant in the context of resource scarce or emerging economy countries.

- Specific impacts and urban areas. Few policy documents have a clear and detailed description of specific impacts on the city, in particular on specific urban areas. Policy support and implementation can benefit from specificity with regards to the concrete hazards faced by selected areas.

- Assessment methodology. Few policy documents present a clear assessment methodology for climate hazard vulnerability and potential adaptation measures. Effective policy goals require a clear methodology for assessing the success and failure of their implementation.

- Simulations. As part of the evidence base, and in tandem with cost assessment, climate simulations can form a useful basis for decision support and are hence preferably explicitly referenced in policy documents. The simulations and scenarios should be transparent in their assumptions and explicit in their treatment of uncertainty.

Based on these analyses, next steps are suggested towards development of a taxonomy of indicators and design guidelines.

1 Introduction

The core goal of RAMSES Work Package 2 (WP2) is to provide a taxonomy of resilient architecture, infrastructure and urban environment indicators, in order to facilitate the design, evaluation and monitoring of measures being deployed to strengthen urban resilience. The first deliverable of WP2 (Kallaos et al. 2014) attempted to identify resilience frameworks and corresponding indicators that are available to assess architecture and infrastructure resilience today. That deliverable showed that resilience assessment is in its infancy, but progressing rapidly. The derivation of a methodology to assess resilience relies heavily on which concept definitions are selected (Pickett, Cadenasso & Grove 2004), the type and scale of the system of interest, as well as the scope of the boundary conditions. Cost effective solutions involving resilience must simultaneously balance site-specific social, technical, programmatic and environmental conditions, as well as economic ones. This concept is clearly challenging to operationalise, as evidenced by the lack of working evaluation and monitoring criteria.

In this follow up deliverable approaches to adequately addressing resilience complexity and feasibility are explored in a series of city case studies conducted in close cooperation with city stakeholders, decision makers and academics in RAMSES. For eight RAMSES case study cities – Antwerp, Bilbao, Skopje, Rio de Janeiro, Bogotá, London, New York and Hyderabad, policy documents for climate change adaptation of urban architecture and infrastructure were analysed, with the findings reported in Chapter 4 of this report. As an introductory framework for the city case studies, we discuss the strategic links between different types of urban infrastructures and planning scales in Chapters 2 and 3.

2 The interplay between blue, green and grey infrastructures and soft adaptation measures

Buildings and infrastructure are artefacts created and used by people to provide services to society. Agglomerations of buildings and infrastructure coalesce and densify in settlements, cities, and urban environments, where they form interconnected, interdependent networks. These urban environments and their integrated or associated artefacts tend to persist both spatially and temporally, but for different time scales depending on the specific system considered. As such, it may sometimes be difficult to distinguish between buildings and infrastructure produced to provide a direct service, and adaptation approaches and measures that integrate (or consist wholly of) artefacts that fall under the category of infrastructure.

This duality of purpose should be acknowledged but need not be disconcerting - buildings, infrastructure, their elements and networks can exist as both as an adaptation approach, and as a system that may require adaptation. This seeming incongruity results from the often overlapping purpose of building and infrastructure elements to both provide a service, and to remedy an identified or expected issue with an existing approach to service provision.

Accepting that systems of infrastructures may both provide for, and require adaptation, and that they do not operate independently of one another, the following sections will briefly provide definitions of how these terms are used, and discuss the close interplay between their variations.

Definitions as used in this document:
Blue & Green infrastructure: Blue infrastructure refers to water and water features, including but not limited to ponds, lakes, rivers, and coastal environments; Blue infrastructure is often included within the term Green infrastructure, which refers to the network of natural, manufactured, or restored multi-functional green spaces supporting natural and ecological processes in and around urban areas (DCLG 2008). Applied specifically for adaptation, **Blue & Green infrastructure approaches** use the application of ecosystem elements and systems to remedy expected or existing issues from climate change. Blue and green infrastructure approaches and adaptation measures may also be applied to capitalize on opportunities for increasing system resilience during an intervention by transforming the methods used for the provision of services.
Grey infrastructure: Grey infrastructure corresponds to the physical interventions and construction measures that use engineered artefacts to provide services for the social and economic well-being of society – including buildings and structures, transportation networks (e.g. roads, tunnels), water and wastewater networks (e.g. drains, sewers, treatment plants), and plants and networks for energy supply and transmission (EEA 2012). Applied specifically for adaptation, **Grey infrastructure approaches** use the application or modification of constructed physical elements and systems to remedy expected or existing issues from climate change. Grey infrastructure approaches and adaptation measures may also be used capitalize on opportunities for increasing system resilience during an intervention by modifying the methods used for the provision of services.
Soft approaches: Soft approaches and adaptation measures can include laws, rules, regulations, policies, cultural norms, habits, and attitudes that maintain the economic, health, cultural, and social standards of a community. Soft adaptation measures are associated with many community characteristics tied to climate change, including preparedness, response, legislature, financing, environmental assessment, reconstruction and rehabilitation planning (Climate-ADAPT 2014).

Table 1: Definitions of blue, green, and grey infrastructure and adaptation approaches, and soft adaptation approaches.

2.1 Blue and Green infrastructure and approaches

Green infrastructure comprises "all natural, semi-natural and artificial networks of multifunctional ecological systems within, around and between urban areas, at all spatial scales," (Tzoulas et al. 2007, p. 169), while green infrastructure approaches address "the urgent social need to make built/urban environments more sustainable and resilient in new developments and in rebuilding or adapting existing developments to new, more sustainable uses. In addition to supporting core urban functions (transportation, drainage, communication, waste disposal), green infrastructure delivers measurable ecosystem services and benefits that are fundamental to the concept of the sustainable city" (Novotny, Ahern & Brown 2010, p. 159). The understanding that green infrastructure supports a diverse network of ecological and physical systems is a relatively recent development, which has introduced additional complexity into defining which functions, services, and administration are entailed in its scope.

Green and blue adaptation approaches and measures may help promote climate resilience through for example, better storm water run-off management, fewer incidents of storm and sewer overflow, flood and storm surge protection, sea-rise defence and reduced temperatures associated with urban heat island effect (Foster, Lowe & Winkelman 2011). They may also help "remove pollutants, conserve energy, reduce erosion, and provide other ecological, cost-effective, and environmentally sustainable services" (Svendsen, Northridge & Metcalf 2012, p. 4).

Good access to urban green spaces has been linked to higher physical activity levels and a lower likelihood of being overweight or obese. Close proximity to green spaces has also been linked to disease reduction, less depression and anxiety; encouraging active and healthier forms of travel such as walking and cycling; increasing residents' participation in physical, leisure and social activities; triggering relaxation, comfort and satisfaction, and more broadly engendering positive effects on the health and well-being of city dwellers. In contrast, a loss of urban green areas has been shown to result in urban dwellers commuting to find recreational services, an undesirable outcome from the perspective of climate change mitigation (Demuzere et al. 2014).

Green infrastructure has been identified by the European Commission (EC) as both a critical tool and a cost-effective investment to counter the loss of biodiversity as a result of habitat degradation and "help maintain healthy ecosystems so that they can continue to deliver valuable services to society such as clean air and fresh water" (EC 2010, p. 1). The United States (US) Environmental Protection Agency (EPA) suggests that the value of green infrastructure should be evaluated in comparison with the combined affiliated costs of grey infrastructure alternatives, the potential of damage averted, and additional benefits including "reduced urban heat island effect, increased property value, reduced noise pollution, increased recreational opportunities, habitat improvement, public education, and community cohesion" (EPA 2014a, p. 10). Additionally the Center for Clean Air Policy (CCAP) has identified five areas where green infrastructure can add value: "(1) land value, (2) quality of life, (3) public health, (4) hazard mitigation, and (5) regulatory compliance" (Foster, Lowe & Winkelman 2011, p. ii).

Characterised as an alternative or complementary approach to typical grey approaches and measures both the EPA and the EC report that the application of green infrastructure can help reduce the impacts of climate change induced weather events and natural disasters, including loss of life as well as property loss and damage (EC 2013c; EPA 2013, 2014a), and can thus be seen as a broad climate change adaptation strategy in itself. Physical risks can be reduced through the strategic use of "functional flood plains, riparian woodland, protection forests in mountainous areas, barrier beaches and coastal wetlands" in combination with appropriate grey infrastructure, (EC 2013c, p. 5). As the local authorities of urban agglomerations are often the key actors in dealing with the outcomes of such events, they are also key players in how green infrastructure measures are prioritised in infrastructure policy and implementation at both the city and regional levels (EC 2013c). Green infrastructure is now understood to encompass a broad range of issues regarding the multi-purpose use of green and blue spaces: their quality and location in urban and peri-urban contexts, as well as their capacity to link various wildlife habitats (EEA 2007; EC 2010; Gill et al. 2007).

2.2 Grey infrastructure approaches and measures

Grey infrastructure has been defined as the "physical interventions or construction measures" that use "engineering services to make buildings and infrastructure essential for the social and economic well-being of society more capable of withstanding extreme events" (EEA 2012, p. 16). They are often categorised into five distinct but overlapping groups that include transport, residential, commercial, utility and municipal functions.. Transport infrastructure includes streets, roads, highways, canals, dams as well as structures linked to rail, port, freight and air systems. Residential buildings and infrastructure comprise the homes, apartments, developments and communities where people live. Commercial infrastructure references retail buildings and structures, manufacturing and industrial sites. Utilities encompass drinking, waste and rainwater management systems, gas pipelines, sewage treatment and energy generation. Finally, municipal buildings and infrastructure aincludes state controlled hospitals, schools, housing, sports facilities, administrative buildings, military infrastructure, coastal defences and flood control (Davis 2011). In comparison to green infrastructure that is characterised as multi-functional, grey infrastructure is often viewed as singular in purpose (EC 2013c).

Historically grey infrastructures have tended to reflect "more traditional" approaches to water and sewage management such as "building more wastewater treatment facilities to deal with increases in runoff from more intense precipitation events" (Foster, Lowe & Winkelman 2011, p. 3). However, the literature also highlights that the boundaries between infrastructures and their affiliated technologies are not completely fixed, citing innovative hybrid grey and green infrastructures such as permeable paving, green roofs, alleys and streets (EEA 2012; Foster, Lowe & Winkelman 2011; Dubbeling et al. 2009; IPCC 2014; EC 2013c). Critically, the definitions of blue, green and grey infrastructure highlight that the goals, functions and impacts of these systems greatly influence one another. Effective adaptation plans combine blue, green, and grey infrastructure and soft adaptation measures. The role of soft adaptation measures, which links all types of physical infrastructures, becomes indispensable in the development of viable adaption and mitigation solutions.

2.3 Soft adaptation measures

Soft adaptation measures can be used to enhance preparedness for extreme weather events such as flooding, landslides, water scarcity, droughts and related issues (EEA 2012). With the growing understanding that risks have increased the last decades, soft measures involving preparedness, response, legislature, financing, environmental impact assessment, reconstruction and rehabilitation planning have become more common practice (Climate-ADAPT 2014).

In an era when uncertainties about the expected changes are large, many types of institutional soft measures are becoming particularly relevant, since they enhance adaptive capacity (EEA 2007, 2012; Engle 2011). The variability and severity of climate impacts will require that most adaptation measures be coordinated across national, regional and local levels. Although measures implemented by the European Union (EU) have been observed to hold strong influence when climate change impacts occur trans-boundary, it has also been stated that greater coordination is necessary "to ensure that disadvantaged regions and regions most affected by climate change will be capable of taking the measures needed to adapt" especially in the sectors "that are closely integrated at EU level through the single market and common policies" such as agriculture, water, biodiversity, fisheries and energy networks (EC 2009, p. 6).

In this capacity the EU continues to have "an important role in providing several instruments which can help improv[e] a project's adaptive response and resilience…" by developing tools which can "apply during design and planning but also in the course of retrofitting" (EC 2013a, p. 20).

These policy tools include many EU regulations affecting infrastructure sectors, such as Eurocodes (EN) for structural design - produced by entities such as the European Committee for Standardisation (CEN), as well as revised guidelines for Environmental Impact Assessment (EIA) and Strategic Environment Assessment (SEA). These tools aid in mainstreaming adaptation and improving the resilience of infrastructure by systematically incorporating climate change adaptation strategies at existing review points during project planning and design phases, permit review, and construction.

For example, article three of the EIA Directive requires that the project EIA must "identify, describe and assess"…"the direct and indirect effects of a project on"…"(a) human beings, fauna and flora; (b) soil, water, air, climate, and the landscape; (c) material assets and the cultural heritage" and (d) the interactions between these factors (EU 2011/92/EU 2012, p. 4). Similarly the SEA emphasises climate change consideration early in the development and planning processes, which the Intergovernmental Panel on Climate Change (IPCC) (2007) considers crucial to boosting resilience and adaptive capacity.

The EU Water Framework Directive (WFD) is another valuable piece of soft infrastructure that establishes a policy framework to protect groundwater sources, as well as "inland, transitional (i.e., fjords, estuaries, rias, and lagoons) and coastal surface waters that prevents habitat deterioration and protects and enhances the status of aquatic ecosystems, as well as the terrestrial ecosystems and wetlands linked to them" (Apitz et al. 2006, p. 80; EU 2000/60/EC 2000; EC 2014b). Specifically, this legislation aims to alter the scope of water management from the local watershed or catchment scale to one that is trans-boundary, "so that measures in respect of surface water and groundwaters belonging to the same ecological, hydrological and hydrogeological system are coordinated" and incorporating monitoring measures with composition targets for water quality (EU 2000/60/EC 2000, p. 4).

The WFD is also intended to diminish the negative consequences of flooding in terms of loss of life and property by making adequate information tools accessible to the public. Specifically, the directive calls for the creation of flood hazard and flood risk maps, as well as flood management plans, and the maps provide updated information on the following scenarios a) floods with low probability, or extreme event scenarios, b) floods with a medium probability (likely return period ≥ 100 years), c) floods with a high probability. Additionally the maps indicate flood extent, water depth and flow, which collectively aid in identifying which existing infrastructure is at risk (Lamothe et al. 2005; EU 2000/60/EC 2000; EU 2007/60/EC 2007).

The Directive also asks Member States to develop cross-sector flood risk management plans, which include measures on prevention, protection and preparedness. They are based on existing land-use policies, planning processes, engineering and non-engineering options, and involve both public and private actors. Regular updates of maps and plans (every six years) will enable authorities to base their scenarios on the latest findings of climate change research (EU 2007/60/EC 2007; EC 2013d).

Other actors that are recognised as creating opportunities to promote better water resource management and developing viable tools to assess development risks are the banking and insurance sectors (EC 2013a). For example the European Investment Bank (EIB) has developed sector-based strategies which require the application of appropriate, cost-effective, climate change adaptation measures where the risk of significant, adverse impacts are present - and will only finance projects that meet requirements outlined in their Environmental and Social Statement Handbook (EIB 2013; EC 2013a).

Another relevant example within the banking sector is the European Bank for Reconstruction and Development (EBRD), which has developed a methodology to assess the risks that climate change and its impacts place on the bank's operations. The project developed guidance and practical tools to integrate climate risk assessment and adaptation into EBRD's project cycle. The EBRD is also participating in the Pilot Programme for Climate Resilience (PPCR), a consortium of institutions supporting innovative adaptation-focused technical assistance and investments in projects in the global south (CIF 2014; EC 2013a).

Insurance is another effective tool to support the mainstreaming of adaptive practices, "by helping to manage climate change risks; by providing incentives for climate risk prevention; and by disseminating information on climate change risks and risk prevention measures" (EC 2013a, p. 29). As a measure, insurance should be used as part of a larger strategic risk management strategy that should be regularly updated based on the practices of its customers' behaviour (EC 2013a).

According to the EC, approximately 1000 km^2 of land, grossly equivalent to the size of Berlin, is utilised annually for new infrastructure in Europe alone (EC 2013a). Due to this trend and the growing population, it is anticipated that "city and regional authorities will play an increasingly important role in climate change adaptation in the future," especially in efforts to develop local adaptation plans that support the maintenance of existing infrastructure (i.e. transit, water, waste, etc.), enlarging the footprint of green infrastructure, and/or mainstreaming more stringent climate-proofing measures into building and planning codes (EC 2013a, p. 8). This trend strongly suggests that the effectiveness of cross-sector blue, green and grey infrastructure systems rests upon interlocking local, regional and national soft adaptation measures (MEEDDM 2010, p. 9). Whether in the form of micro or macro policies, soft infrastructure creates important pathways for not only implementation, but for the monitoring and evaluation of solutions at the building, site, neighbourhood, city, region and nation scales.

There is robust evidence and high agreement that soft measures play an important role in the implementation of mitigation options - such as good spatial planning of human settlements and infrastructure, and that many of these measures have wide ranging co-benefits beyond energy cost savings, despite legitimate barriers (IPCC 2014). Barriers include split incentives amongst building actors, fragmented markets and inadequate access to information and financing, all of which deter the market- based uptake of cost- effective opportunities. There is also robust evidence and high agreement that the portfolios of energy efficiency policies and their implementation have advanced considerably in recent years (IPCC 2014) Specifically, well-constructed building codes and appliance standards are used as examples of some of the most environmentally and cost- effective instruments to support emission reductions (IPCC 2014), as summarised in Table 2.

Sector and cross-sector mitigation pathways and measures:
Human Settlements, Infrastructure and Spatial Planning: "Mitigation options in urban areas vary by urbanization trajectories and are expected to be most effective when policy instruments are bundled (robust evidence, high agreement)" (IPCC 2014, 25).
Agriculture, Forestry and Other Land Use (AFOLU): Playing a central role in food security and sustainable development, "the most cost- effective mitigation options in forestry are afforestation, sustainable forest management and reducing deforestation, with large differences in their relative importance across regions. In agriculture, the most cost- effective mitigation options are cropland management, grazing land management, and restoration of organic soils (medium evidence, high agreement)" (IPCC 2014, 25).
Buildings: "Most mitigation options for buildings have considerable and diverse co- benefits in addition to energy cost savings (robust evidence, high agreement)" (IPCC 2014, 24). "Strong barriers, such as split incentives (e.g., tenants and builders), fragmented markets and inadequate access to information and financing, hinder the market- based uptake of cost- effective opportunities (robust evidence, high agreement)" (IPCC 2014, 24). "Building codes and appliance standards, if well designed and implemented, have been among the most environmentally and cost- effective instruments for emission reductions (robust evidence, high agreement)" (IPCC 2014, 24).
Transport: "Technical and behavioural mitigation measures for all transport modes, plus new infrastructure and urban redevelopment investments, could reduce final energy demand in 2050 by around 40% below the baseline, with the mitigation potential assessed to be higher than reported previously (robust evidence, medium agreement)" (IPCC 2014, 22).
Energy Supply: "Decarbonizing (i.e. reducing the carbon intensity of) electricity generation is a key component of cost- effective mitigation strategies in achieving low- stabilization levels (430–530 ppm CO_2eq); in most integrated modelling scenarios, decarbonisation happens more rapidly in electricity generation than in the industry, buildings, and transport sectors) (medium evidence, high agreement)" (IPCC 2014, 21).
Industry: "CO_2 emissions dominate GHG emissions from industry, but there are also substantial mitigation opportunities for non- CO_2 gases (robust evidence, high agreement)" (IPCC 2014, 25). "Systemic approaches and collaborative activities across companies and sectors can reduce energy and material consumption and thus GHG emissions (robust evidence, high agreement)" (IPCC 2014, 25). "Important options for mitigation in waste management are waste reduction, followed by re- use, recycling and energy recovery (robust evidence, high agreement)" (IPCC 2014, 25)

Table 2: Summary of IPCC mitigation pathways (IPCC 2014)

Local soft approaches by EU member states may also link to local, regional, national, and international programmes. Table 3 shows examples highlighting instruments recently promoted in Italy to support the implementation of mitigation measures. The approaches are classified according the scale of origin of each initiative (i.e. Local, Regional, National, and International), a description of its main activities, and those groups who are eligible to apply.

As an example of the importance of soft approaches and measures, ‘energy efficiency’ applies to a broad range of issues that are dependent on local needs, constraints, and available resources. Subsequently these factors influence the availability, relevance and selection of appropriate measures. This correlation highlights the need to provide policy makers and the public with a better understanding of the impacts of adaptation and mitigation measures. An example of one approach in Italy is the evaluation of the cost effectiveness of building improvement measures. The Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) defined a range of effectiveness points for varying measures (i.e. insulation, solar panels, etc.) in terms of energy efficiency and investment payback time (ENEA 2013). Critically, these economic efficiency oriented assessment tools must be balanced by social and ecological benefits assessments.

Initiatives by scale of origin	Description of main activities	Eligibility
Local		
Cariplo Foundation, Italy (Cariplo 2014) (ACTIVE)	Promotion of local investment in energy efficiency and renewables.	Non-profit organisations
Regional		
2007-2013 Operational Program Energy Initiative, Campania Region (Campania 2014) (ACTIVE)	Priority is devoted to energy saving and sustainable use of regional resources primarily by supporting renewable energy production.	Public and private organisations in Campania.
Implementation of the Covenant of Mayors, Province of Naples (Napoli 2013) (CLOSED)	The province has earmarked funds to incentivise municipal Sustainable Energy Action Plans.	All municipalities included in province of Naples.
National		
Kyoto Fund (Law Decree 83/12 and Law 296/06), Italian Ministry of the Environment (CDP 2014) (ACTIVE)	The fund provides resources to implement Kyoto Protocol principles in Italy.	Private citizens, local administrations and small and medium enterprises for energy efficiency and renewable energy projects.
2014 Italian National Fund following the 2012/27/EU Directive (D.Lgs. 102/2014 2014) (ACTIVE)	National fund that finances energy efficiency works by energy service companies (ESCO) or public-private partnerships. Examples of funded projects include public lighting systems, district heating networks, improvements for energy performance in public buildings and industrial processes.	Public and private organisations within Italy.
Operational Programme "Energy" (POI ENERGIA) Structural Fund + National Fund, Italian Ministry of Economic Development (MISE) as Management Authority and Ministry of the Environment (POI Energia 2014) (ACTIVE)	Finances actions aimed at increasing renewable energy sources (RES) and improving the energy efficiency of public and private buildings, as well as manufacturing processes.	Public institutions (e.g. Municipalities, Hospital, Schools) and private enterprises of Campania, Sicilia, Calabria and Puglia regions.
Operational Programme "Research and Competitiveness" (PON REC) Structural Fund + National Fund, Italian Ministry of Education, Universities and Research (MIUR) as Management Authority (PONREC 2014) (ACTIVE)	Finances topics related to climate change such as smart mobility; renewable energy and smart grid; energy efficiency and low carbon technologies.	Small and medium enterprise, companies, Universities, Public and private research centres (even companies) of Campania, Sicilia, Calabria and Puglia Region.
"Machinery" call under the Cohesion Action Plan, Italian Ministry of Economic Development (MISE) (MISE 2014) (CLOSED)	Subsidies linked to an investment program to support energy efficiency in machinery and promote innovative technology.	Small and medium sized businesses within Italy.
Initiatives by scale of origin	**Description of main activities**	**Eligibility**
International		

Intelligence Energy Europe (IIE) (ACTIVE), previously included into CIP (Competitiveness and Innovation Framework Programme) (CLOSED). Activities are now funded under Horizon 2020 (EC 2014c) (ACTIVE).	The program includes action to increase energy efficiency, promote renewable energy sources and efficiency in transport sectors, especially about fuels.	Private and public enterprises within Europe.
Special sub-programme of Intelligent Energy Europe (IEE), European Commission, Topic "Mobilizing Local Energy Investments" Project Development Assistance (MLEI-PDA) (EC 2014d) (ACTIVE)	Finances feasibility studies, business plans, etc. for mobilising funds for investments in the following sectors: energy efficiency in public and private buildings (i.e. social housing, street and traffic lighting); Renewable energy sources (RES) in buildings; district heating/cooling; decentralised Combined Heat and Power (CHP) systems; urban transport; facilities; alternative fuels; freight logistics in urban areas; local infrastructure, including smart grid and ICT equipment.	Local authorities within the EU who prioritise the realisation of small to medium projects that emphasise energy efficiency.
7 FP "The future of European Union research policy," topic "Smart Cities and Communities" included into 8.8 area of Energy theme (CLOSED)	Proposal could be related to Energy networks, Energy production from renewable energy sources (RES), transport, ICT.	Public and private organisations and companies within Europe.
ELENA (European Local Energy Assistance), European Commission and European Investment Bank (EIB 2014) (ACTIVE)	Offers funding to up to 90% of costs linked to technical assistance for energy investment proposals. If the project is positively evaluated, it stipulates an agreement between the public authorities and the European Bank of Investments (IBE)	Local and regional authorities within the EU, as well as private enterprises can participate.
European Energy Efficiency Fund (EEEF), European Commission (EEEF 2014) (ACTIVE)	The fund supports investments linked to energy savings, energy efficiency, renewable energy sources (RES), district heating and transportation.	Local and regional authorities within the EU but also public and private companies that work for them (i.e. energy service companies)

Table 3: Example of linkages between Italian and European soft mitigation measures (Source: T6 Eco)

3 Interdependence of critical infrastructure

The aim of this chapter is to produce resilience indicators that can be used by managers of critical infrastructures in networks and management bodies in areas vulnerable to climate change risks, mainly the risk of flooding.

The introduction intends to demonstrate that urban technical networks are propagating vulnerability. To boost the resilience of a territory, urban technical networks taken individually and as a whole constitute an essential lever for improving the conditions of urban resilience. The idea is to establish a resilience analytic framework with respect to three capacities, resistance, absorption and recovery (see Figure 4): the framework simultaneously focuses on the basic concept of resilience and on systemic propagation of risks in urban areas via these networks.

The first part sets out to present methods to assess a portion of the resilience of networks: their resistance capacity. Here the aim is to furnish a methodological and operational framework to enable the managers of networks to develop performance indicators. The indicators are mainly used to assist with management of infrastructures. All managers have their own performance indicators, and continue to develop them to optimise their infrastructure management. The indicators assess the resistance of infrastructures through the failure and ruin modes feared by managers. They are an essential tool to improve the resilience conditions of infrastructures. Performance indicators assess resistance capacity: operators produce and improve the indicators to monitor their infrastructures.

The second part presents an approach that takes account of interdependences among critical infrastructures. It is extremely innovative, but rather difficult to set up in view of the need for input data for models. However, establishing a resilience strategy, irrespective of the spatial scale, to prevent and/or manage crises, is impossible nowadays if no account is taken of these relations of dependence. Simple statistical indicators may be produced such as systems that are the most “aggressive” vis-à-vis other systems, for example, or, on a smaller scale, the most sensitive components. A more operational but more simplistic method is presented for this complex approach based on the modelling of systems and their relations with each other and the environment: consideration of interdependences using participatory methods.

The third part of this chapter addresses indicators in the making, in other words those that are now being developed by the scientific community. These are indicators that assess the absorption capacity of systems (their ability to operate in degraded mode) and indicators that assess system restoration capacities, in due consideration of various characteristics in connection with the area in which they are located. These groundbreaking indicators are based on the graph theory (Lhomme 2012), and are not currently deployed in the resilience strategies of risk managers and operators on a territorial scale. For the purposes of implementation and testing, in fact, a set of additional tools based on Geographic Information Systems must be developed.

3.1 Critical infrastructure as the main lever of urban resilience

Our analysis of cities, and most especially our analysis of urban flood risks considers flood levees and technical networks (power supplies, water, transport and telecommunications) as urban technical systems. Levees protect cities when they operate normally, i.e. when the functions for which they were designed are carried out. If this is not the case, levees disintegrate and enable water to rise and flood the city. Urban technical networks, on the other hand, propagate city flood risks through chain malfunctions. Our assessment of urban resilience to flooding takes account of both phenomena.

A city may be viewed as a system composed of a number of subsystems (Berry, 1964). Consequent literature confirms the importance of systemic analysis to study the urban phenomenon (Pumain et al., 1995; Sanders, 1992). These works have already given rise to full-scale models, often in connection with urban dynamics, which are difficult to apply to our problem. It is for this reason that we are tabling a new approach.

The dynamics of urban systems are closely linked to economic activity (Vilmin, 2008). Indeed, because it creates jobs, economic activity attracts the population to the heart of the system. Originally they came from the hinterland, and this rural exodus in the wake of the industrial revolution provides the best illustration of how important economic activity is to city dynamics. Nowadays this phenomenon is emphasised by the attraction of one city over the inhabitants of another, but this competitive feature among employment niches indicates the importance of other urban components that attract a workforce: housing and the systems that arise from this. This produces a circular system (Figure 1):

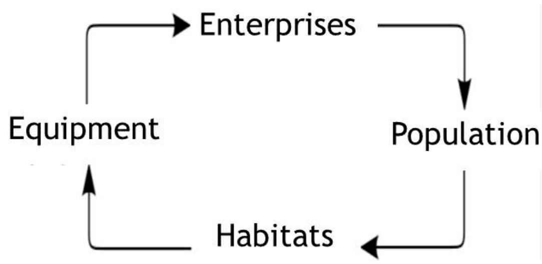

Figure 1. A simplified view of urban dynamics – The arrows symbolise how one item attracts another (adapted and translated from Serre, 2011)

However, it appears to be important to break general systems down into two different components: i) technical systems – the networks, ii) public infrastructures that will constitute the city's core, with local decision-making bodies (town hall), "sovereign" functions (police, justice system) and non-commercial functions (education, health etc.). The two categories are distinguished by their nature: linear/isolated, technical/social, content/container. The linear logic of the modelling above, moreover – because events occur in a precise determined framework – has become obsolete in the modern era. It is the intertwining of urban components and their interrelations around the decision-making core that produce the system's dynamics. It is also necessary to represent the support on which the dynamics are played out and which makes a direct contribution: the physical environment (Figure 2).

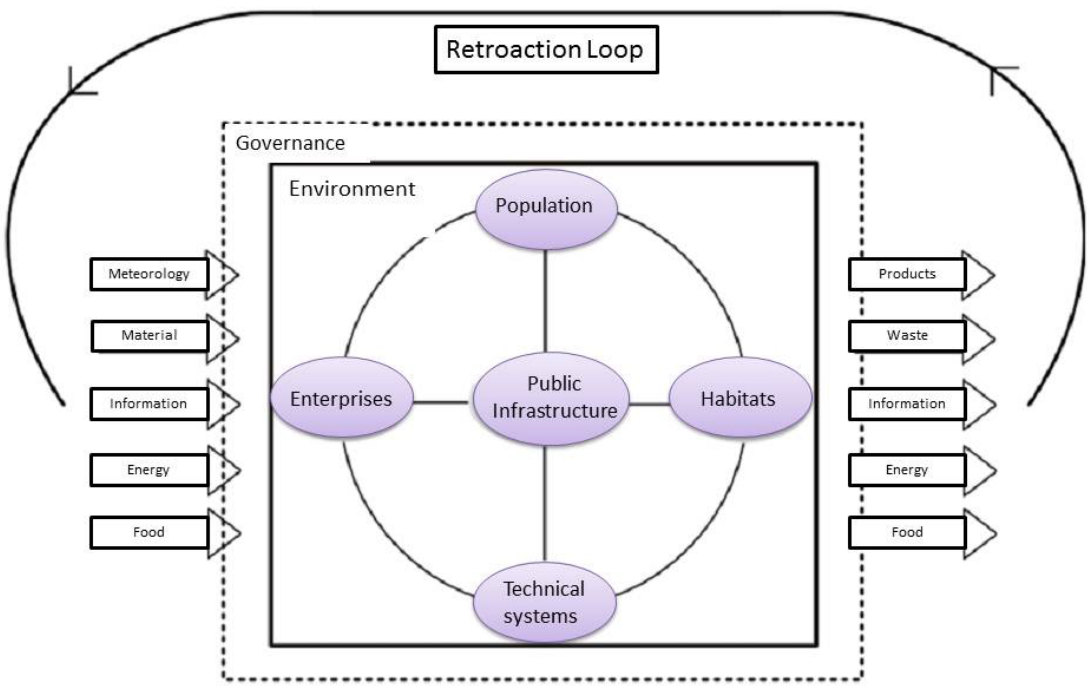

Figure 2. Model of the urban system (translated from Serre, 2011)

A city is considered to be an open system. This means a study must be conducted of the city's relations with its environment. For example, city-country relations constitute a major factor, enabling the city to ensure it will survive. The city brings in certain quantities of raw materials and food for its own consumption, but it also procures these to transform them and manufacture finished products to be traded with other cities. Trading with other cities constitutes the second type of relationship between the system and its environment, and it is generally composed of manufactured goods. One of the main items produced by a city, which also presents it with a major challenge, is waste. Waste production highlights one particular characteristic of the systemic analysis: retroaction. Waste, in fact, can be considered as system output, but it cannot be said it has no consequences for the city and its environment. The last component, a vital factor in terms of flood risk, is obviously weather forecasting.

Finally, we have the issue of the system's boundaries. Boundaries are difficult to establish. What is more, the influence of decision-making bodies on higher levels - *département*, state etc. – makes modelling much more complex. Therefore it would seem to be important to represent these higher authorities in the model, using the term of governance. In our case, the boundaries would be the administrative boundaries (Figure 2).

Cities develop interactions among people, activities and goods, but although the occupational density caused by the city – employment, housing, infrastructures etc. – brings wealth and facilities, it also leads to vulnerability and risk. By considering the city as a system, we have singled out interrelations among the various components of an urban complex. It is useful to study the interrelations following a disruption on the basis of the urban model created. A study of the different urban components and their vulnerability to flood risk makes it possible to produce a model of the urban environment in a flood situation. It transpires that, due to their implementation constraints and their structures, not only do networks constitute an "entrance" for urban flooding, but also an "entrance" for risk due to the domino effects created by networks. Flooding then spreads across networks, and the road system assists propagation when the rainwater system overloads, in a number of possible scenarios. A systemic approach to cities faced with a flood process could thus be considered (Figure 3).

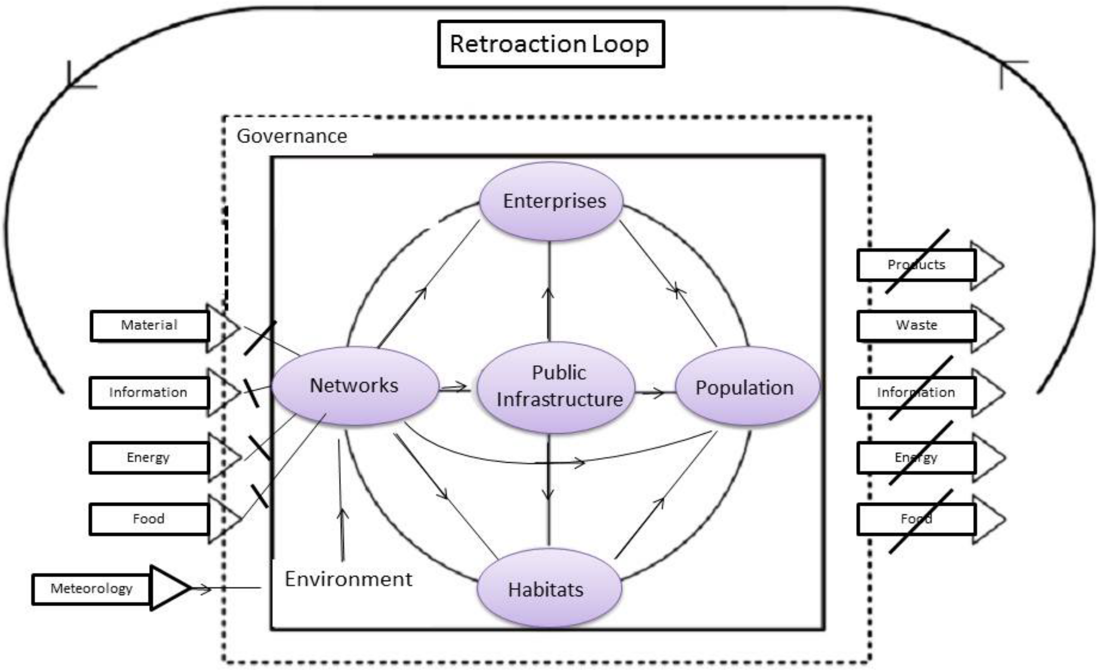

Figure 3: Technical networks and propagation of flood risk in cities (translated from Serre, 2011)

To build a resilient city, therefore, it is not enough to construct resilient buildings. Apparently there is a greater need in the first instance for resilient technical networks. Our research aims to come up with a method to assess the resilience of these networks.

Due to the specific features of flood risk and to the desire to deploy a systemic approach in preference to an analytic approach, the idea is to study the resilience of urban technical networks in order to study urban resilience (Lhomme et al., 2010). In this regard, three capacities are of the essence for a study of the resilience of technical networks (Figure 4):

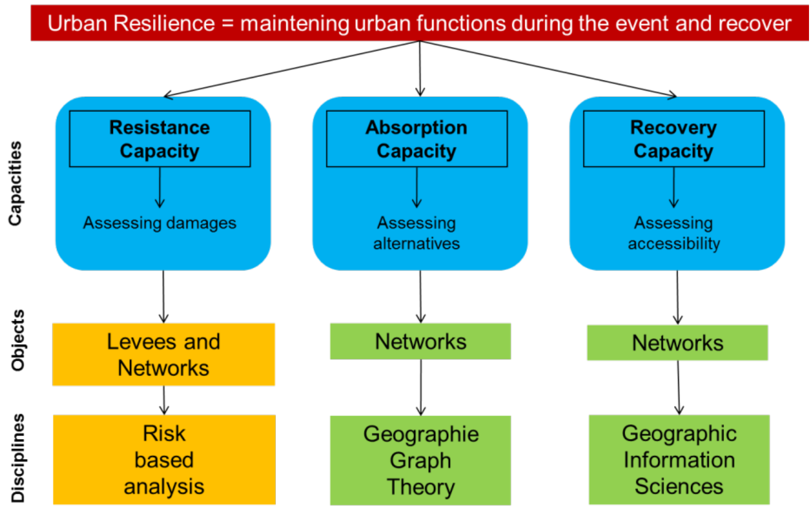

Figure 4. Capacities to be studied to address the resilience of networks and protection devices (translated from Serre, 2011)

i) Resistance capacity during disruptions

The issue is to determine the material post-flood damage to the levee and networks. The more extensive the damage to a technical system is, the more likely a malfunction of the entire system, and the more difficult it will be to restore. Utilisation of Operational Safety methods determines damage to the system and takes account of interdependences among systems producing domino effects.

ii) Absorption capacity during disruptions

This involves a study of alternatives a network can provide after a failure of one or more components. In other words, the challenge lies in studying the network configuration in order to characterise its redundancy. These alternatives allow the service to be continued and enable the network to be operated in degraded mode. The methods produced by the graph theory will be used here.

iii) Recovery capacity

Recovery is an essential capacity for a system to be resilient. For a network, recovery can simply be the time required to restore one of the damaged components in order to resume normal service. Here purely technical aspects are combined with organisational concerns. In the cases examined, however, the aspects analysed concern accessibility of services that help restore the network and any damaged components. The aim is to use spatial analysis features in preference to organisational features requiring a great deal of information: Geographic Information Sciences provide responses.

Why assess resilience in terms of these three capacities?

This proposal of a conceptual framework for assessment of urban resilience simultaneously deploys the systemic urban model presented above (Figures 2 and 3) and the concept of resilience:

- The systemic urban model of risk spreading throughout a city through protective infrastructures and technical networks.
- The concept of resilience, and its main characteristics such as redundancy (risk absorption capacity) and rebound (recovery capacity).

To these conventional capacities we have added the resistance capacity of infrastructures, an essential capacity with closer links to performance and safety of structures. This capacity is included in the resilience assessment because it greatly influences the ability of networks to operate in degraded mode, and the subsequent restoration of infrastructures. Readers may be interested in the writings of Serre 2011, Lhomme 2012 and Toubin et al. 2014 on the subject.

This model addresses the definition of urban resilience submitted here. Resilience is "the ability of a system to absorb a disruption and recover its functions following the disruption". This means urban resilience has two dimensions:

- The ability of the city to function when a number of the components of the city system have been disrupted.
- The ability of the city to rebuild itself (recover or adapt its functions) following the disruption.

3.2 Resilience at operator level: what are the indicators?

3.2.1 The context of management of grey infrastructure

In this section we define the concepts of management of civil engineering structures (system of civil engineering, maintenance, diagnosis and risk analysis), and subsequently the various tools of infrastructure management. We then present two specific examples of infrastructure management for large-alignment civil engineering structures.

A civil engineering system (a structure or a set of structures) is defined on the basis of the structural components (or subsystems) of which it is composed, and also by the functions it carries out. On each level into which the system is broken down, structural components in turn carry out functions that make a contribution to the overall functions of the infrastructure (Figure 5).

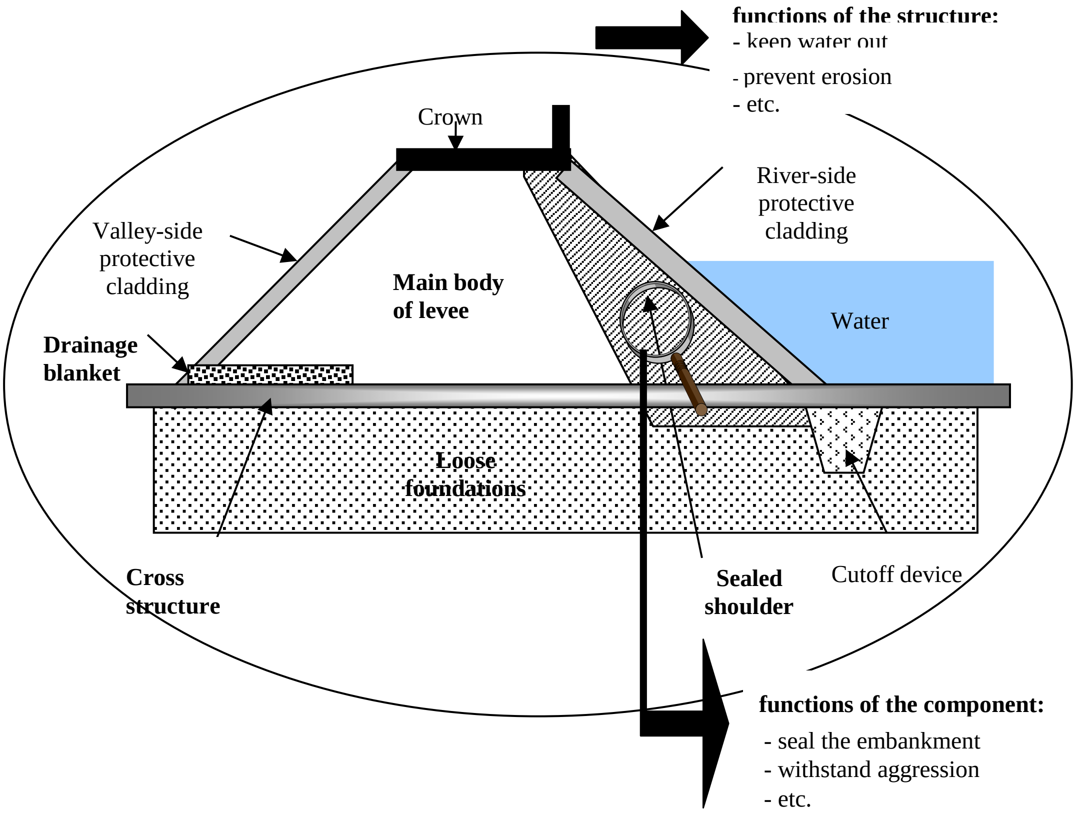

Figure 5. Components and functions of specific civil engineering: a levee (translated from Serre, 2005)

Two types of analysis define a civil engineering system: structural and functional (Cremona, 2002).

The ability of a structure to carry out the functions for which it was designed is known as its performance. The performances of a civil engineering system are apt to change during its lifespan: the functions initially intended when it was built may be voluntarily changed by the system manager or by external events, and degradation may disrupt the initial functions. There are three main reasons for loss of performance (Cremona, 2002):

- ageing of the infrastructure
- human error
- intended or unintended external causes

Two categories of performance loss are considered (Figure 6):

- degradation, meaning a reduction in the performance of a function that nevertheless remains above the functional threshold or limit state (the status or phenomenon to be avoided) (Cremona, 2002).
- failure, meaning the alteration or cessation of the ability of a system to carry out the function(s) required to the levels of performance defined in technical specifications ((AFNOR standard, 1994). In this case, at least one of the performances is below the functional threshold.

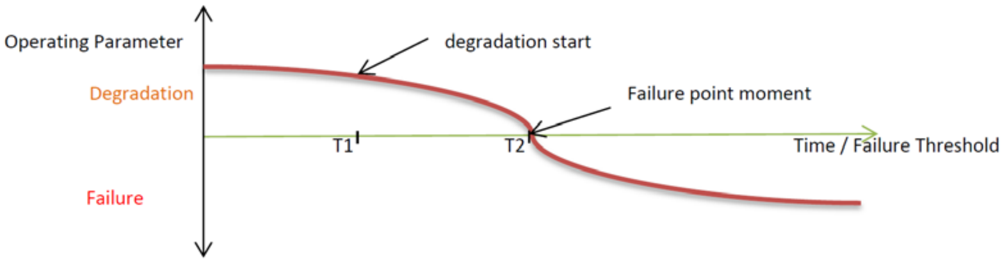

Figure 6. Degradation and failure (adapted from Zwingelstein, 1996)

Assessment of the performance of a civil engineering structure entails an assessment of its status, followed by an assessment of its performance (Cremona, 2002). Status assessment is an analytic phase during which degradations of the structure and their historic background are investigated; here the quality of the information available in connection with the structure is essential. Its performance is then assessed in the same way as at the design stage, albeit on the basis of the actual structural status of the item during operation.

Maintenance of civil engineering structures

Maintenance includes "all activities to maintain or restore a system to a status or to given operational safety conditions, in order to carry out a function required. These activities are a combination of technical, administrative and management activities" (AFNOR standard, 1994).

Depending on the type of structure and the operating policy for structures, two primary maintenance strategies may be applied to the structures: corrective and preventive, as shown in Figure 7 below.

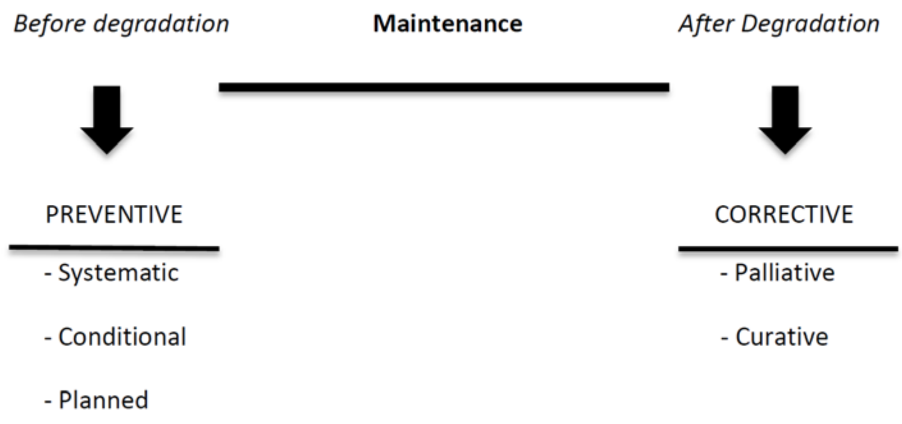

Figure 7. Maintenance strategies (adapted from Zwingelstein, 1996)

Preventive maintenance seeks to anticipate performance losses through close monitoring of the status of the structure, and to apply corrective measures prior to failure. It is applied to structures with a large risk component – the bursting of a dam, for instance.

Conversely, corrective maintenance occurs after failure or degradation has been detected, and is deployed in contexts where the stakes are limited.

Maintenance of civil engineering structures chiefly consists of supervision, which in most cases is dictated by regulations. Supervision consists of inspection techniques with a common framework for different civil engineering structures: regular visual inspections carried out several times a year (detection of malfunctions and preventive maintenance), detailed inspections carried out every year or every few years (major maintenance) and close supervision in the event of accidental stresses, evolutive degradations or imminent risks. Supervision also includes auscultation of structures and continuous measurement (Cremona, 2002).

Risk analysis and diagnosis of civil engineering structures

Operational Safety is the Science of Failures, including knowledge, assessment, prediction and control of failures (translated and paraphrased from Villemeur, 1988). For many years it has produced methods for industrial facilities to identify, analyse, manage and reduce risks (Peyras, 2003). These methods carry out a diagnosis, assess status, and analyse safety and the risks of system failure. A start has been made on applying them to the context of civil engineering structures.

Diagnosis of a structure is "identification of the probable cause of the failure or failures through logical reasoning based on a number of data from an inspection, a check or a test" (AFNOR standard, 2001). The past history of the structure submitted for diagnosis is investigated to search for the degradation mechanisms that led to its current status at the time of the assessment.

Assessment of the status of a structure consists of determining, at a given point in its lifespan (usually the present), its structural condition (status of degradations). The next phase is an investigation into the conditions in which the structure performs its functions, and this seeks to assess its performance.

Risk is measurement of a hazard associating a measurement of the occurrence of an undesirable event and a measurement of its effects or consequences (translated and paraphrased from Villemeur, 1988).

For the entity managing the structures, analysis of the risks entailed by its structures is essential to adapt the maintenance tasks to be carried out. Risk analysis consists of answering the following three questions (Kaplan, 1997):

- what can go wrong?
- how likely is it to go wrong?
- if it does go wrong, what are the consequences?

A risk analysis survey on a structure, therefore, seeks to assess its operational safety (the second question in Kaplan's list). Operational safety corresponds to the ability of an entity to carry out one or more required functions in a given set of conditions. It may be characterised by a number of different concepts, particularly reliability and durability, defined by standards (AFNOR standard, 1988):

- reliability, meaning the structure's ability to carry out its functions in a given set of conditions over a given period of time.
- durability, meaning its ability to retain a status that enables it to carry out its functions in given conditions of utilisation and maintenance, until a limit state has been attained.

The concepts of diagnosis, assessment of status and performance and risk analysis are summarised with a time scale in Figure 8 below:

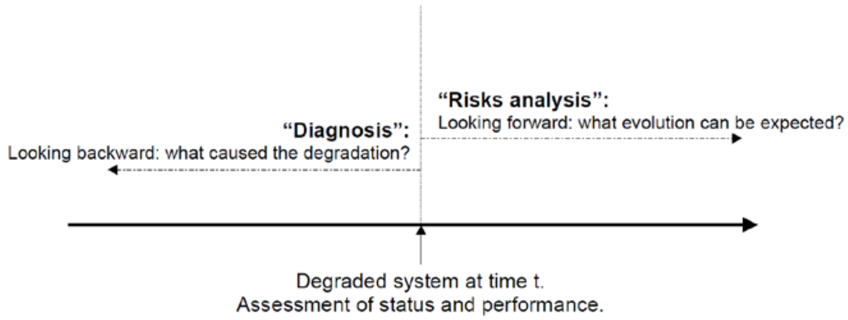

Figure 8. Diagnosis, assessment of status/performance and risk analysis (adapted from Peyras, 2003)

In order to establish a diagnosis for a structure, assess its status and performance, or conduct an analysis of the risks involved (assess its operational safety), there are two possible approach families, exemplified by that of Peyras et al. (2004) and Zwingelstein (1995).

Internal methods are based on in-depth knowledge of the system studied (a set of interconnected industrial components, a civil engineering structure). It is possible to use modelling to analyse degradation and breakage mechanisms to predict future patterns of behaviour. Two different modelling methods may be used, depending on the type of model describing the system:

- physical modelling, based on a physical representation of the continuous or discrete processes of degradation within the system, in due consideration of the equations governing internal phenomena. This calls for in-depth knowledge of the system and its representation using physical and mathematical models reinforced by digital simulation.
- functional modelling: systems are studied on the basis of the functions they ought to carry out and for which they were designed. The principle of functional modelling consists of determining interactions between the components of a system and its environment, in such a way as to formally establish links between failures of functions, their causes and effects.

External methods are applied in contexts in which the modelling of mechanisms (physical or functional) is not technically possible or is not suited to the level of concern, due to complexity or cost. Depending on the information available, a distinction is made between methods based on statistical analysis and those based on expert knowledge. Readers may be interested in the writings of Peyras et al., 2004, on the subject.

3.2.2 Devices for management of infrastructures

Concepts of infrastructure management

Civil engineering structures are mostly consequent infrastructures with a considerable technical and financial value.

Infrastructure management means seeking to control the costs of investment, operation and maintenance. It has two closely related aspects: technical management and financial management (Lair, 2000).

Technical management concerns all phases of the lifespan of the structure, from design to possible dismantling. It consists of seeking or maintaining the level of performance required over a given period of time.

The structure's financial management concerns all the costs incurred over the various phases of its lifespan – these include, for example, purchase, construction, operation, maintenance, renovation etc.

Infrastructure management forms part of the principles of sustainable development, and its primary concepts are as follows:

- transmission to future generations
- economic rationalisation
- consideration of the environment

This principle has become an essential factor among the various civil engineering disciplines, and an appropriate infrastructure management device is applied to the various structures. Scientific and technical work in connection with the management of infrastructures is one of the main concerns of management entities and research bodies (AUGC, 2003a, 2003b). Two primary missions may be considered:

- guaranteeing the safety of structures: malfunctioning and degradation of structures may damage people and property (local residents, users and operating personnel). In a society that has become extremely sensitive to risks and the identification of risks, system managers must ensure high levels of safety in their structures.
- guaranteeing the continuity of structures: the problem of infrastructure management in the modern era is mainly due to management of old and/or ageing systems. Structures, therefore, must be maintained or improved to the best possible technical and economic conditions, if we are not to steer future management towards an impasse, leaving it to our successors to carry out major repairs or replace what we should have treated in good time, with considerably fewer resources (translated and paraphrased from Delfosse, 2001).

The approach to infrastructure management

The main aims of management of a set of structures (the term Inspection-Maintenance-Repair policy or "IMR" is also used) are as follows (Cremona, 2002):

- to ensure the structure carries out the functions required.
- to guarantee the safety of users and protection of the environment.
- to ensure that infrastructures are preserved for a certain amount of time, generally long term.

To address these aims, the management device (or IMR device) contains the procedures used to carry out maintenance. It includes the methods and tools (supervision, data acquisition and processing etc.), organisational procedures, personnel with different levels of qualifications, databases (inspections, historical records etc.) and regulations.

If infrastructure assets are to be managed, there must first be knowledge of the assets, they must be assessed and plans must be made for maintenance action to be taken, and subsequently all information concerning this action must be recorded in order to draw up an infrastructure history (Delfosse, 2001).

Knowledge of the assets means having a precise inventory of the structures to be managed. At the outset it is important to define what we wish to manage and to establish a common vocabulary for the parties involved in the management process.

Assessment means using indicators to determine the status and subsequently the performance of the structures to be managed.

Making plans means defining priority action to be taken on structures in accordance with objectives, adding in the cost of actions. Performance indicators constitute valuable assistance for the planning process in that they help managers assess the performances of their structures and monitor changes to performances in real time.

The tools of infrastructure management

Maintenance strategies are based on forecasts of developments in structures, depending on their environment and the stresses to which they will be subjected. These strategies depend on the type of infrastructures (Cremona, 2002). Infrastructures are characterised by the number of structures of which they consist - isolated structures such as bridges, dams etc., or linear structures such as underground systems, roads, levees etc. – and by their homogeneity or heterogeneity.

In the context of a large number of homogeneous isolated infrastructures or homogeneous linear infrastructures, where statistical data are available and mechanisms are properly controlled, maintenance based on reliability can also be a useful method. It is based, among other factors, on the reliability ratings of system components (Zwingelstein, 1996):

- identification of parameters forming part of the limit state conditions
- statistical characterisation of these parameters (laws and moments)
- investigation of the likelihood the limit state conditions will not be met

This approach is habitually applied in the offshore and nuclear industries, and also in distribution networks. Readers may be interested in the writings of Zwingelstein, 1996 on the subject.

Reliability-based maintenance has limitations when data are available in insufficient quantities: difficult experimental measurements, few statistical data etc. This suddenly makes probability calculations complex or even impossible, and it becomes difficult to demonstrate they are valid.

For heterogeneous isolated or linear infrastructures, in situations of largely unknown structures, the data available are of poor quality or are very few, making it difficult to predict developments of degradations.

In this context, the easiest way to assess future developments in degradations is to examine the laws of evolution of existing structures with the same design with similar mechanisms, on the basis of feedback (Cremona, 2002).

3.2.3 Examples of infrastructure tools for constructions in systems on the basis of performance indicators

All system management entities are faced with managing heterogeneous large-alignment infrastructures. In this section we present four examples: underground sewage systems, roads, railways and flood protection levees. It should be noted that, irrespective of the type of structure, the principles of management are based on the discussions of section 4.1, and only the performance indicators vary.

Definitions and conception of performance indicators

Managers of civil engineering structures within infrastructure need to assess the performance of their structures, and to this end they use performance indicators.

Here we attempt to define parameters, indicators, criteria and performance indicators. Depending on areas of activity, these terms may be used in different ways and their meanings may vary significantly. For the purposes of our research, we intend to adopt the definitions set out below.

A performance indicator is defined as information that should help an individual player or, in a more general sense, a group of players, to steer the course of an action towards achievement of an objective or should help them to assess the outcome (translated and paraphrased from Bonnefous et al., 2001). In civil engineering, a performance indicator provides information on the ability of a structure to withstand the stresses for which it was designed. In this regard a performance indicator is merely a specific type of indicator.

An indicator is defined as "a parameter, or a value derived from parameters, which points to, provides information about, describes the status of a phenomenon/environment/area, with a significance extending beyond that directly associated with a parameter value" (OECD, 1993). Thus an indicator may be a parameter or may be composed of a number of parameters. A parameter corresponds to information measured or noted in relation to the structure.

These indicators may subsequently be accumulated to assess a criterion. A criterion is defined as a "factor of judgment on the basis of which an object is measured and assessed" (paraphrased from Laaribi, 2000) and as a "g function defined in accordance with A, which takes its values from a totally ordered set and which represents the decision-maker's preference in accordance with a point of view" (paraphrased from Vincke, 1989).

A structure's performance is generally evaluated on the basis of criteria. The management entity, therefore, must combine all the criteria available to it to obtain an overall evaluation of the performance of its structure. In this case multi-criteria methods may be employed (see section 3), although the management entity may also merely avail itself of the value of each criterion, with no accumulation. Management entities, in fact, tend to produce a criterion for a specific function to be carried out by the structure. This enables them to analyse the performance of specific functions in connection with a specific component (Cremona, 2002).

In this regard, a performance indicator may therefore arise from the value (Figure 9):

- of an indicator
- of a criterion
- of reasoning based on a number of criteria

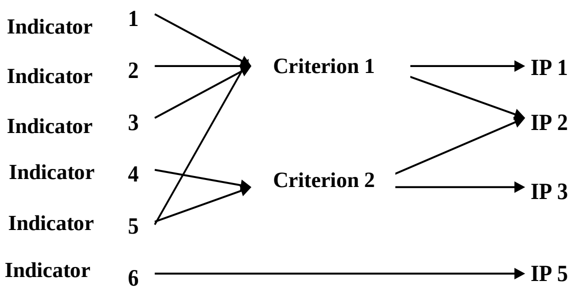

Figure 9. Construction of performance indicators (PI) (translated from Serre, 2005)

Performance indicators are information to help the parties involved evaluate the outcome of an action. The value of performance indicators is produced by the value of the indicators and criteria from which they are constructed.

We now move on to examine the successive phases of the approach to assess the performance of civil engineering structures.

Assessment of the performance of a civil engineering structure involves an assessment of its status, followed by an assessment of its performance (Cremona, 2002).

Assessment of status is a phase of diagnosis in which an investigation is conducted of the structure's degradations and their history, and here the quality of the data available concerning the structure is vital.

Assessment of performance is then carried out as at the design phase, albeit on the basis of the actual structural status of the item during operation.

Regardless of the type of civil engineering structure, the general approach in the course of a final phase to assess its performance is practically identical. We can produce a general approach through an examination of examples of assessment of the performance of several civil engineering structures. This is carried out in 3 phases (Cremona, 2002):

- historical and documentary analysis of the structures

- definition of components of structures and of their functions
- analysis of degradation and/or breakage mechanisms

The first phase of analysis of structures for the management entity is a precise definition of the management problem it faces. There may be a number of problems – these could be a failure of the structure or of its components, a degraded structure or an ageing set of structures that must be restored etc.

First and foremost, an examination of documentation concerning the structures (design and inspection documents) is an essential prerequisite for assessment of performance. These documents contain important information that is necessary to enable a comprehensive appraisal to be carried out. A check must be run to ascertain that they are accurate, and also whether they have been updated in the wake of modifications to the structure.

During the second phase of definition of the components of the structure and of their functions, the management entity seeks to define the civil engineering system it has to operate. To this end it analyses its structure in order to ascertain its components and the functions they are meant to carry out. This helps the entity to determine the components that require action to be taken with respect to its initial problem.

During the last phase, the entity analyses and models the mechanisms affecting the structure, and this enables it to assess the structure's performance using performance indicators.

3.2.4 Examples of performance indicators, by types of infrastructure

Underground sewage systems

The total length of sewage systems in France (wastewater and rainwater systems) is between 160,000 km (Diab, 2002) and 250,000 km (Vasconcelos et al., 2004), half of which is more than 40 years old. They are used to collect and convey wastewater and rainwater. The large discrepancy is due to a lack of knowledge of the network and to the difficulties involved in drawing up estimates. There are two categories: structures for which camera inspection gives enough data to understand their condition and environment and smaller structures for which it is not enough (diameters of less than 800 mm).

Information concerning the condition of these structures is obtained either from visual inspections, or via televised inspections in the case of smaller units. This also gathers data concerning the condition of piping. Other data concerning the environment of the structures also play a decisive role in assessing network performance – these concern the type of soil around pipes, the items on the ground above pipelines (roads, buildings etc.), roots in proximity to the pipes etc. (Laffréchine, 1999). Some of these data are extremely difficult to collate, and it may even be impossible to collate them without using destructive procedures. Even though CCTV cameras can inspect smaller pipes, it is not enough to give sufficient information to understand the evolution of the surrounding environment.

Traditional management procedures are primarily based on the management of emergency situations: management entities take action only when the system has failed and the effects are observed on the environment (Abraham et al., 1998).

Methods and tools are developed to enhance the management of infrastructures through the deployment of preventive maintenance policies, this involves assessment of the performances of structures, and so performance indicators (Diab, 2002 and Le Gauffre et al., 2004) have been created. Databases are becoming an indispensable tool for proper management of networks (Breysse and Boissier, 2002), and some managers use GIS systems (Dupont et al., 2004, Laffréchine, 1999). These methods and tools help managers focus on the maintenance solutions best suited to their structures and their financial resources.

By way of a summary of this example, sewage systems are essentially large-alignment structures placed in an unknown, heterogeneous environment. Managers seek to implement policies that enable them to give priority to their courses of action (Diab, 2002), and to this end methods are presently being developed to combine the utilisation of performance indicators, databases, statistics produced by visual and video inspections, and GIS.

First, let us take the example of the construction of a performance indicator for a sewage system, developed by Diab (2002). The study aims to establish priorities for courses of action to renovate the network as part of an operational plan. This means it is necessary to determine areas of risk, and establish a hierarchy for them (Diab, 1993). The methodology used is based on a simple multi-criteria approach that takes account of hydrogeotechnical risks, hydraulic and structural risks, and also the consequences of disruptions (risk of impact). It is inspired by the context of Paris (type of urban terrain, inspection-friendly unit structures etc. (Table 4).

Risks	Criteria	Note	Indicators (examples)
		Note	
1) Linked to terrain (geotechnical risks) SCORE G	1.1 Dragged fines 1.2 Settlement 1.3 Dissolution of gypsum layers 1.4 Empty spaces 1.5 Bloating clays	f t d v a	- Position of collector with respect to layer of terrain - Extent of water circulation - Thickness of gypsum layer - Size of overload
2) Linked to effluent (hydraulic risks) SCORE H	2.1 Mechanical action by effluent 2.2 Physical-chemical action 2.3 Hydraulic loads	m p c	- Slope of segment - Sand bed load - Shape of invert - Presence of chemical waste - Loading phase - Segment vulnerable to Seine flooding
3) Linked to the structure (endogenous risks) SCORE E	3.1 Geometry of collector 3.2 Condition of segment	g e	- Type of section - Thickness and type of materials - Number, length and distribution of fissures
4) Linked to the surroundings and functioning of sewage system (risks of impact) SCORE I	4.1 Consequences for functioning of sewage system 4.2 Consequences for functioning of other systems 4.3 Repercussions on road system 4.4 Consequences for buildings in proximity and political and social environment	r x w z	- Collector category (primary, secondary, discharge etc.) - Type and size of other systems - Distance between vault and roadway - Size of road system - Presence of historical monuments nearby

Table 4. The various risks and their breakdown of indicators and criteria (translated from Diab, 2002)

The approach then sets out performance indicators for the risks as scores, as the result of the combination of the various indicators and criteria, and a combination of the performance indicators as scores, in order to obtain an overall performance indicator, also as a score format (Figure 10).

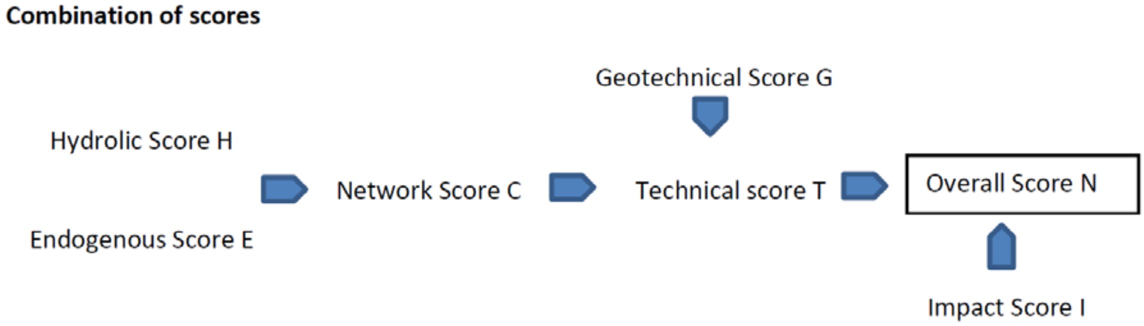

Figure 10. Combination of PIs and production of overall PI (adapted from Diab, 2002)

This example shows the way in which indicators and criteria may be combined to obtain performance indicators for a specific risk and for the overall risk. The performance assessment approach presented in paragraph 3.1.2 is also followed. This approach depends on the quality of the data gathered and the experts allocating the scores.

Roads

Roads form part of large-alignment structures. By way of example, the total estimated length of "Route Nationale" roads in France ("RN") is 30,000 km (Courilleau, 1997).

Road inspections consist of visual examination, and also examination using specific data-acquisition tools towed behind cars, of all possible data in relation to the road's topmost layer (VSS, 1997, 2000).

Managers use these surface measurements to assess the road's entire load-bearing structure (supporting platform). They seek to assess the performance of road layers underneath that are not directly visible, although their deterioration is manifested by visible symptoms on the road surface. Performance indicators are submitted to assess the performance of roads (OECD, 1997, SETRA, 2000b, VSS, 1996).

The data are stored and deployed in databases (SETRA, 1993, 2003), and subsequently in GIS to assist management entities in their maintenance projects (David, 2002, EPFL, 2001, SETRA, 2000a).

Methods are being developed to assess road performance using indicators. In conjunction with GIS systems, the indicators enable managers to deploy maintenance plans on segments earmarked as priorities in the GIS system.

Flood protection levees

Flood protection levees are mostly ancient structures (the first levees go back to the Middle Ages). They are generally soil embankment constructions, using silt or sand, or even gravel. The history of their construction explains their contents. Old levees are often structures built in stages over several periods, depending on the development of usage of rivers or protection requirements.

The oldest levees were usually built with local materials. This means they may be composed of a large number of different materials, even along a single water course (sandy materials along the centre basin and silt in areas nearer the mouth of the water course). In a given section, however, embankments are generally homogeneous with no zoning and no specific internal drainage devices.

The non-availability of heavy earthworks and compacting equipment when the old levees were built means the embankments are not so compact, with no specific anchoring to the foundations, which have not received any treatment to seal them. This brief description of ancient flood protection levees demonstrates that they are relatively fragile structures.

The designs of the most recent levees are more similar to dams, with materials zoned to separate sealing and drainage functions.

90% of flood protection levees are embankment structures (Mériaux et al., 2001), and are therefore prone to the breakage mechanisms typical of such structures (Serre 2005): overtopping, internal erosion, washout and slippage.

Of these four mechanisms, overtopping and internal erosion are the causes of the majority of levee breakages:

- Overtopping is responsible for the breakage of flood protection levees. In the case of the Loire levees, overtopping was the cause of almost half the breakages that occurred during the three instances of flooding in the mid-nineteenth century (Mériaux et al., 2001). In more than two thirds of the overtopping events, a low point was identified on the levee’s longitudinal profile that induced the flow concentration. Higher water levels on the concave bank of the curves of the river or upstream of bridges or thresholds obstructed by debris could also have been the cause of recent overtopping incidents.
- Internal erosion has also been responsible for a large number of levee breakages (CFGB, 1997). In France, between 1970 and 1997, 16 instances of internal erosion were reported in flood protection levees. During flooding of the River Rhône in 1993 and 1994, internal erosion mechanisms were the cause of all sixteen breaches of the Camargue levees. Animal lairs were responsible for thirteen of the breaches, while the other three were caused by piping across the levee.

The areas protected by levees represent high stakes. Most flood protection levees are public safety features, and the length of these levees has been estimated as 7,500 km in mainland France to protect approximately 2 million people over a surface area of some 15,000 km^2 (Mériaux et al., 2004).

Despite the high stakes, during major flooding the levees experience major failures that could lead to breaches of the structures. This is because the levees are mostly in poor condition, but it is also due to poor or even non-existent management of the constructions.

The numbers of the parties involved in management of levees are extremely large, and all too often the owners are unknown or are dormant. In many cases, the absence of any effective administration means there is much room for improvement of levee management.

The levees, moreover, are poorly documented or not at all, and acquisition of data for levees is a complex and costly business since the structures are heterogeneous.

In short, management of these largely unknown structures, in poor condition and extremely heterogeneous, is most complex. It is for this reason that an effective management facility must be set up urgently to improve levee safety. Methodologies now exist to conduct an accurate assessment of the condition of a small section of a given levee segment (Fauchard and Mériaux, 2004).

3.3 The resilience strategy of cities and territories: taking account of the interdependence of critical infrastructure

There is a gap between the theory and practice of resilience indicators. In particular, interdependences between the components of critical systems are often overlooked when assessing resilience and developing indicators. Yet, cities in the modern era are increasingly dependent on increasingly complex and technically advanced systems - energy, water, transportation and telecommunications systems - that are not isolated from each other.

Modelling the failure scenarios of critical infrastructures is therefore a major challenge, as damage to a component in one system may entail adverse consequences in another. Methods that address the interdependences are therefore increasingly important.

In this section, we address some of the theoretical work on this subject, focussing primarily on Lhomme’s (2012) work related to flood risk, and Toubin et al.’s (2014) “participational approach”.

3.3.1 *Modeling the interdependence of critical infrastructure through analysis of systems*

The work of Lhomme (2012) deals with the operation of urban technical systems and their failure mechanisms, specifically focussing on the case of flood risk. The starting point for the work was the Operational Safety methods, which were originally developed to study industrial systems with complex operating systems (numerous components, multiple looped failures etc.) for which it is extremely difficult, if not impossible, to produce an operating model using conventional physical approaches (Villemeur, 1988).

This approach applied the Operational Safety methods to the case of flooding, with the objective of assessing the resistance capacity of interdependent urban technical systems in order to determine chain damage processes.

For the purposes of application of the methodology, technical systems were divided into four categories, as follows:

- Energy systems
- Transport systems
- Water systems
- Telecommunications systems

Initially an external functional analysis was carried out of all urban technical networks to establish all common functions performed by urban technical networks with respect to their environment (transporting flows, withstanding external pressures etc.).

Next, for each of the four major network families, a structural analysis was carried out, in which all the components of the various systems were identified. Following this, internal functional analyses were conducted, to identify the interactions between the components of the system and between the system and its environment. The interactions were represented on functional block diagrams (FBDs)– Figure 11 shows the example of an FBD for the electricity network.

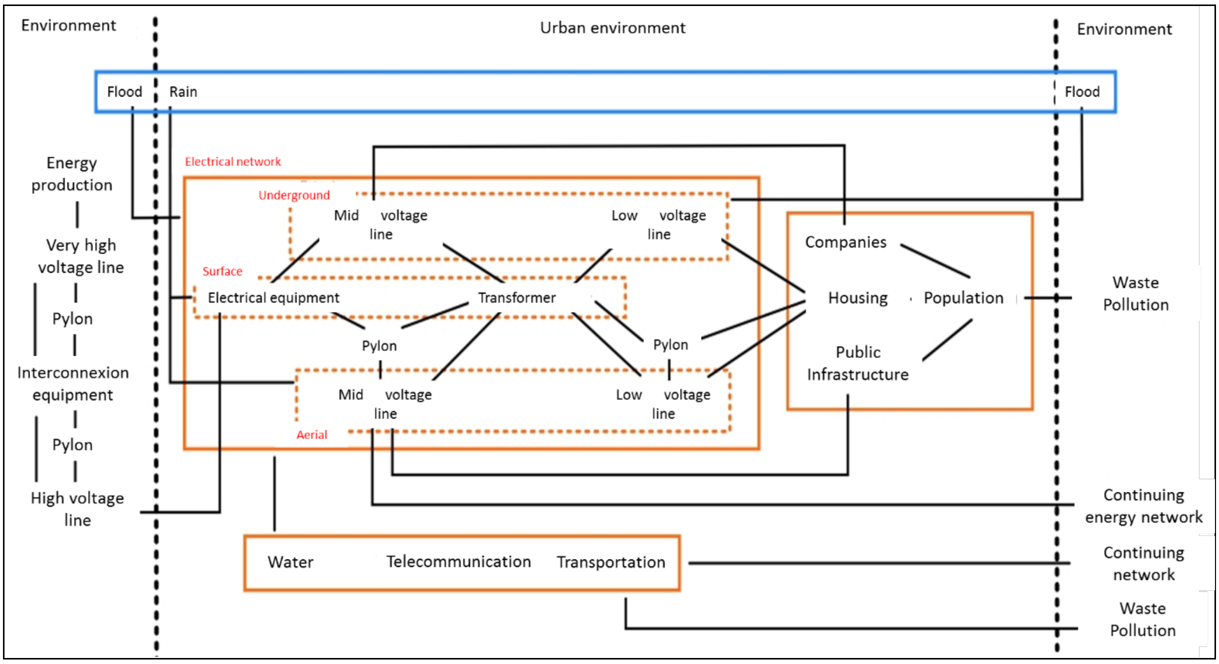

Figure 11. FBD of electricity contacts showing the structural breakdown of the electricity network and the contact relations among components (translated from Lhomme, 2012)

The FBDs clarified the functions performed by the various components of the different networks. In the case of flooding risk they were identified to be:

- ensuring service continuity;
- withstanding hydraulic flows;
- guaranteeing hydraulic flows;
- withstanding mechanical pressures;
- permitting proper operation of the other components of the urban system.

Once components and their functionality have been identified, a Failure Mode and Effects Analysis (FMEA) can be carried out. This is a process that produces failure scenarios, by examining the following aspects of system failure:

- the inability of a component to carry out a necessary function;
- the effects through which a failure of a system component is observed;
- the events leading to failure modes;
- the consequences associated with a component's ability to carry out a necessary function.

FMEA takes account of the interdependence of the various networks, tracing the consequences of failure of a component in one system into eventual effects in other systems.

As such, the number of scenarios that could arise (which is a function of the number of components and the number of systems) is potentially huge, making an exhaustive analysis difficult. Solutions that can automate the production of scenarios have therefore been sought.

Automation of FMEA requires construction of a database that, for each component in each network, specifies its functions, possible causes of failure, and effects of failure. An algorithm can then use this information to establish all direct cause-effect relationships between the components. These relationships underpin the interdependences between the components of the different networks.

The result of the FMEA analysis is a set of failure scenarios that provide information about what failures could be expected following disruption of one component, and conversely, the possible causes of a given failure. To date it has been validated in certain specific tests. It will subsequently be added to a GIS tool in order to spatialise the information obtained and take account of the configuration of networks. By confronting zoning of the contingency with respect to the current status of various components of the urban technical networks, the components directly affected by the contingency may be identified. Subsequently, by applying the methodology presented, it will be possible to establish interdependences among the various networks, and thus determine the effects caused by damages, and spatialise them.

Although it is potentially a powerful tool, in practice, the methodology presented in this section comes up against the problem of a lack of readily available data, or reluctance to share strategic data, or (as is most frequently the case) both problems simultaneously.

In the next section, we present an extension of this methodology that aims to free itself from unavailable data: the participational approach.

3.3.2 Operationalising consideration of interdependence of systems through a participational approach

As intimated in the previous section, a major difficulty faced when identifying the interdependences among urban services lies in the collation of data. Occasionally network managers are reluctant to share critical information concerning security or competition, and data are often simply unavailable due to the long history of networks and their increasing complexity. While many studies attempt to produce a model of network interdependences (Ouyang and Dueñas-Osorio, 2011, Rinaldi et al., 2001), another approach – as developed by Toubin et al. (2014) - focuses on participation between the network managers.

A tool for self-diagnosis of the continuity of urban services

Briefly, this methodology involves construction of a "snapshot of operation" of a system, on the basis of a self-diagnosis conducted by each service. Subsequently, meetings are arranged with stakeholders - the local authority organiser and the network managers - with a view to sharing experiences and information that lead to co-construction of a snapshot of the network's operation.

The initial phase of the approach, devised by the "Risk & Performance Centre" (CRP, Montreal Polytechnic), is to identify the incoming resources necessary for operation (Robert et al., 2009) and characterise the system's resilience when faced with failure of these resources: impact timeline, autonomy capacity or restoration period (Toubin et al., 2011). Depending on the knowledge of the management entity questioned, it is possible to broaden the behaviour of the system beset by disruptions in relation to its incoming resources (power supply, goods, information, services) or to its internal resources (personnel, data, infrastructures). The criticality of incoming resources is scaled from essential to negligible, and the autonomy capacity is also represented when it is known.

The outcome is a snapshot of the service as viewed by the management entity interviewed, which can be transformed into an input/output diagram (Figure 12 shows external resources only).

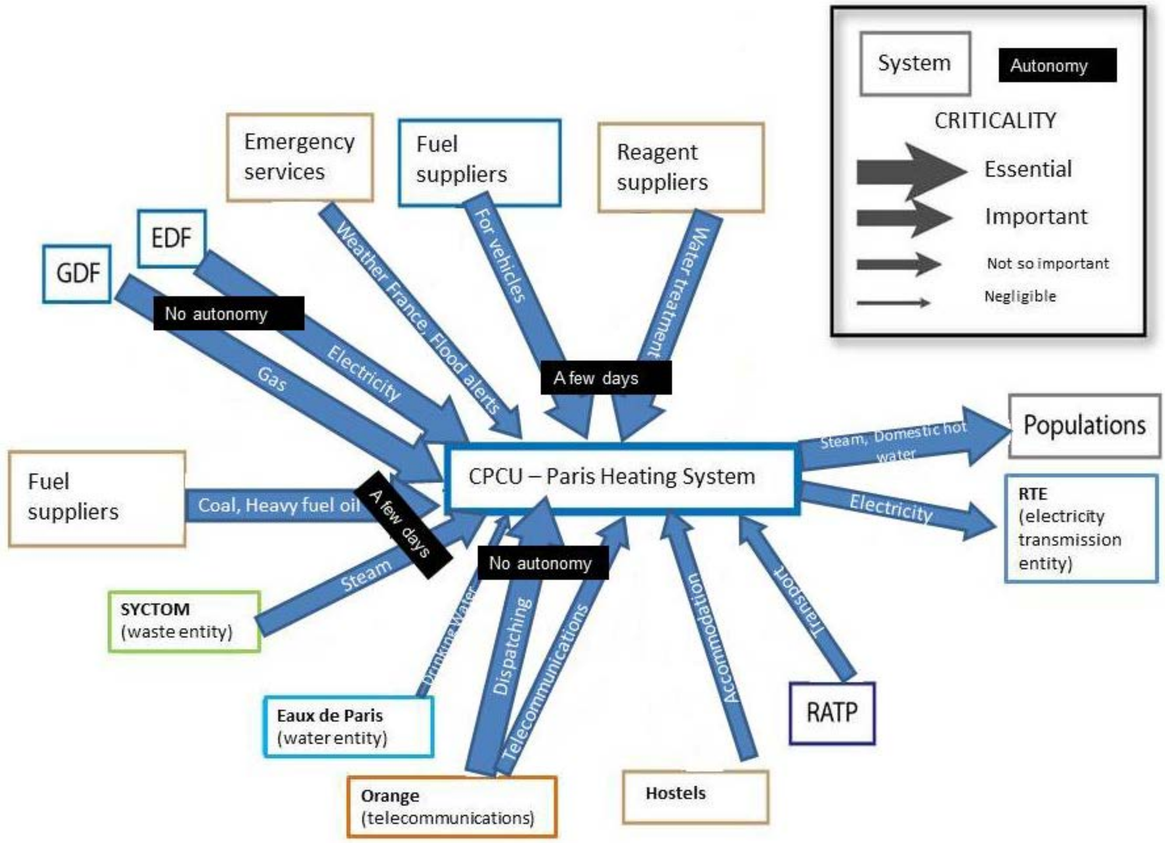

Figure 12. Sectoral snapshot of the Paris urban heating system produced by self-diagnosis (translated from Toubin et al., 2013)

The second phase involves the sharing of information among the managers of services. To do this, sectoral snapshots are transformed into a matrix that records the interdependences among the urban services studied (Figure 13), and the results are presented to managers at cooperative workshops. The aims are to first validate the model of interdependences, and subsequently discuss the difficulties they could cause during crisis management.

As a case study, a group of city managers were gathered for a tabletop exercise where the scenario was a large flood like the one in Paris in 1910. The discussions enabled services to be hierarchised with respect to their role (central or peripheral) during flooding (as illustrated in Figure 13). The representation shown here is as comprehensive as possible and singles out services that are essential to the largest number of services, particularly services in connection with electricity, hydrocarbon resources or telephone systems.

Other issues in relation to management of interdependences emerged from these discussions: technical/organisational differentiation and types of different solutions in response. Dependences acting directly on operation of the system, in fact, quite often require technical solutions: for example, the utilisation of a generator at factories in the Paris sewage system flood area to keep the plants going. A solution could also occasionally be found for these technical dependences through organisational strategies: for example, cleaning units deprived of electricity would not be resupplied, but would be shifted to other unaffected areas to continue to provide the service. The organisational difficulties very often concern all managers, and could be solved collectively: for example, identification of the competences necessary to make preparations for the crisis during and after the crisis, requirements in terms of travel and accommodation for the personnel mobilised.

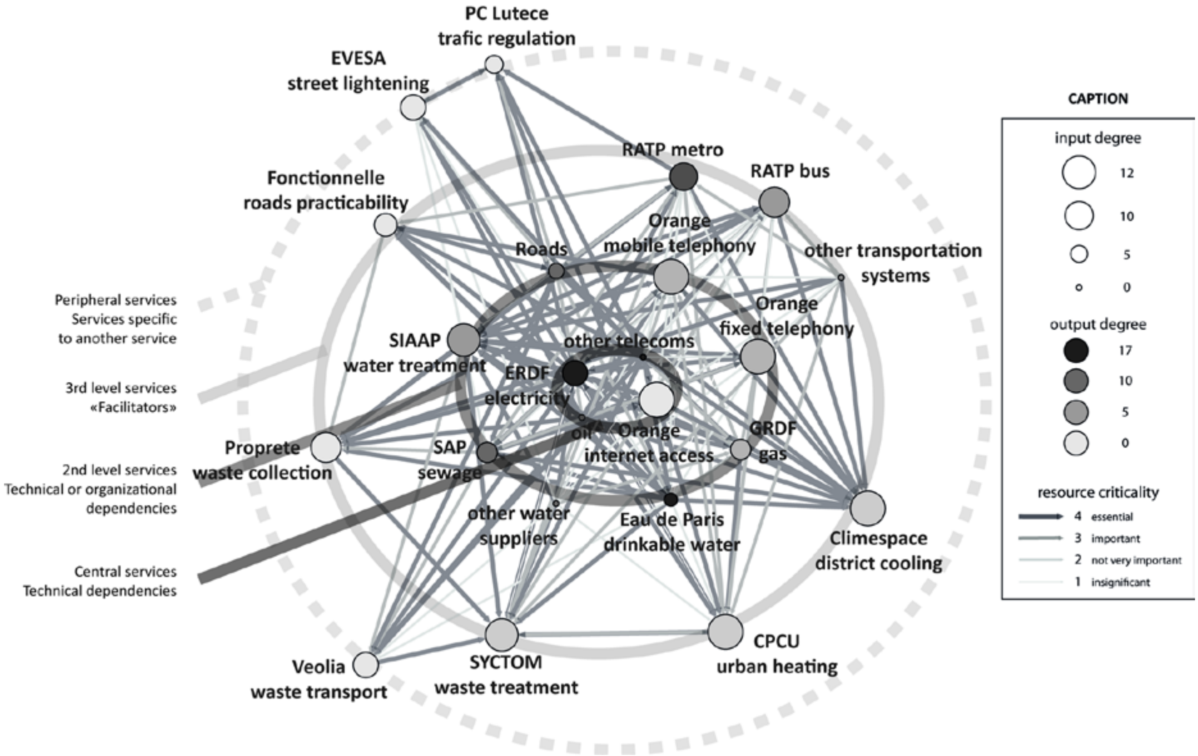

Figure 13. The hierarchisation of Paris systems that emerged from discussions with system managers (the links show exchanges of resources between 2 systems - the sum of the weightings of links entering a node gives the node's input degree, and the sum of outgoing links gives the output degree) (Toubin et al., 2014)

3.4 Resilience indicators for absorption and recovery capacities

In Section 3.1, we asserted that resilience of a system or network consists of three components: resistance capacity, absorption capacity, and recovery capacity (Figure 4). The discussion in the preceding sections related to possible performance indicators for resistance capacity. In this section, we address possible indicators for absorption and recovery.

3.4.1 Indicators in the making for absorption capacity

The absorption capacity of a system describes the ability of a network to absorb damage – to continue to function despite the failure of a component. This is related to the continuity of circulation of the flows within the network. The idea is to ascertain whether or not any alternative flows exist when one branch of a network fails. Broadly speaking, the number of alternative paths within a network is referred to as "redundancy".

An organisational or technical system must therefore be redundant if it is to be resilient. In a general sense, if a component of a system is no longer operational, a redundant system can mitigate the failure via an alternative. The disruption will be absorbed and the service will be partially guaranteed. This does not mean that a resilient system must reach a "maximum" level of redundancy as in a complete graph (or even more redundant structures, because each link on a complete graph may be doubled, tripled etc.). There is, in fact, a level beyond which redundancy may be of no use whatsoever, or even counterproductive (Parrochia, 2008). Classifications of redundancy indicators must take account of this effect, and place upper limits on redundancy.

In seeking to establish indicators of redundancy, graph theory has provided some useful approaches (Lhomme, 2012). The most intuitive solution to examine the redundancy of a graph is to study the number of independent paths between two peaks on the graph. The more independent paths the two peaks have, the greater their redundancy. Graph theory suggests several possible indicators for measuring redundancy:

1. **Degree**. The degree of a point (vertex) in a graph is the number of paths emanating from it. It is known that the number of independent paths between two vertices cannot be greater than the minimum degree of the two vertices. However, this upper bound is not precise enough to be useful as a measure of redundancy.

2. **Redundancy ratio.** To calculate the redundancy ratio of a vertex, the total number of paths connecting it to all its neighbours of neighbours is divided by the number of connections that would exist if every point was connected to every other point (i.e. if it were a “complete graph”). This indicator can be used to distinguish between types of graphs (linear, square or complete), and to measure the overal redundancy of a given network, but it is not useful for measuring the redundancy at a given point

3. **Clustering coefficient**. This indicator measures the number of connections in the immediate vicinity of a given vertex. For robust structures (networks with many inter-connections) this can be a useful measure of redundancy, but it is not useful in weaker structures.

Given the limitations of the above indicators, Lhomme (2012) developed two other indicators (Figure 14):

4. L**ocal mean number of paths**. This is the sum of the number of paths between a vertex and the neighbours of its neighbours.

5. **Local mean number of alternatives**. This is the average of the number of paths among the neighbours of a point, in the event that this point is removed.

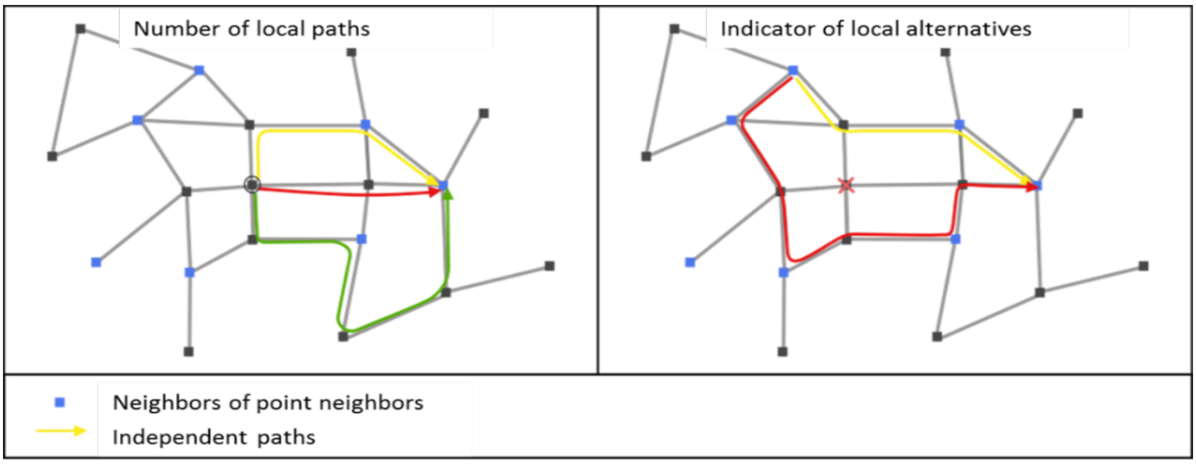

Figure 14. The two new indicators: to the left, the local mean number of paths, and to the right the local mean alternatives indicator at a point (Lhomme, 2012)

In tests on theoretical networks, these two indicators have been shown to be more successful at distinguishing between points that can be eliminated from a network without great effect, and those whose elimination is more likely to have knock-on effects. However, neither of these two indicators takes any consideration of the quality of alternative paths – only of the number. Quality of alternatives can be very important. For example, in the case of a transport network, the role of journey distances is extremely important. . An alternative path may exist, but if it is much longer, it is a poor quality alternative.

For example, Figure 15 illustrates a transport network around a river, with connections across the river possible via bridges. The redundancy of points in the network (as measured by the indicators 4 and 5) is characterised as very weak, weak, average, or strong. The points on either side of the bridges are characterised as having at least average redundancy. However, if the quality of the alternatives was taken into consideration, these points would likely be identified as having only very weak redundancy. The indicators must therefore be modified to address the quality of alternatives. This can be done by using weighted means.

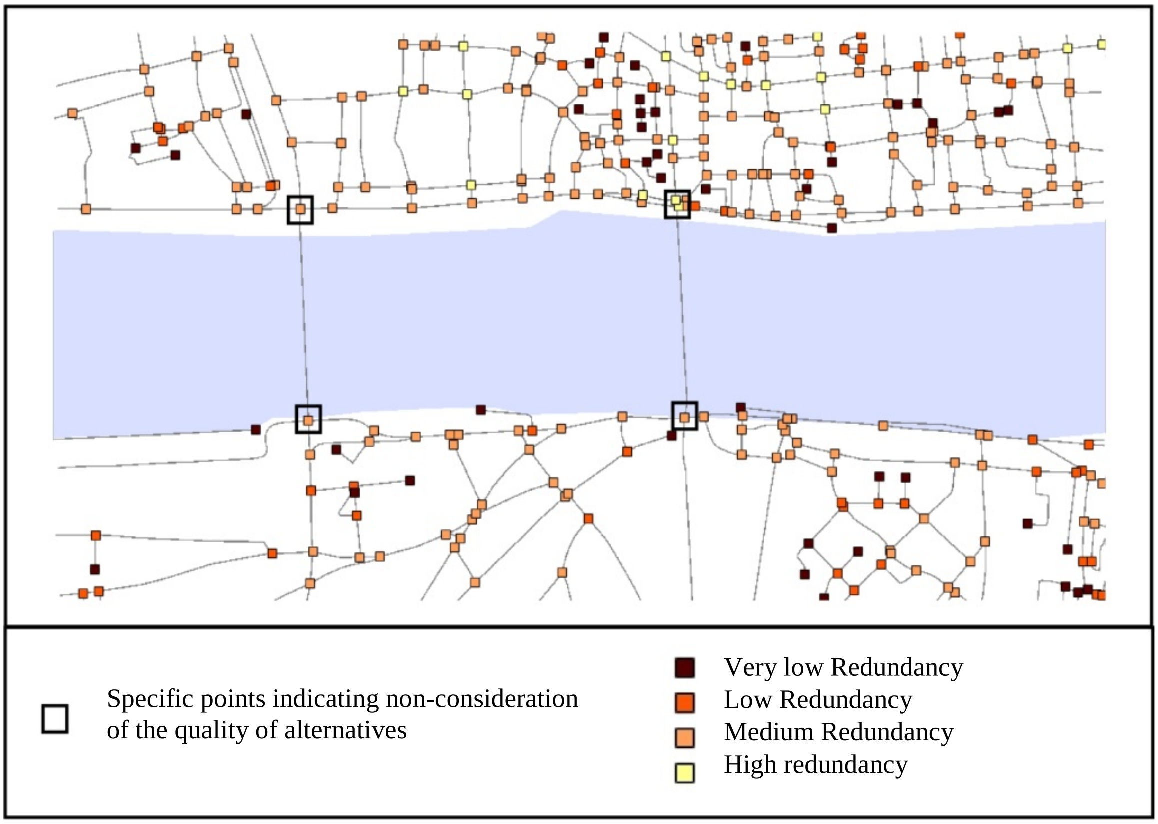

Figure 15. A transport network in which the redundancy of each node has been characterised by the local mean number of paths, taking no consideration of the quality of alternatives. (translated from Serre, 2011)

This type of indicator is still at the experimental stage. Its operationalisation involves a phase of collection of a large number of technical data, and also development of geographic information systems that are capable of measuring absorption capacity. Managers must then have an understanding of the tools to enable them to be used to their full potential.

3.4.2 Indicators in the making for recovery capacity

The recovery capacity of a system refers to its ability to repair components following damage. A key characteristic of a system that influences the recovery capacity is the accessibility of the damaged components vis-à-vis the units responsible for making repairs. The more difficult it is to gain access to a certain area, the more problematic restoration of the area will be, in comparison to other more accessible areas. How then can accessibility be assessed?

The concept of accessibility has a number of definitions. It may refer to geographic accessibility, physical accessibility or social accessibility (Chiaperro, 2002). In this context, accessibility does not only depend on spatio-temporal criteria, but also on the service level of the transport system, which itself is dependent on a large number of factors: population density, density of activity, political choices etc.

In the case of individual transport, the service level available chiefly depends on:

- The structure of the network (sinuosity and configuration of routings).
- The quality of infrastructures, in terms of their technical characteristics (number and width of routings, existence of a central lane separator etc.).
- Topographic constraints (gradients, sinuosity).
- Prevailing regulations.
- The technical characteristics of the vehicle used.
- The congestion disrupting operation of the system and altering service quality, depending on the days of the year and times of day.

Focussing just on the spatial criteria of accessibility, three specific indicators have been identified as useful:

A. **Shortest-path indicator.** This assesses the minimum journey length and journey time to a restoration centre, and the minimum cost of transportation. Illustrated in Figure 16.

B. **Scheduling indicator.** This is also based on shortest paths, but in addition it takes account of hierarchical scheduling of repairs – if there is a queue for repair at the closest repair centre, a more distant centre may actually be optimal.

C. **Hardship indicator.** This indicator takes into account the difficulty of the journey – particularly in the case of flooding, where some paths become unaccessible. This is accounted for by “lengthening” some paths.

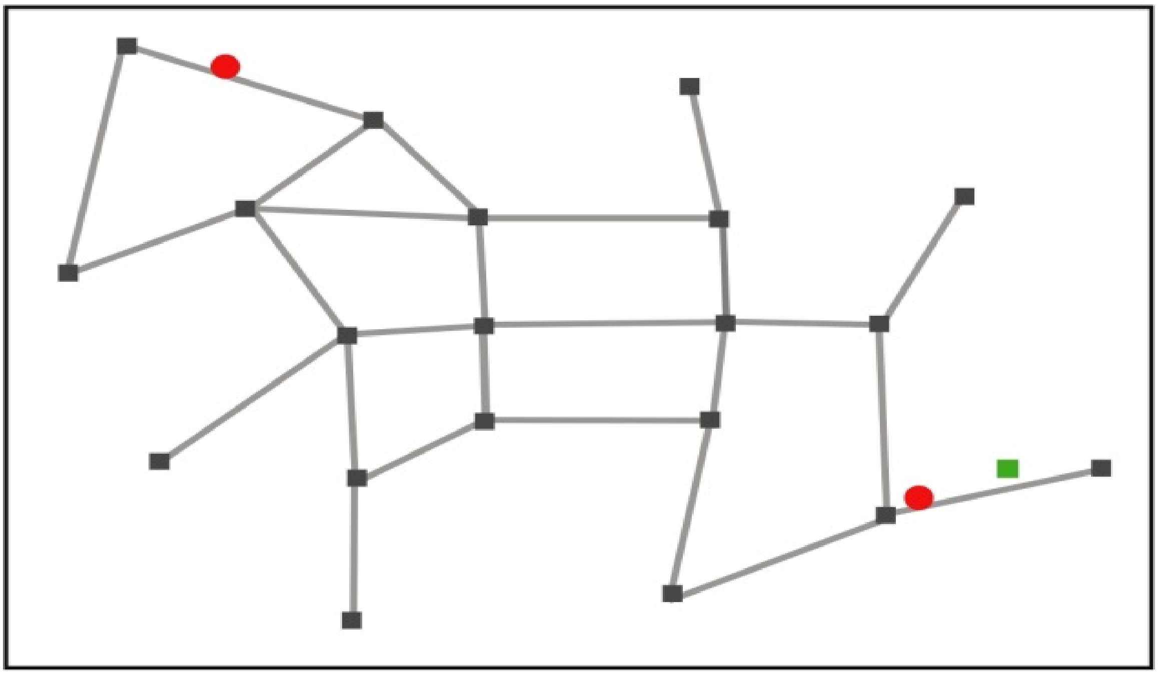

Figure 16. Illustration of the importance of the shortest path for restoration of technical networks. The damaged components are shown in red, and the restoration centre in green. In this case, one damaged component is much better positioned than the other. The shortest-path indicator singles out this difference (Lhomme, 2012).

These three indicators developed may be combined to obtain an overall accessibility indicator. This is done by simply totalling the normalised indicators by weighting the values of the indicators, depending on the importance attached to each factor.

Using these spatial indicators for the restoration of urban technical services is an interesting option, and can be used to optimise strategies when strategies exist. Their application is, however, dependent on the development of basis GIS applications.

3.5 Results of assessment

The main results presented in this chapter concern assessment of the resilience of technical networks, analysed on an individual basis and subsequently together, as a system of systems.

The results of assessment of the technical networks may be interpreted as follows:

- Resistance capacity: each network manager uses performance indicators of more or less developed status. The indicators give some idea of the status of the network and its ability to carry out the functions it was designed for, taking due consideration of the risks involved. These indicators are operational. Even though accidents will always happen, it may nevertheless be claimed that resistance capacity is certainly taken into account by the managers, and that to date this capacity has been a priority.
- Absorption capacities (assessing capacity to operate in degraded mode): indicators either already exist or are being developed. They are a useful concept for understanding this essential capacity from the point of view of resilience, although their operationality is not on the agenda: they must be taken into account in the years ahead, provided there is sufficient access to managers’ data, and provided investment is forthcoming to develop tools to spatially represent the interest of the indicators.
- Service restoration capacity: indicators created on the basis of theories in connection with spatial analysis exist, and could become operational if tools can be developed to assist spatial decisions/simulation.
- The interdependence of technical networks: implementing a resilience strategy for various locations makes sense only if it includes the present interdependences among all the technical systems (and this is not yet the case). Two approaches were presented. The first is based on systemic modelling of infrastructures and their relationships. This is a powerful approach because it can furnish exhaustive modelling of the phenomena acting within this system of systems. The difficulty lies in its operational use at a given location: the concept comes up against issues concerning a lack of data or data confidentiality. To overcome this difficulty, a second approach was presented on the basis of a participatory arrangement. Local decision-makers and network managers came together to construct resilience strategies on a joint basis. The approach was applied in the area managed by Paris Town Hall in respect of a flooding scenario similar to the 1910 floods, and the parties continue to meet in connection with this approach. The idea is not to work on the basis of new indicators, but rather on the implementation of a participational approach.

Beyond the resilience indicators tabled, some of which have still to be devised, the most important aspect is to take up a position to be able to implement these complex approaches with the stakeholders: infrastructure managers and risk managers on all local scales. Two aspects are crucial in this regard:

- Developing an operational participatory approach to work on collective implementation of a resilience strategy.
- Developing tools for visualising and simulating collective decisions to improve resilience in certain areas. GIS constitute a major lever in the achievement of this objective.

4 RAMSES case study city analyses

Chapter 4 addresses the state of the applied art in RAMSES case study cities using document analysis (all RAMSES cities), meetings with the municipality (Bilbao, Antwerp), and comparison, analysis, and discussion of results from the RAMSES case study cities.

4.1 Methodology

For each case study city, resilience measures for architecture, infrastructure and urban planning were extracted from municipal policy documents on climate change adaptation, and on architecture, infrastructure and urban planning, each document was evaluated according to a range of questions aiming.

Similar to the methodology used in the Norwegian Cities of the Future programme (Rambøll 2012), each document is evaluated to assess city authorities' level of awareness and capacity to implement resilient architecture, infrastructure and urban planning strategies:

- Resilient architecture and urban planning dimensions are mentioned and taken into account in the executive summary, introduction or conclusion [significance]
- Resilient architecture and urban planning dimensions are mentioned and taken into account in the goals and strategies described in the document [operationalisation]
- Specific impacts and urban areas are described in detail [impact]
- Cost assessment of vulnerability and potential measures has been performed [cost]
- The proposed measures are legally binding [legal framework]
- The methodology for assessing and monitoring resilient architecture and urban planning dimensions is clear [methodology]
- Resilient architecture and urban planning dimensions are integrated in checklists for project development used by city officials (urban, neighbourhood and building scale) [checklists]
- Resilient architecture and urban planning dimensions are integrated in simulations of urban climate and environment used in RAMSES, and how they can be improved [simulations].

4.2 Antwerp

The main policy document selected for analysis of Antwerp is the Strategic Spatial Structure Plan of the City of Antwerp: "Strategisch Ruimtelijk Structuurplan: Antwerpen Ontwerpen" (SA 2012a, 2012b, 2012c). This document was selected because of its legal relevance and scope; the document is essential for the development of the city and its implementation is mandatory.

The Structural Plan of Antwerp is organised in three parts: Book 1 - The generic policy is restructured with the informative section as a guide. Book 2 is a book of illustrative maps. Book 3, the guiding and binding (legal) section, deals with the various sectoral issues, strategic measures, actions and suggestions to the authorities, including a general vision of a future spatial policy for the city consisting of generic and active policies.

The Strategic Spatial Structure Plan includes many urban typologies to embrace the complexity of the city of Antwerp: the Water City, the Eco City, the Port City, the Rail City, and the Porous City. The Plan presents the vision for each of these city types as well as the goals for the main element represented by each city type: water for the Water City, open space for the Eco City, the port for the Port City, De Lijn (The Line) for the Rail City, and morphology for the Porous City. For the Eco City, for example, the green structure of parks has to be located in "the main open space connections" defined by the Plan. For the Port City, "the redrawing of the contact areas between the town and the port, will transform the area in a zone with mix of functions which connects both the port and the city with the river" (SA 2012a, bk. 3 p. 61). In addition to urban typologies, functions and urban scales form the main drivers for the Strategic Spatial Structure Plan, in particular the duality between the metropolis and the villages within the polycentric city, and heritage, and living and working functions.

Resilient architecture and infrastructure dimensions are mentioned and taken into account in the introduction and the conclusion of the Structure Plan of the City of Antwerp. The goal is to develop the city and improve urban life, keeping in mind that it is a complex system that contains diverse elements and scales (SA 2012d, p. 232). The city and its territory are undergoing fast changes that are expressed in infrastructure projects such as the Singel, the High Speed Line and the new tram lines. Neighbourhoods such Prestibel, Eksterlaer and Eilandje are being developed, and abandoned industrial urban areas are being re-integrated into the city.

Resilient architecture and infrastructure dimensions are considered and described throughout the entire document (goals and strategies) such as water, vegetation, open spaces and mobility structures, morphology types and mix of functions. The goals for water and vegetation are to improve urban structure and to reconnect the city with the river Schelde and the harbour. This means that the quality and accessibility of the public domain around the river, streams, docks and channels will be improved, with the water structure forming part of a large network of parks, natural elements and open space areas, i.e., "the basic structure of the open space of the city" (SA 2012d, p. 30). Open spaces are developed into an urban park structure, to achieve readability of the open space structure, to maximize the growth of nature, to differentiate recreational use and to ensure a well-balanced structure of built and non-built areas (SA 2012d, p. 46).

Urban mobility and morphology are among the main issues taken in consideration throughout the policy document. The Plan aims to strengthen public transportation, to develop coherent parking policy, to discover the street as public space and to handle the closing of the Ring for the road network (SA 2012d, p. 68). Vacant buildings or vacant lots are to be used for residential or economic activities. Urban development with mix of usage is encouraged, while gated communities (housing projects with privatized public domain) are proposed avoided (SA 2012d, p. 96).

Specific impacts and generic types of urban areas are described in detail in the document. Climate change impacts are described in detail for specific areas. The area Berendrecht- Zandvliet, for example, is described in detail related to the consequences of tides, flooding and the accessibility of the port area. The Plan proposes direct interventions, with sets of urban areas included and described in detail (maps are presented in SA 2012b) as part of main urban structures such as the ‘hard backbone’ (impermeable areas), the ‘soft backbone’ (green structure of parks), urban centres as part of a large network, and vegetation and water channels.

Costs are mentioned but they are unfortunately not specified or referred to in the entire Plan. In the legal section of the Plan, the costs are mentioned as part of a to-do-list: "Summary of actions, measures and projects" (to do list): "insert costs of urban developments" (SA 2012d, p. 304).

The legal section in Book II obligates the municipality and its institutions to fully implement the mandatory provisions by decree of the government (SA 2012d, p. 320). In the final phase of the preparation of the Plan, the mandatory provisions were submitted to a comparison with overall municipal policy in order to eliminate any potential differences and conflictsand define "a strategic way to make choices or even to set mandatory criteria" (SA 2012d, p. 8).

In addition to the general legal framework, the Plan proposes that a legal framework should be initiated and developed by the city for each of the selected strategic projects. Ideally the site development process should include configuration of the legal framework for each of the interventions: "The vision and urban design will be translated into a binding legal framework (spatial implementation) and the necessary impact studies will be executed or prepared (…). Public participation happens according to legal requirements." (SA 2012d, p. 24).

The Plan does not contain assessment methodologies or checklists for project development. There is no assessment proposed to evaluate the results of the policy, nor are benchmarks proposed to assess the excellence of the achievements. It is implied in the Plan that simulations were made as a basis for further action in terms of flooding and sea level rise.

Simulations were already carried out in the Sigma Plan in 1976, launched as a result of major flooding in Antwerp and Ruisbroek, a village on the south of Antwerp. The plan proposed a combination of three actions to limit the risk of flooding to 1% per century. These three elements were: raising the dikes, realization of flood control areas, and construction of a flood barrier to Oosterweel (SA 2012d, p. 45). Nowadays the Sigma Plan is the subject of a new planning process considering new data on climate change hazards. New calculations indicate sea level rise to such an extent that it requires new safety measures and an updated Sigma Plan (SA 2012d, p. 49). Flooding and sea level rise are the only hazards mentioned in the Structure Plan.

4.3 Bilbao

Bilbao is the largest municipality and the capital of the province of Biscay in the Basque Autonomous Community in Northern Spain - it is also the tenth largest city in Spain. Within the scope of RAMSES work package 2, Bilbao was the first case study city to be analysed, and involved a more in-depth assessment than the other case study cities. The analysis involved four policy documents prepared by local and regional authorities. Three out of the four analysed policy documents in the case of Bilbao present detailed descriptions of specific impacts and urban areas.

The following documents were considered for the analysis of Bilbao:

- Action Plan for Sustainable Energy 2020 Bilbao ("Plan de Acción para la Energía Sostenible de Bilbao 2020") (Bilbao 2013a)
- Measurement of Urban Sustainability in Bilbao and its neighborhoods (“Medida de la Sostenibilidad Urbana en Bilbao y sus Barrios”) including the Plan of Sustainability Indicators of Bilbao ("Plan de Indicadores de Sostenibilidad Urbana de Bilbao") (Bilbao 2013b)
- Manual of Urban Planning in the Basque Country for Mitigation and Adaptation to Climate Change ("Manual de Planeamiento Urbanistico en Euskadi para la Mitigacion y Adaptacion al Cambio Climatico") (ihobe 2012)
- Pre-diagnosis of the Revision of the General Urban Plan of Bilbao ("Prediagnostico de la Revision del Plan General de Ordenacion Urbana de Bilbao") (Bilbao 2012a)
- Executive Summary of the Pre-diagnosis of the Revision of the General Urban Plan of Bilbao ("Resumen Ejecutivo del Prediagnostico de la Revision del Plan General de Ordenacion Urbana de Bilbao") (Bilbao 2012b)

In each planning document we captured key dimensions of resilience that were identified and categorized as possible indicators. The key findings from the analysis of each planning document are:

Action Plan for Sustainable Energy 2020 Bilbao. Plan de Acción para la Energía Sostenible de Bilbao 2020 (Bilbao 2013a)**.** The document emphasises mitigation strategies to reduce greenhouse gas emissions by improving the level of efficacy of technical networks and construction systems. The document emphasises public indoor services (e.g. sport centres, public buildings and municipal dwellings) and public outdoor spaces (e.g. street lighting renovation and district heating). Although the improvement of green infrastructure is mentioned (e.g. green belt), its potential effectiveness in reducing and adapting climate change (CC) impacts (e.g. heat island effect, flooding, landslides, and broader issues of health and well-being) are not addressed. Although actionable priorities are ranked in the document in relation to general weaknesses and threats, these items are not explicitly linked to spatial CC impact assessments.

Plan of Sustainability Indicators of Bilbao. Plan de Indicadores de Sostenibilidad Urbana de Bilbao (Bilbao 2013b)**.** The document contains sustainability indicators to analyse current and future scenarios, in addition to an action plan. Although guidelines are proposed, more detailed descriptions of the specific impacts of interventions in urban areas are currently not included. We recommend that spatial CC impact assessments, in addition to cost/risk estimation are used to supplement scenario planning of how specific measures and action areas are prioritized. We suggest that the broader planning framework of Bilbao should become more strongly integrated with the language of sustainability indicators already in use to ensure measurable, strategic implementation.

Pre-diagnosis of the Revision of the General Urban Plan of Bilbao. Prediagnóstico de la Revisión del Plan General de Ordenación Urbana de Bilbao (Bilbao 2012a). This planning document outlines several indicators that in fact consist mainly of recommendations, which do not necessarily capture the effects of impacts they intend to measure. The document addresses specific instances of greenhouse gas mitigation, while adaptation strategies are often lacking. It is recommended that a longer planning timeline, scenario planning and spatial CC impact assessments, in addition to cost/risk estimation of damage, are included to support planning prioritization. Mitigation-based approaches were generally well defined and concrete, and focused on the introduction of technologies that facilitate greater energy and emission efficiency. However, many of the mitigation-based approaches outlined overemphasise the building scale, or transport technologies such as vehicles. Although the relevance of other key infrastructures and services of the city is outlined, we suggest that the improvement and development of green and blue infrastructures should be equivalently prioritized. Adaptation-based approaches were less explicit and often expressed as generalized guidelines and perceptions of good planning, without examples of specific application or outcome assessment in identified sites. While general weaknesses and threats were identified, adaptation-based approaches in all of the documents were less developed into actionable plans, highlighting a key opportunity to identify and integrate the critical concerns of existing planning policies such as, but not limited to, heat island effects, flooding, and landslides.

Manual of Urban Planning in the Basque Country for Mitigation and Adaptation to Climate Change. Manual de Planeamiento Urbanístico en Euskadi para la Mitigación y Adaptación al Cambio Climático" (Ihobe 2012). The document presents a list of useful adaptation and mitigation strategies to be implemented in the municipalities of Basque Country. Inclusion of scenario planning and cost/risk assessment analyses would further support the development of the strategies presented.

This document review highlights the potential to coordinate existing strategies and further develop the planning policies of the city of Bilbao and the Basque Autonomous Community through the inclusion of resilience concepts, dimensions, and indicators. In short, the analysis of these planning documents was consistent with the previously conducted review of scientific literature, standards, design guidelines and assessment schemes (Deliverable 2.1), along with testing of the review results in stakeholder and expert workshops, which show that few operational indicators and assessment frameworks for urban climate resilience exist in practice. Additionally, those that do exist focus mainly on risk and vulnerability, with little attention for identification of opportunities for intervention, design and synergies with other urban policy areas.

The Bilbao policy documents show fruitful initiative towards inclusion of resilience indicators. However several “indicators” consist mainly of recommendations or they do not measure properly the achievements they intend to measure. For example, effective actions to increase citizens’ awareness of the effects climate change express goals rather than indicators. An indicator would be a number of new projects, events or programmes to engage people.

The approaches mainly fall into two categories: specific mitigation and vague adaptation. Mitigation based approaches are generally well defined and concrete, and focused on the introduction of technologies for energy and emission efficiency. Many of the mitigation approaches are detailed even to the scale of exact buildings or vehicles. Adaptation approaches are less explicit and could be considered as more generalized thoughts about good planning, without application to identified areas or situations. While general weaknesses and threats are identified, there are few precise examples of applications.

The existing information (e.g. reports, detailed plans, historical data, etc.) needs to be coordinated into more consistent planning documents without overlaps and contradictions. Risk assessment including cost-benefit analysis should be considered in the policy documents to prioritise actions more efficiently in a long-term perspective.

4.3.1 Risk analysis and resilience strategy of infrastructure

In addition to the analysis of policy documents, a preliminary study was performed to establish a rough picture of the risk assessment strategy of the municipality of Bilbao. Ideally this gap analysis should provide elements to help the city identify potential weaknesses and priorities for action.

Analysed documents

- Manual de planeamiento urbanístico en Euskadi
- Pre-diagnóstico de la Revisión del PGOU de Bilbao
- Plan de Emergencia Municipal (PEMU)
- Manual de Usuario de la Aplicación informática del PEMU de Bilbao
- Plan de indicadores de sostenibilidad urbana de Bilbao
- Plan de acción para la energía sostenible de Bilbao 2020

The documents have been searched for:

- Risk identification, characterization and assessment on the one hand,
- Proposed action and indicators on the other hand.

Framework of analysis

As the documents are not standardized, nor they are all specifically dealing with risk assessment we have first developed a framework for efficient screening and characterization of the relevant information. This framework consists of a grid of characteristics derived from the UK cabinet office, UNISDR, ICLEI and Deliverable 2.2 from the RAMSES consortium featuring:

- the type of risks that should be taken into account (natural disasters, climate effects and impacts);
- the different time frames for action: before, during or after the damaging event, corresponding respectively to adaptation, absorption/resistance and recovery phases;
- the sectors of infrastructure that should be considered;
- the existence of adequate indicators;
- etc.

Match-making

The documents from the Bilbao municipality have been analysed for the risks identified in the framework and confronted with proposed action plans and existing indicators. The key questions to establish categories were:

- Is the risk identified?
- Is the risk addressed?

The study resulted into five categories which are defined as follow:

- Category 1: Risks are not identified
- Category 2: Risks are identified but not addressed[2].
- Category 3[3]: Risks are partially addressed but not identified.
- Category 4: Risks are identified and partially addressed.
- Category 5: Risks are identified and addressed.

Resilience capacity

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[2] A risk can be identified and not prioritized based on the risk assessment.

[3] We found this category useful to highlights the potential synergies between programs on which the municipality may built-up strengthen resilience

In a second phase, the documents were analysed to determine the resilience capacity of the city. Resilience capacity was estimated in an *ad hoc* way by trying to couple specific action with corresponding indicator. Here, again several categories can be found:

- An indicator correspond to an action
- An indicator exists without obvious correspondence to an action
- An action is proposed without corresponding indicator
- A mentioned capacity does not correspond to either an action or an indicator.

This analysis has been done for all the indicators and actions which have been found, some of which are not intended to address a particular risk. This is the case in particular for energy efficiency and climate mitigation strategies.

Transport sector: from category 2 to 4

Most risks are at least partially addressed. Some risks are not considered important and may need re-evaluation in the light of climate change.

Consideration of technology risk is highly developed in accordance with road safety and accidents reduction, as well as with the collapse of infrastructure. In this vein, it is worth highlighting the PEMU´s measures to improve public transport and roads, and the PGOU's aims to improve the management and state of roads. Likewise, health risks are also taken into account, in particular, those associated with the collapse and / or blockage of essential services. To that end, the PEMU promotes measures to diversify the transportation routes and reduce urban traffic, such as the disincentives to the automobile parking. The *Plan de Acción para la Energía Sostenible de Bilbao 2020* promotes the diversification of public transport lines, and the expansion of Bilbao subway and tram lines. Finally, the PGOU works to reduce traffic chaos.

However, the risk of damage and deterioration of infrastructure associated with floods, avalanches, tidal and snow, though well identified, would require specific actions to address the risk correctly. Similarly, the impact that droughts and heat waves pose to infrastructure needs being re- evaluated.

Water and sanitation sector: from category 2 to 4

Most risks are at least partially addressed. Some risks are not considered important and may need re-evaluation in the light of climate change.

Water supply and sanitation infrastructures have been primarily analysed from the point of view of natural hazards and their impact on the state of infrastructure and service provision. In this line, the PEMU has taken steps to prevent damage to the drainage capacity, such as limitation of land use in flood zones, out of the way of intense drainage; or the use of surface and subsurface drainage practices to address avalanches. In addition, the PGOU is conducting strategic actions directed towards floods risk, water supply and the proper use of port areas, among others. Regarding technological risks, the Action Plan for Sustainable Energy 2020 Bilbao includes structural measures to reduce drinking water leakage (Bilbao 2013a).

However, it would be advisable to distinguish between supply and sanitation strategies. It is also necessary to develop specific strategies to address the collapse of the sewage, water infrastructure damage caused by dam break, and the collapse and / or blockage of essential services related to the failure of piped supplies. Similarly, the impact that droughts and heat waves pose to water infrastructure needs being re- evaluated.

Waste management sector: category 1 and 5

Risks do not seem to be identified as such. However, some actions of the sustainability plan, by reducing the volume of organic waste, may help reduce the risks of sanitary hazards associated with flooding.

In particular, the actions implemented by the Action Plan for Sustainable Energy 2020 Bilbao to improve waste management are relevant, such as the promotion of the separate collection of waste, containers provision, proximity to waste collection points, closing the cycle of organic matter and upgrading the landfill of waste of Artigás Bilbao 2013a).

ICT sector: Average index: Category 1

Most risks are not addressed.

The risks associated with natural phenomena (such as floods, avalanches, tidal and snow) or with technological events (such as dam break, gas leaks, explosions, electric infrastructure and power grids failure), or with energy service disruption have been identified. In addition, the city of Bilbao is also aware of the health risks associated with the stoppage of normal activity against collapse and / or blockage of essential ICT infrastructure services.

However, no actions seem to be put in place to adapt, absorb and recover from a prolonged disruption of supplies of electricity, transportation networks and post services in particular, and the damage or destruction of assets and internal networks in general.

Energy sector: Average index: Category 1

Most risks are not addressed.

The risks associated with natural phenomena (such as floods, avalanches, tidal and snow) or with technological events (such as dam break, gas leaks, explosions, electric infrastructure and power grids failure), or with energy service disruption have been identified. In addition, the city of Bilbao is also aware of the health risks associated with the stoppage of normal activity against collapse and / or blockage of essential electric infrastructure services.

However, no specific measures seem to address specifically the upstream oil and gas, electricity generation and electricity networks, such as the introduction of performance levels for the gas and electricity industry, including supply restoration timescales and contingency arrangements.

Most studies on network vulnerability conclude that the electricity network is the most aggressive network because all the networks depend on electricity supply.

Interdependencies

Many elements of critical infrastructure take the form of networks which provide service by allowing flows of water, passengers, information, electric power, fuels, etc. These networked infrastructures create different dependencies within and between infrastructure sectors:

- Geographical dependencies: infrastructures are often close enough to be damaged by the same event. Failure of one form of infrastructure can lead directly to damage to another and damage can also occur inadvertently during infrastructure repairing.
- Physical dependencies: Systems are physically connected and one is dependent on the other to function.
- Logical dependencies: infrastructures can influence one another without being physically connected due to logistics.

Major disruptive events have shown dramatically that the four core sectors (energy, ICT, transport and water) are all interdependent to some extent and are all absolutely dependent on the provision of energy and ICT (see Table 5). Furthermore, energy and ICT are now intertwined: Energy infrastructures – both supply and demand – are increasingly reliant on communication and control systems and the loss of electricity supplies can disrupt communication and information services, which in turn complicates emergency responses related to health and safety. Each sector depends on the other sectors' resilience and it is essential that these interdependencies are both understood and managed to improve the resilience of infrastructure.

Sectors	Energy	Transport	Water	ICT
Energy	All sectors depend on energy to carry workforce to sites;	Transport for the fuel supply chain All sectors depend on transport to carry workforce to sites and distribute food	Water is required for cooling power stations and fuel refining; All workplaces require water for staff	ICT for control and management system of electricity and gas; Increasing dependence on ICT for sensing and reporting the condition of the infrastructure
Transport	Transport wholly dependent on fuel and increasingly electricity;	All sectors depend on transport to carry workforce to sites and distribute food	All workplaces require water for staff	ICT for management of services and networks; Increasing dependence on ICT for sensing and reporting.
ICT	ICT wholly dependent on energy for all services;	All sectors depend on transport to carry workforce to sites and distribute food	Same as above	Same as above
Water	Water wholly dependent on energy for pumping, processing and control systems	All sectors depend on transport to carry workforce to sites and distribute food	Same as above	Same as above

Table 5: Examples of interdependencies across the four main sectors. The table should be read as follows: Sector 1 (row) depends on Sector 2 (column). Source: (RAEng, 2011; Wilbanks et al., 2012).

Challenges and opportunities

Operators, asset managers, and policy makers tend to identify threats and vulnerabilities within their domains of responsibilities, which has two consequences:

- The overall picture in which they interact with other actors is never complete;
- They tend to protect themselves from risk relevant to their domain of responsibility, often by considering worst case scenarios, and thus applying disproportional risk mitigation measures.

From the risk assessment point of view this approach is effective but it narrows down the possibilities for cost-effective risk mitigation. If the issue would be taken from a resilience point of view, more alternatives to mitigate risks would exist. A resilience analysis requires assessing the infrastructure from a holistic point of view, enhancing coordination and timely response throughout the interdependencies.

For example, the mitigation of risk for the networked system due to the potential failure of a critical node, besides the avoidance that such an event may develop, can also be tackled by increasing the capacity of the dependent nodes to withstand the perturbation. This requires a higher level of communication and coordination among the operators of the various networked infrastructures.

From sectors to assets, technical approach

The analysis of infrastructure by sector is useful but has also limitations. Key infrastructures such as dam, power plant, communication tower or waste water treatment plant largely benefit from individual assessments for risk characterization. In practice, each piece of infrastructure is described through a FMEA (Failure Mode and Effects Analysis; *AMFE: Análisis modal de fallos y efectos*). FMEA is an in depth analysis of components, assemblies and subsystems to study the interactions between components of a system and its environment and identify links between the functions failure, their causes and effects.

All the different rows of an FMEA provide indicators of failure probability and of risks associated with this failure. The systematic analysis of the FMEAs of the different assets in case of a natural disaster such as flooding:

- reveals which risks are taken into account;
- reveals which interdependences are identified;
- establishes scenario of failure propagation;
- provides ground for addressing other risks and dependencies.

The different FMEA of the critical infrastructure can be combined to search for cascading effects (Figure 17).

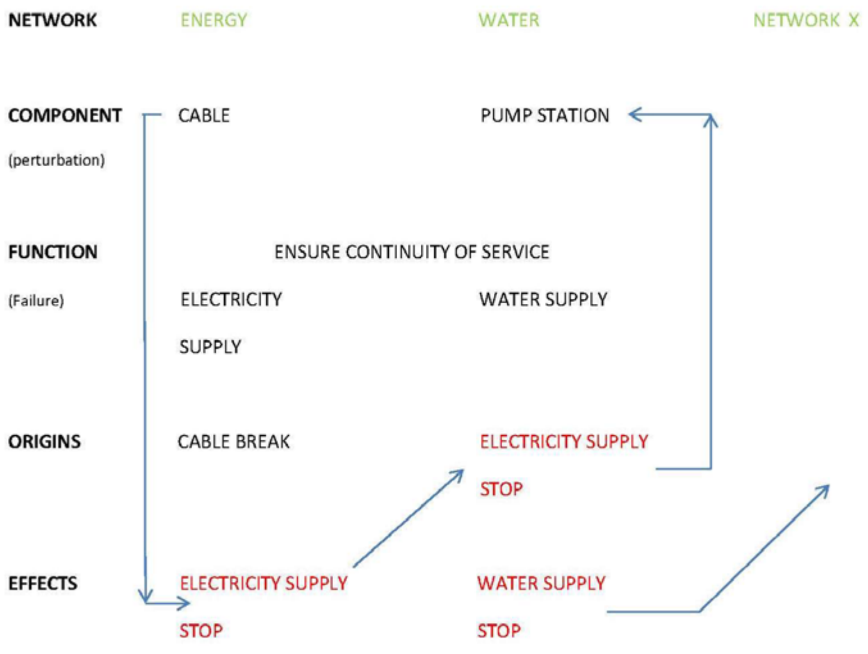

Figure 17: Different FMEA of the critical infrastructure can be combined to search for cascading effects (adapted from Lhomme 2012)

The analysis of all the FMEAs and their inter-linkages is robust and comprehensive. It is useful:

- to refine and adjust individuals FMEA;
- to assess interdependencies, as moving from sectors to assets and networks provides a better ground for analysing the influences of networks on one another.

After compiling the FMEA data, it is possible to determine the most important failure modes of the systems, their causes and their effects. This powerful methodology, briefly sketched here, has been used successfully to produce network failure scenarios.

Analysis of FMEA inter linkages is a long process which needs dedicated resources and intense capacity building. Given the number of possible combinations, an automated approach is needed to analyse all of these scenarios - software is available.

Organisational settings, a collaborative approach

An alternative to the computer-based FMEA coupling analysis has been tested in Paris over the past two years to prepare the city to flooding.

The individual FMEAs can be analysed by the asset operators themselves. In that framework, urban service managers and operators gathered regularly (every 2/3 month) and exchanged about the protection of their assets and emergency plans.

If this option is less intense in terms of resources, the difficulties should not be underestimated. The collaborative learning curve starts by the identification of weaknesses, some of which might be important. Relevant operators and municipal services can be reluctant to cooperate at the beginning of the process. Most operators are not willing to provide detailed data, because of security (fear of terrorism or sabotage) or economic competition.

However, with time, this approach is also rewarding: in Paris, all the emergency plans prepared by the operators had to be modified to take into account unforeseen dependencies (Toubin et al., 2014). This experiment has proven to be successful and the club is still gathering today independently of the incubating structure, despite a lukewarm start.

This organizational approach appears as the most efficient and cost effective today to identify interdependencies and build long term coordination capacity.

4.4 Bogotá

The policy document selected for this analysis is the Structure Plan of the City of Bogotá, POT Act 364 (SDP 2013). This document was chosen because of its legal relevance and scope; it is essential for the development of the city and its implementation is mandatory.

Colombia is a country that has usually been very aware of environmental conditions over the centuries, due to its natural exposure to earthquakes, floods and landslides (SDP 2013). Initially environmental concerns might appear to be due to the occurrence of natural environmental hazards rather than as a consequence of awareness of the effects of climate change. But the introduction also clearly states the need to integrate risk management and adaptation to climate change in Bogotá's urban policy, requiring modifications of the previous plan to "integrate risk management and adaptation to climate change to land use, incorporating purposes of the Law 1523 of 2012" (SDP 2013, p. 25). The main resilience characteristic of the plan is that it considers the interaction and interdependency of all structures from natural to the built environment as a whole. The plan is based on the overlapping of strategic interdependent structures: the main ecological structure, functional structure of services and social structure. The social structure consists of economic and spatial dimensions.

The Structure Plan of Bogotá has an entire chapter dedicated to risk management and climate change, chapter IV. This chapter has five sections that contain principles, definitions and determinants of risk management for climate change (section 1). Among the definitions there are threats, vulnerability, and vulnerability to climate change, risk of climate change to public assets, climate change, resilience and resilient territories. The district system of risk management (section 2), decisions on land use associated with risk conditions (section 3), guidelines for safe and sustainable urban planning and construction (section 4) and the instruments and mechanisms for risk management and mitigation and adaptation to climate change (section 5) are considered in this chapter. Though a large range of resilience dimensions are included in the plan, the approach lacks specificity. The effectiveness of the plan will highly depend on the further development of projects and initiatives to achieve the general goals indicated in the plan. The most relevant question is land use and where to build and where not to. This also links to the urban densification agenda and the protection of existing flood plains. The weakness is that most of the steps necessary to carry out the goals in the plan are not embedded in the plan, nor referred to.

Urban areas, proposals and definitions are mentioned throughout the whole plan but despite the abundant graphic material, urban areas are not described in detail. The maps present the whole district but not specific urban areas. Specific impacts of climate change are described in general. Costs are mentioned and their relevance is clear in the plan but no detailed cost assessment of vulnerability is found in the plan, nor is there any reference to where these may be found elsewhere. There are sections dedicated to risk management and climate change (part I, chapter VI: 'Section 1. Principles, definitions and determinants of risk management', p.111) and mechanisms of evaluation of the structure plan (part V, chapter IV, p.459). Regarding the legal status of the plan, the Structure Plan is a legal document which contains the planning regulations, and its implementation is mandatory.

Flood risk, forest fire, social impact assessments among many other technical assessments related to climate change adaptation are mentioned and included in the plan. No clear methodology for assessment is presented (what is precisely assessed, how it is assessed and what is the aim of the assessment) because of the complexity of such assessment. Specific risk plans are developed for each type of assessment such as the District Management Risk Plan of Wildfires and General District Management Risk Plan. In part VI, chapter I, there is a list of documents that are part of the Structure Plan.

The document 'Monitoring and evaluation of the results regarding the achievement of the goals outlined in the Structure Plan adopted by Decree 190 of 2004' (SDP 2013, p. 466), which is part of the plan, contains a thorough description of the indicators which constitute the assessment of the plan (SDP 2012). These indicators assess equality, productivity and sustainability. The document contains a series of lists with the goals and the achieved results for each of the areas of interest, and the percentage of the achievements related to the total expected (SDP 2012, p. 18). Detailed simulations of urban climate and environment are not included in the Structure Plan of Bogotá. However, the Regional Plan for Climate Change for Bogotá Capital Region – Cundinamarca – PRICC is cited as the source for finding information on simulations. This plan is the main source of information for decision-making related to climate change in the Bogotá – Cundinamarca region.

4.5 Hyderabad

Hyderabad is one of the emerging large cities in India and there is tremendous effort by various institutions to make the rapid population and economic growth of the city more resilient in terms of disaster risks and climate change. The documents selected for the analysis of resilience in terms of climate change for the city of Hyderabad are: (i) Mainstreaming Climate Change Adaptation and Disaster Risk Reduction Into District Level Development Plans, Training Module; (ii) Critical Infrastructures and Disaster Risk Reduction (in the Context of Natural Hazards), Training Module; (iii) Revised Development Plan (Master Plan) of erstwhile Municipal Corporation of Hyderabad Area (HMDA Core Area) Zoning and Development Promotion Regulations. It is important to note here that the selection of these documents for analysis is not only based on their relevance in terms of legality and scale but also on which institution was responsible for drafting the policy document. The first two documents are prepared by a national institution in collaboration with international development agencies as part of a long term partnership for disaster risk reduction and climate change; whereas the Revised Development Plan is prepared solely by the local institution (Hyderabad Urban Development Authority) and approved by the Government. We compared these documents for an indication of whether local authorities are addressing these issues in the same manner as international institutions.

The primary focus of document (i) Mainstreaming Climate Change Adaptation and Disaster Risk Reduction is on the operationalization of concepts such as Climate Change Adaptation (CCA) and Disaster Risk Reduction (DRR) into local district level development plans for various departments. The document is prepared by two national institutions (National Institute of Disaster Management; Gorakhpur Environmental Action Group) and an international institution (Institute for Social and Environmental Transition, or ISET). As stated in the first few pages of the document through the message by the President of ISET, "…I see is the inadequate capacities at district and lower levels to understand, appreciate, plan and respond to them effectively as the key hurdle in operationalizing integration of climate and disaster concerns. This training manual will guide you as a trainer through a step-by-step process to address these capacity gaps" (Gupta et al. 2014, p. v).

Ensuring that policies are understood and implemented at local levels is crucial. In most developed countries, local institutions are robust and capable of ensuring implementation of policies; however this is not the case in emerging economy countries and even worse in underdeveloped countries. Hence this document is very relevant as it does not only state what is to be done but also how it is to be implemented, including how to build the capacities of the local institutions for understanding and ensuringpolicy implementation. In the specific case of Hyderabad, national institutions such as the National Institute of Disaster Management (NIDM) - one of the instiutuions involved in drafting the document - mandate the integration of DRR and CCA concerns; local authorities do not understand or have the capacity to deal with these issues. .

This document describes a step- by- step training module, specifically designed to aid local authorities with effective implementation of CCA and DRR, and addresses many of the resilient architecture and infrastructure dimensions identified in RAMSES Deliverable 2.1. The second section of the document presents a detailed description of key concepts and issues; amongst others terms such as Hazard; Vulnerability; Disaster; Disaster Risk; Risk Assessment; Disaster Management; Disaster Preparedness; Disaster Mitigation; Capacity Building; Coping Capacity; Community Based Disaster Risk Management; Sustainable Development and Resilience. The relationships between Climate Change and Disaster Risk and Development are also discussed. The next section describes the various climate change and disaster related policy documents at the national level.

The final section of the document presents a case study of Gorakhpur District in northern India with the main objectives being:

- "To understand the tools, techniques and methods adopted in Gorakhpur district for mainstreaming CCA and DRR.
- To learn the processes of mainstreaming DRR into departmental level development plans.
- To draw a strategy for mainstreaming DRR & CCA concerns at district level plans" (Gupta et al. 2014, p. 69).

Hence the document describes specific impacts and the urban area in detail, including local climate hazards such as heavy precipitation, drought, floods, storm, landslides, urban heat island effect and low rainfall. Based on the case of Gorakhpur, the document also attempts to develop a generic approach which could be replicated in other districts of India in order to integrate CCA & DRR concerns into development plans.

One of the things lacking in this document is the cost assessment for this local level capacity building process, either integrated in the document or referenced to. The proposed capacity building measures are not legally binding since this is only part of a proposed training module; neither is it integrated in checklists for project development used by city officials.

Document (ii) Critical Infrastructures and Disaster Risk Reduction has its primary emphasis on operationalization of and indicators for Critical Infrastructures (CI), i.e., “elements of the infrastructure that support essential services in a society. They include such things as transport systems, air and sea ports, electricity, water and communications systems, hospitals and health clinics, and centres for fire, police and public administration services" (UNISDR 2009, p. 8 quoted in Bach et al. 2013, p. 7). This document was prepared by the National Institution for Disaster Management (NIDM) as the above document (i), along with international development agency (GIZ German India Office).

This training module document is divided into four main parts: Learning Unit A deals with definitions of CIs, underscores the relevance of this sector and gives first examples of indicators for CI vulnerability. Learning Unit B offers a closer look at natural hazards and their specific effects on CIs. Concepts for vulnerability assessments are presented and discussed in Learning Unit C and the relevance of CI vulnerability for India in particular is brought in the perspective. Learning Unit D finally gives some examples on vulnerability reduction strategies for CIs.

Resilient architecture and infrastructure dimensions are considered and described throughout the entire document (goals and strategies). The first part of the document is about understanding various concepts within CIs specific to hazards, such as preparedness, redundancy, replicability and robustness. This section further describes the complexities of CI and as an example discusses the development of the power sector in India.

The document outlines various examples of specific impacts and urban areas in order to describe the CI sector and their vulnerabilities, with Indian as well as international cases. Cost assessment is mentioned in brief within various parts of the document; however no detailed cost assessment of vulnerability or potential measures is presented or referred to.

This is a training module developed by national and international agencies, and there is no clear indication that this document is legally binding or its implementation assessed. There is no clear discussion on the specific relevance of the document and the target audience.

The third document (iii) is the Revised Development Plan (Master Plan) of erstwhile Municipal Corporation of Hyderabad Area (HMDA Core Area) Zoning and Development Promotion Regulations. This plan is prepared by the Hyderabad Urban Development Authority (HUDA) and approved by the Government from time to time. Within the first few pages, the Plan states that "the revised Development Plan (Master Plan) for the erstwhile Municipal Corporation of Hyderabad Area (HMDA Core Area) makes provisions for anticipated population of around 6 million by year 2031 with adequate reservation for future residential zones and related amenity areas, and the Revised Development plan proposes to strike a balance between the growth of population, physical and social infrastructure, conservation of heritage and ecology and rejuvenating the core city area and to provide for efficient and effective circulation network" (HUDA 2010, p. 3).

The actual plan document, however, fails to address these issues, especially within a resilience perspective. There is no clear methodology found in this plan for the assessment of measures for resilience to climate change. The plan does not have a clear division of sections in terms of introduction, main body and conclusions.

The three documents discussed above indicate that climate change resilience in Hyderabad is being addressed by national and international level agencies rather than being locally (district level) driven. This is a key hurdle for effectively operationalising integration of climate and disaster concerns in Hyderabad. The local/district level not only lacks the capacity to deal with these crucial issues, but also has higher priority and more immediate issues to address, such as provision of housing and infrastructure, enforcing zoning regulations, etc. While including resilience dimensions into these urgent provisions appears to be the most effective manner in which to advance this topic, the potential integration of climate and disaster concerns within the Revised Development Plan is not mentioned. The key to effective operationalisation of any plan emphasising integration of climate and disaster concerns is to build capacities at district and lower levels to understand, appreciate, plan and respond to the proposed strategies, as discussed within document (i). The strategies should be flexible and adapt to the given context, avoiding ‘one size fits all’ procedures.

4.6 Greater London

*4.6.1 **Background***

Greater London is the capital of the United Kingdom (UK), with a population of about 8.5 million inhabitants (GLA 2014c), located on the Thames river in the Southeast of the UK. It represents a large administrative area (1600 km^2), and is itself comprised of 33 smaller subdivisions (32 boroughs and the City of London). Greater London is part of a metropolitan region with a population of between 14 and 22 million, depending on its definition.

Considering the multifaceted nature of climate change hazards and potential impacts, adaptation inherently involves a tremendous amount of overlap between different policies, laws, and regulations, implemented by different political and social entities at a myriad of scales. London itself is expected to follow the laws and regulations of not only the UK, but also EU policy, as well as global treaties.

Working top-down from global to local, the collection of potentially applicable regulations, policies, and guidance on climate change resilience relevant to London includes:

- International treaty - Kyoto Protocol (UN 1998)
- EU strategy on adaptation to climate change (EC 2013b)
- National level (UK including England and reserved[4])
    - Planning and Compulsory Purchase Act 2004 (PCPA 2004)
    - Climate Change Act 2008 (CCA 2008)
    - Planning Act 2008 (PA 2008)
    - Localism Act 2011 (LA 2011)
    - UK Department for Environment, Food and Rural Affairs (Defra), Adapting to Climate Change Programme – adaptation objectives and actions (Defra 2013a)
    - National Planning Policy Framework (NPPF) (DCLG 2012, 2014d, 2014e)
- Greater London
    - GLA Act 2007 (GLAA 2007)
    - GLA / Mayor of London - Climate change adaptation strategy (CCAS) (GLA 2011c)/ Mitigation and energy strategy (CCMES) (GLA 2011a)
    - UK CCRA – UK Climate Change Risk Assessment - Specific to London (LCCP 2012)
    - The London Plan: Spatial Development Strategy for Greater (as amended) (GLA 2011d, 2013)
- Boroughs
    - Implementation through local plans, strategies, and policies (33 boroughs)

While these policies apply to or affect climate change adaptation in general, some hazards have been deemed worthwhile of having their own policy approaches. Flooding is one of these hazards.

The EU Floods Directive (EU 2007/60/EC 2007) requires all EU countries to take a common approach to flood risk management (all flood types: river, lakes, flash floods, urban floods, coastal floods, including storm surges and tsunamis). This includes preparing:

- Preliminary Flood Risk Assessments published December 2011
- Flood hazard maps and flood risk maps by December 2013
- Flood risk management plans must be drawn up for mapped zones by December 2015.

UK Flood policy then consists of a set of rules specific to the UK, as well the UK interpretation and implementation of higher level EU flood policy (HMG 2014; EC 2014a). The Floods Directive is transposed into English law through the Flood Risk Regulations 2009, which complement the Flood and Water Management Act 2010.

- EU Policy - Floods Directive 2007 (EU 2007/60/EC 2007)
- National Risk Assessment
    - Flood Risk (EA 2009)
    - Climate Change Risk Assessment: Floods and Coastal Erosion (Defra 2012; Ramsbottom, Sayers & Panzeri 2012)
- National Policy
    - Flood Risk Regulations 2009 (FRR 2009)
    - National Flood Emergency Framework for England (Defra 2013c)
    - Flood and Water Management Act 2010 (FWMA 2010)

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[4] "Climate adaptation policy is a devolved matter. Scotland, Wales and Northern Ireland have established their own adaptation programmes while Defra leads for adaptation policy in England and UK reserved matters. The UK Administrations are committed to working closely together to share best practice and develop UK wide initiatives where appropriate" (DECC 2013, p. 171).

    - National flood and coastal erosion risk management strategy (EA 2012b)
    - National Planning Policy Framework (NPPF) (DCLG 2012, 2014d, 2014e)
- London Risk Assessment
    - London Regional Flood Risk Appraisal (GLA 2009)
- London Policy
    - Thames Estuary 2100 Plan (EA 2012a)
    - London Strategic Flood Framework (GLA 2012)
- Borough Risk Assessments and Policies

From this collection of documents, two planning documents were chosen for analysis from the regional level, and then each borough plan was assessed for compliance with higher level policy goals and requirements.

The translation of higher level climate change policies and guidance to a city-level climate change adaptation strategy for Greater London falls upon the Mayor of London and the Greater London Authority (GLA). The GLA Act (GLAA 2007) charged the Mayor with a 'climate change duty', requiring an assessment of potential climate change impacts on London – along with preparation of a Climate Change Adaptation Strategy (CCAS) outlining how stakeholders will work together to manage the impacts. All subsequent GLA plans and strategies are required to consider adaptation and mitigation (GLA 2011c, p. 19).

The CCAS is the first document selected and analysed.

The National Planning Policy Framework (NPPF) (DCLG 2012) represents the top-level of UK planning policy. Regional policies must adhere to the requirements of the NPPF. The London Plan (GLA 2011d) is the regional application of the NPPF, setting out the policy guidelines for Greater London.

The London Plan is the second document selected and analysed.

The London Plan is not only a planning policy document for Greater London, but it is also represents the authoritative document responsible for ensuring that the planning policies of the 33 boroughs are in line with both the NPPF and the CCAS. Each borough is responsible for developing its own 'Local Plan' outlining local planning policy.

The local plans of all 33 boroughs were analysed to assess their respective CCAS.

4.6.2 Managing risks and increasing resilience: The Mayor's CCAS

The Mayor's climate change adaptation strategy (CCAS) 'Managing risks and increasing resilience' is an informal strategy document which sets out the basic framework for London's adaptive responses, with a specific focus on three key climate risks, flooding, drought, and overheating:

1. Analyses current vulnerability - establishes a risk baseline to assess change.
2. Identifies how climate change may affect risk baseline.
3. Prioritises key climate risks and opportunities.
4. Provides a framework that:
    a. identifies the appropriate scale for response
    b. identifies GLA action space
    c. identifies other stakeholders action space
    d. facilitates action
    e. identifies and prioritises gaps in climate and risk knowledge.
5. Establishes a strategy for future climate change adaptation.
6. Highlights climate change opportunities.
7. Demonstrates how London can set an international example (GLA 2011c, p. 20).

The six reasons for adaptation highlighted in the CCAS display a thorough understanding of the issues climate change may bring to London:

1. Not adapted to current climate.
2. Climate is already changing - further changes are unavoidable.

3. Urban areas are particularly vulnerable.
4. Proactive action is cheaper and more effective than reaction.
5. Adaptation can provide co-benefits.
6. Some complex actions require cooperation at different scales (GLA 2011c, p. 18–19).

The CCAS notes that the GLA is not solely responsible for (or capable of) making the actual adaptation responses that will be necessary: "the Mayor has only limited powers to implement the measures necessary to prepare London for the range of impacts and opportunities presented by climate change" (GLA 2011c, p. 20). Cooperation between agencies is required to ensure implementation of adaptation measures, as many "are beyond the Mayor’s direct control, but … have strategic implications for London" (GLA 2011c, p. 20). Much of this responsibility falls on other stakeholders, both in the private sector (in the case of privatised infrastructure), or lower down the governmental hierarchy. In the case of London, these are the 33 boroughs that comprise greater London.

The CCAS takes a risk-based approach to the threat of climate change impacts and the need for adaptation:

> Climate change risk = probability x consequence (determined by exposure[5] & adaptive capacity) (GLA 2011c, p. 20).

Risk management is used to address the gap between "what society is able, or prepared, to cope with and the increased risk of a future impact" (GLA 2011c, p. 22). The CCAS addresses this gap between acceptable and unacceptable levels of risk (the ‘adaptation gap’), with successive applications of adaptation measures and actions applied to reduce risk. Figure 1 shows a diagrammatic representation of this risk management approach, using the example of surface water flooding. Four steps, or options, are shown to address the surface flooding adaptation gap:

1. Increase the capacity of the drainage system
2. reduce the amount of rainwater entering the drainage system through absorption and retention of rainfall
3. Improve the maintenance of drainage systems (restore full capacity)
4. Accept more frequent and intensive flooding (GLA 2011c, p. 20).

[5] Elsewhere in the document “exposure” is replaced by “vulnerability”.

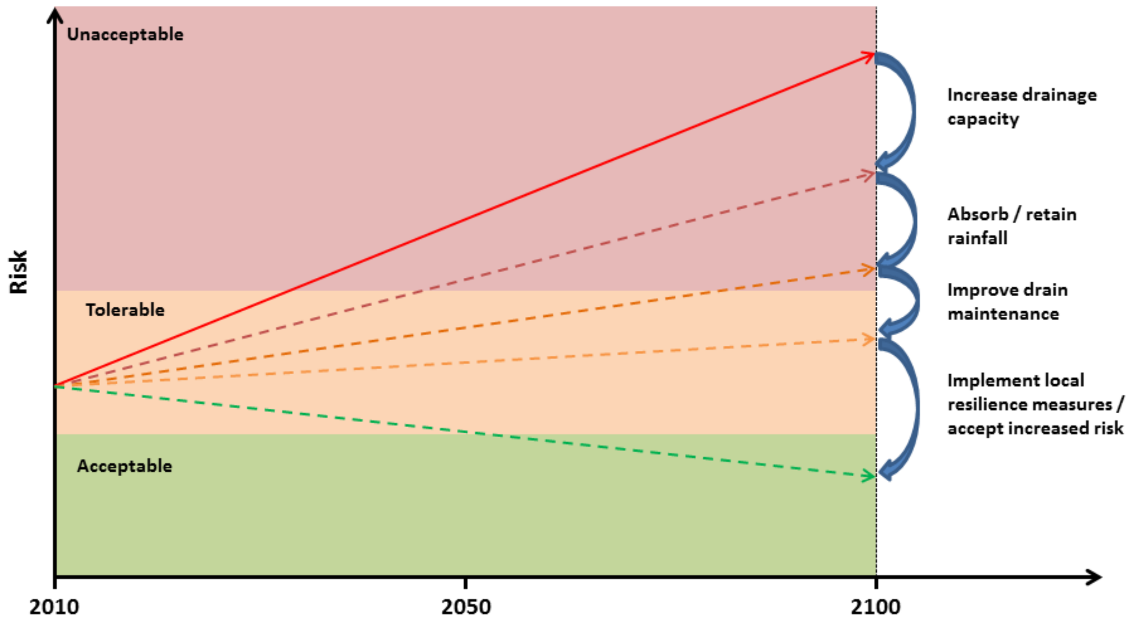

Figure 18: GLA approach to risk management (GLA 2011c)

The CCAS contains a limited number of policies and actions, as "adapting to climate change is not about drafting lots of new policies" (GLA 2011c, p. 21). The CCAS is intended mainly as a strategic document that will act to mobilize actions from the necessary stakeholders. It appears to fall upon the regional and local authorities to implement this strategy into actionable policy.

4.6.3 The London Plan: Spatial Development Strategy for Greater London

The London Plan is in a constant state of amendment, revision, and updating. The "Revised Early Minor Alterations to the London Plan (REMA)" were included in this analysis - as of 13 October 2013, they "are operative as formal alterations to the London Plan" (GLA 2013, 2014d). Drafts that have not yet passed review, such as the "Draft Further Alterations to the London Plan" were not included (GLA 2014a, 2014b). The London Plan is "the strategic, London-wide policy context within which boroughs should set their detailed local planning policies" (GLA 2011d, p. 10).

The London Plan is first and foremost a spatial strategy document for Greater London. While it contains policies spanning a wide range of topics relevant to climate change adaptation – e.g. energy, buildings, green space – there are a wide range of other planning documents, regulations, standards, and guidance that may overlap, complement, or contradict the London Plan. An enlightening visualisation of the fragmentation and overlap in current planning policy is found in the DCLG housing standards review document (Figure 2) (DCLG 2014c, p. 7). One of the current policy goals is to "simplify and rationalise" - stepping from this fragmented and confusing system (as now) to a more streamlined collection of approaches, and finally of providing a single, unified system (stage 2) (DCLG 2014c, p. 12).

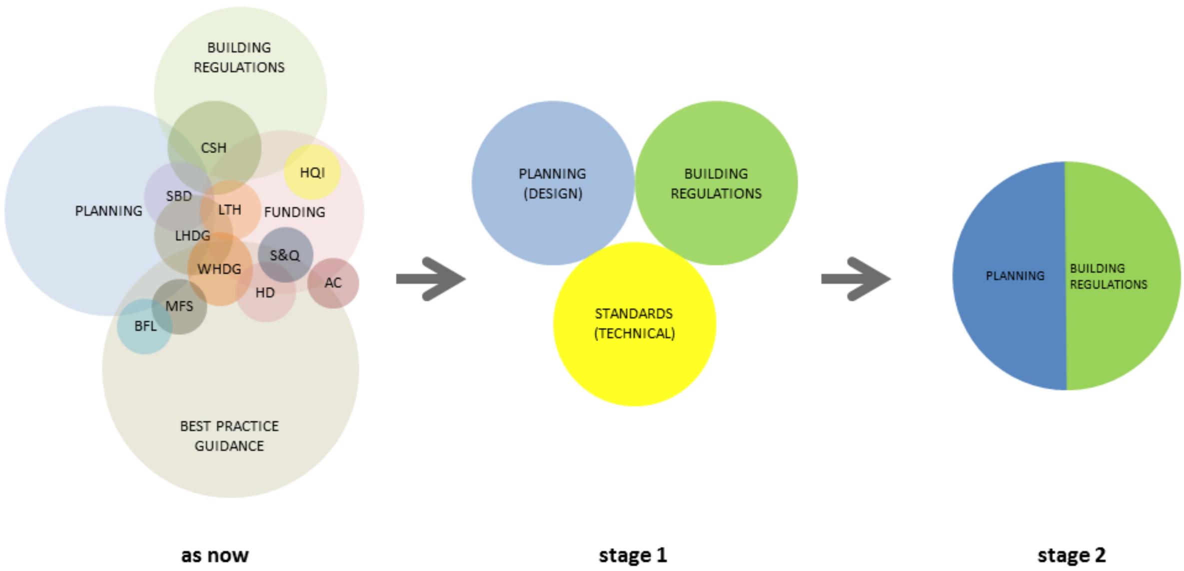

Figure 19: Fragmentation in the planning process (DCLG 2014c)

The policies promoted in the London Plan can be divided into three groups:

- Strategy: Represent statements of Mayoral strategic policy, (providing the context for all other London Plan policies
- Planning: Policies that will be applied by planning authorities regarding planning applications
- Framework preparation: Policy advice to direct boroughs in their local development framework (LDF) or Local Plan preparation (what the NPPF terms "local plans") in two categories:
    - o Flexibility: allowing authorities to consider how their circumstances differ London overall.
    - o Focus: Areas where specific local conditions necessitate a more in-depth analysis to determine policies. (GLA 2011d, 2013)

The London Plan includes a successive approach to a number of climate change related topics, described as hierarchies. Within these hierarchies, the requirement generally exists to either complete each step before moving to the next, or to prioritize the earlier steps.

London Plan energy hierarchy:

1. Lean: reduce energy demand and consumption
2. Clean: supply energy efficiently
3. Green: use renewable energy (GLA 2011d)

London Plan decentralised energy (DE) hierarchy (target of 25% of heat & power through local DE by 2025:

1. Connect to existing DE networks
2. Site wide Combined Heat and Power (CHP) network
3. Communal heating and cooling (GLA 2011d, p. 148).

London Plan cooling hierarchy:

1. "Minimise internal heat generation through energy efficient design
2. Reduce the amount of heat entering a building in summer through orientation, shading, albedo, fenestration, insulation and green roofs and walls
3. Manage the heat within the building through exposed internal thermal mass and high ceilings
4. Passive ventilation
5. Mechanical ventilation" (GLA 2011d, p. 151).

London Plan drainage hierarchy:

1. "Store rainwater for later use
2. Use infiltration techniques, such as porous surfaces in non-clay areas
3. Attenuate rainwater in ponds or open water features for gradual release
4. Attenuate rainwater by storing in tanks or sealed water features for gradual release
5. Discharge rainwater direct to a watercourse
6. Discharge rainwater to a surface water sewer/drain
7. Discharge rainwater to the combined sewer" (GLA 2011d, p. 155).

Co-benefits of urban greening: "green roofs and walls …to deliver as many of the following objectives as possible:

1. adaptation to climate change (ie aiding cooling)
2. sustainable urban drainage
3. mitigation of climate change (ie aiding energy efficiency)
4. enhancement of biodiversity
5. accessible roof space
6. improvements to appearance and resilience of the building
7. growing food" (GLA 2011d, p. 153).

Flooding resilience: "Development adjacent to flood defences will be required to protect the integrity of existing flood defences" (GLA 2011d, p. 154).

Developments with flood risk "will need to address flood resilient design and emergency planning by demonstrating that:

1. the development will remain safe and operational under flood conditions
2. a strategy of either safe evacuation and/or safely remaining in the building is followed under flood conditions
3. key services including electricity, water etc. will continue to be provided under flood conditions
4. buildings are designed for quick recovery following a flood" (GLA 2013, p. 22–23)

Costs and benefits are not directly addressed in the London Plan, as there is a continually updated portfolio of support documents that fulfil this role: e.g DCLG 2014a, 2014b, 2014c; Defra 2013a, 2013b; GLA 2010, 2011b; LCCP 2009, 2014; Metroeconomica 2004a, 2004b; Stern 2006; UKCIP 2002; URS 2010.

4.6.4 The Local Plans: The 33 Boroughs of Greater London

A myriad of policies affecting the interactions between UK planning policy, regional planning policy (Greater London), and local policy (the 33 boroughs) have been enacted in the past 10 years, yielding a situation where higher policy is changing at a much faster rate than the local authorities are responding. Planning policy in Greater London has been moving much faster than most individual boroughs, leading to many Local Plans and Policies referencing outdated and withdrawn (Greater London) documents and policies. An example from one borough regarding their development of a Climate Change Adaptation Plan:

> The Council reached Level 2 in the agreed timescale. However, the indicator NI188 has subsequently been abolished (Wandsworth 2010, p. 14).

The Local Plan is the "plan for the future development of the local area, drawn up by the local planning authority in consultation with the community" consisting of the "development plan documents adopted under the Planning and Compulsory Purchase Act (PCPA) 2004" including core strategies, other planning policies considered to be development plan documents, as well as "old policies which have been saved under the 2004 Act" (DCLG 2012, p. 53).

Local Plans represent "the heart of the planning system", so they must be "in place" and "up to date" (DCLG 2014e). They "set out a vision and a framework for the future development of the area" and are "a basis for safeguarding the environment, adapting to climate change and securing good design" (DCLG 2014e).

> The Local Plan should make clear **what** is intended to happen in the area over the life of the plan, **where** and **when** this will occur and **how** it will be delivered (DCLG 2014e emphasis in original).

The PCPA 2004 required borough planning authorities to replace the old portfolio of planning documents, the Unitary Development Plan (UDP), with a new Local Development Scheme (LDS) consisting of Local Development Documents (LDD) (PCPA 2004). This policy was explained in a (since withdrawn) policy statement which introduced another term: Local Development Framework (LDF) (DCLG 2004). The LDF was intended to comprise the entire portfolio of necessary planning documents, including the LDS and Core Strategy (CS), as well as a Proposals Map, community consultation documents, other Development Plan Documents (DPDs) and Supplementary Planning Documents (SPD) (DCLG 2004).

The actual development plan then consists of the Regional Spatial Strategy (RSS) covering the region (in London this is the Spatial Development Strategy (SDS) – "the London Plan") and Development Plan Documents (DPD) produced by local planning authorities within their Local Development Framework (LDF)LDF (DCLG 2008). The Core Strategy (CS) is the principal Development Plan Document (DPD) (DCLG 2008).

"The Greater London Authority Act (GLAA) 2007 widened the Mayor's powers to deal with strategic planning applications and gave him responsibility for a number of new statutory strategies. The Localism Act (LA) 2011 abolished the London Development Agency and transferred land and housing responsibilities to the Mayor" (GLA 2013, p. 5).

The Planning Act 2008 amended the PCPA 2004 to reference Development Plan Documents (DPDs) as a specific type of planning document (PA 2008, p. 97). The Planning Act 2008 also amended the PCPA 2004 to include requirements for regional and local planning authorities to address climate change mitigation and adaptation:

> The RSS [Regional Spatial Strategy] must include policies designed to secure that the development and use of land in the region contribute to the mitigation of, and adaptation to, climate change (PA 2008, p. 98)
>
> Development plan documents must (taken as a whole) include policies designed to secure that the development and use of land in the local planning authority's area contribute to the mitigation of, and adaptation to, climate change (PA 2008, p. 98)

The PCPA 2004 allowed Unitary Development Plan (UDP) policies to remain in effect for a period of three years, which expired in 2009. The LDF was in turn superseded by reference to the Local Plan in the National Planning Policy Framework (NPPF) in 2012 (DCLG 2012, 2014e), though the recent revision to the London Plan considers the LDF and Local Plan to be equivalent (GLA 2011d, 2013).

Local Plans are required by the National Planning Policy Framework (NPPF), a planning document that maintains a "presumption in favour of sustainable development, which should be seen as a golden thread running through both plan-making and decision-taking" (DCLG 2012, p. 4). Local Plans are expected to consider climate change "over the longer term, including factors such as flood risk, coastal change, water supply and changes to biodiversity and landscape" (DCLG 2012, p. 23).

Of the 33 boroughs, there is a wide variability in the approach to developing and presenting a Local Plan. Some do not have a Local Plan that is 'in place' or 'up to date' at all. Other boroughs have excellently researched and extensive documents with separate Climate Change Adaptation Plans. Some boroughs have websites that are easily navigated, with relevant documents in place and readily accessible, while others do not seem to be supportive of online access to documents and policies (albeit this is subjective and hard to document).

While the Local Plan is intended to include specific details about the policies that are expected to be implemented, in many cases only vague aspirational wording (encourages, expects, should) is included instead of authoritative or binding phrasing (shall, will, requires).

4.6.5 Discussion

Overall, the UK appears to have a solid and well-informed strategy to address the threat of climate change. The UK Climate Change Act of 2008 requires mitigation efforts, including an 80% reduction from 1990 emissions by 2050 (§1), as well as identification and reporting of climate change risks and impacts (§56-57), development of an adaptation program (§ 58), and adaptation reporting protocol (s. 59) (CCA 2008).

London itself has a sound strategy in the form of published mitigation and adaptation plans, and translation into planning policy. There are a myriad of policies in place addressing climate change, which followed a logical framework in their development and implementation:

1. The evidence base for climate change
2. Realized and forecasted changes to historical patterns
3. Current and expected future risks from changes
4. Adaptation and resilience policy approaches and responses.

Whether these policies transform into physical actions remains unknown. Whether those actions then result in successful adaptation is difficult to assess. Successful adaptation comprises a reduction in risk and increased resilience to an uncertain event, from an undetermined baseline. As such, successful adaptation generally relies on assessing counterfactuals (what would have happened otherwise cannot be observed in order to be proven or disproven) - unsuccessful adaptation will be easier to assess.

It remains unclear whether many of the boroughs are able to perform the tasks they have been assigned. Regarding floods policy, the Mayor of London noted that the boroughs:

> …have the responsibility for mapping and managing surface water flood risk. There is significant concern that most boroughs do not have the skills to meet this challenge (GLA 2011c, p. 31).

It will also be difficult to assess the success or failure of London's adaptation scheme considering the fragmented application of policies across the 33 interconnected and interdependent boroughs. Compounding the problem is the variability in demographic and topographic factors in affecting the risk and response to climate change hazards.

4.7 New York City

4.7.1 Background

New York City (NYC) is the most populous city in the United States (US), with a population of about 8.5 million inhabitants (DCP 2014b), located on the Atlantic coast in New York State in the Eastern US. It represents a large administrative area (790 km^2), and is itself comprised of 5 smaller subdivisions known as boroughs (Manhattan, Brooklyn, Queens, the Bronx, and Staten Island) (DCP 2014a). New York's metropolitan region includes about 21 million inhabitants.

NYC published its first long-term sustainability plan (PlaNYC) report *A Greener, Greater New York,* including climate change mitigation and adaptation, in 2007. This report represented an ambitious effort to address climate change mitigation and adaptation in New York City, while enhancing the quality of life of its inhabitants.

NYC then convened the New York City Panel on Climate Change (NPCC) to work with the NYC Office of Long Term Planning and Sustainability (OLTPS), and the NYC Climate Change Adaptation Task Force to address the risks of a changing climate on NYC and develop a protocol for adaptation. The NPCC 2010 report *Climate Change Adaptation in New York City: Building a Risk Management Response* produced a number of key findings (NPCC 2010):

1. New York City should begin to adapt to climate change today
2. New York City already faces a number of climate risks without climate change as a factor

3. Temperature increases and sea level rise are already occurring and, along with other climate changes, will continue to occur and accelerate in the future
4. There is a potential for "tipping points" in the climate system, such as a rapid melt of polar ice sheets, which would have a great magnitude of consequence on the city
5. To effectively respond to climate change, the city should develop Flexible Adaptation Pathways (Rosenzweig & Solecki 2010, p. 143–144)

Before many of the recommendations could be implemented, in October of 2012, Hurricane Sandy hit New York City, leaving a trail of destruction in its wake. As a response, the most recent PlaNYC report *A Stronger*, *More Resilient New York* draws heavily upon the lessons learned from Hurricane Sandy. Much of the damage, destruction and economic loss from Sandy was caused by a larger than predicted storm surge, which caused widespread flooding and damage to buildings, as well as cascading effects to many systems, especially utilities and transportation.

4.7.2 ***PlaNYC: A Stronger, More Resilient New York***

While there are many documents produced in support of adaptation in NYC, only the PlaNYC report represents a policy document putting forth a mandate and strategy. The PlaNYC report draws upon and integrates other documents in its analysis, and yields an overall strategy, as well as changes to codes, regulations, and policy.

For this reason, *PlaNYC: A Stronger, More Resilient New York* is the only document selected and analysed.

PlaNYC is first and foremost a strategy document, and as such does not constitute code, standards, or law. The report outlines the strength and resiliency plan across the above-mentioned systems, introduces a set of strategies and initiatives, and notes the stakeholders, actors, and regulatory agencies responsible for its implementation. Many of the report's initiatives have already been implemented (22 completed and 202 in progress) (NYC 2014b). Most notably, PlaNYC convened the Building Resiliency Task Force (BRTF), an "expert panel of engineers, architects, developers, and property owners, along with representatives of City government" (NYC 2013, p. 73), charged with undertaking a comprehensive review of current code standards and proposing changes. BRTF has a website tracking all proposals and their status toward being converted into codes, standards, and laws. Proposals include not only new codes, but upgrades to existing codes as well of revision of existing codes to "remove barriers" to resiliency. As of October 2014, 29 proposals have been made, and 16 successfully implemented (BRTF 2014).

PlaNYC makes it clear that complete protection against all foreseeable events is impossible, and presents strength and resilience as dual goals:

> re•sil•ient [ri-zil-yuhnt] adj.
>
> 1. Able to bounce back after change or adversity.
>
> 2. Capable of preparing for, responding to, and recovering from difficult conditions.
>
> Syn.: TOUGH
>
> See also: New York City (NYC 2013, p. i)

Following Sandy, New York has decided that coastal "retreat" is simply not possible, due to the density and quantity of built space occupying the waterfront, which "simply cannot be picked up and relocated elsewhere" (NYC 2013, p. 236). New York proposes resilience through a "mix of defenses, built up in layers—defenses at the coastal level, at the building level, and at the infrastructure level" (NYC 2013, p. 236).

Hurricane Sandy is used throughout the report as an example of what is to be expected from climate change. The effects of the storm on various systems are examined, failures and successes are noted, and plans are considered for addressing risks, reducing vulnerabilities, and making New York more resilient.

PlaNYC considers the potential impacts of climate change on the following systems:

- Coastline and Waterfront Infrastructure
- Buildings
- Insurance
- Utilities
- Liquid Fuels
- Healthcare
- Community Preparedness and Response
- Telecommunications
- Transportation
- Parks
- Environmental Protection and Remediation
- Water and Wastewater
- Other Critical Networks (Food Supply & Solid Waste)

A Risk Assessment is presented for each system, addressing gradual and extreme hazards from climate change, and the potential impacts over time. PlaNYC subcategorizes climate change induced hazards:

1. Gradual
    a. Sea level rise
    b. Increased precipitation
    c. Higher average temperature
2. Extreme Events
    a. Storm surge
    b. Heavy downpour
    c. Heat wave
    d. High winds

Strategies, measures, and initiatives are then presented to address these risks. The issue of overlapping, fragmented, and/or competing/contradictory regulatory fields is addressed and specific initiatives are developed with targeted implementation by specific stakeholders.

Resilience characteristics are pervasive within the different strategies for each considered system. Some highlights of approaches and initiatives presented for four systems (Coastal, Buildings, Utilities, and Transportation) are highlighted below.

Coastline and Waterfront Infrastructure

The regulatory framework for the coastline necessitates collaboration between "over a dozen City, State, and Federal agencies [that] play a role in regulating New York City's waterfront and many waterways. In some cases, efforts by these agencies are not completely aligned. This lack of unified and coordinated regulatory oversight can lead to delayed and unpredictable waterfront activity, complicating the achievement of important public goals, including coastal resiliency" (NYC 2013, p. 41). Coastal protection initiatives especially involve intensive cooperation with the US Army Corps of Engineers (USACE) (NYC 2013, p. 58–65).

A set of strategies is developed for different areas depending on hazard, geomorphology, and land use. Each strategy has affiliated measures (or clusters of measures) recommended to address the strategy, as well as associated (more specific) initiatives, with lead agencies. Strategies, measures, and initiatives are developed depending on the best approach considering a host of variables specific to each area. This included modelled risk and cost effectiveness, as well as public considerations ("waterfront access, navigation impacts, recreational benefits, environmental impact, contribution to ecosystem restoration, social and environmental justice, and impact on neighborhood character and quality of life for residents and businesses") (NYC 2013, p. 50).

Coastal flooding – Strategies and Measures (NYC 2013, p. 50–56)

1. Increase Coastal Edge Elevations (10 initiatives
    a. Beach Nourishment)
    b. Armor Stone (Revetments)

    c. Bulkheads
    d. Tide Gates / Drainage Devices
2. Minimize Upland Wave Zones (9 initiatives)
    a. Dunes
    b. Offshore Breakwaters
    c. Wetlands, Living Shorelines and Reefs
    d. Groins
3. Protect Against Storm Surge (10 initiatives)
    a. Integrated Flood Protection System
    b. Floodwalls / Levees
    c. Local Storm Surge Barrier
    d. Multi-purpose Levee
4. Improve coastal design and governance (11 initiatives)

Buildings

Much of the initial damage from Hurricane Sandy's storm surge and subsequent flooding occurred in buildings. PlaNYC notes that it is "…important to supplement coastal protection measures by pursuing resiliency at the building level, offering multiple approaches to protect a wide range of the city's structures against the full spectrum of climate risks"…"to reduce the impacts of climate change, while also enabling the city to bounce back quickly when such impacts are felt" (NYC 2013, p. 69).

PlaNYC's approach to building flooding is a direct result of assessments made after hurricane Sandy, which showed that storm surge and wave action was responsible for 97% of extensively damaged or destroyed buildings, while inundation flooding was responsible for the majority of non-structural damages (NYC 2013, p. 75)

Three approaches to building categorization are used, based on different attributes affecting resiliency:

- Physical characteristics (height, construction type, proximity to other structures)
- Building use
- Building age

Though there is a diverse regulatory structure for buildings, two city agencies share primary responsibility: (NYC 2013, p. 71).

1. Department of Buildings (DOB) – construction codes and standards
2. Department of City Planning (DCP) – planning, zoning, use, density

Many of the PlaNYC recommendations, as well as "…Federal, State, and local standards are incorporated into Appendix G of the Building Code" Flood-Resistant Construction (NYC 2013, p. 72).

The flood resilience strategies applied to buildings depend on the flood risk assessed and presented spatially through the US Federal Emergency Management Agency (FEMA) Flood Insurance Rate Maps (FIRMs), with the coastal floodplains divided into subzones based on vulnerability (See Figure 20):

- A Zones: the 100-year floodplain—an area that has a 1 percent or greater chance of flooding in any given year;
- V Zones: the portion of the 100-year floodplain subject to high-velocity wave action (defined as a 3 foot or greater breaking wave);
- Coastal A Zones: the portion of the 100-year floodplain subject to breaking waves between 1.5 and 3 feet; and
- Shaded X Zones: the 500-year floodplain— an area that has a 0.2 percent or greater chance of flooding in any given year (NYC 2013, p. 45).

The 100 year floodplain, also defined as the Special Flood Hazard Area (SFHA), is the area to which floodwater is modelled to rise during the base flood (i.e. 100 year flood, or 1% annual risk flood) – the elevation of this level above sea level is the Base Flood Elevation (BFE). FEMA storm surge analyses for coastal flood studies utilize the ADCIRC (ADvanced CIRCulation) coastal circulation and storm surge computer model in conjunction with the Simulating Waves Nearshore (SWAN) computer model. The storm surge analyses result in stillwater elevations for the base flood, which does not account for all effects from waves. A separate overland wave modeling analysis is combined with the storm surge analysis to determine coastal SFHAs and BFEs (FEMA 2014).

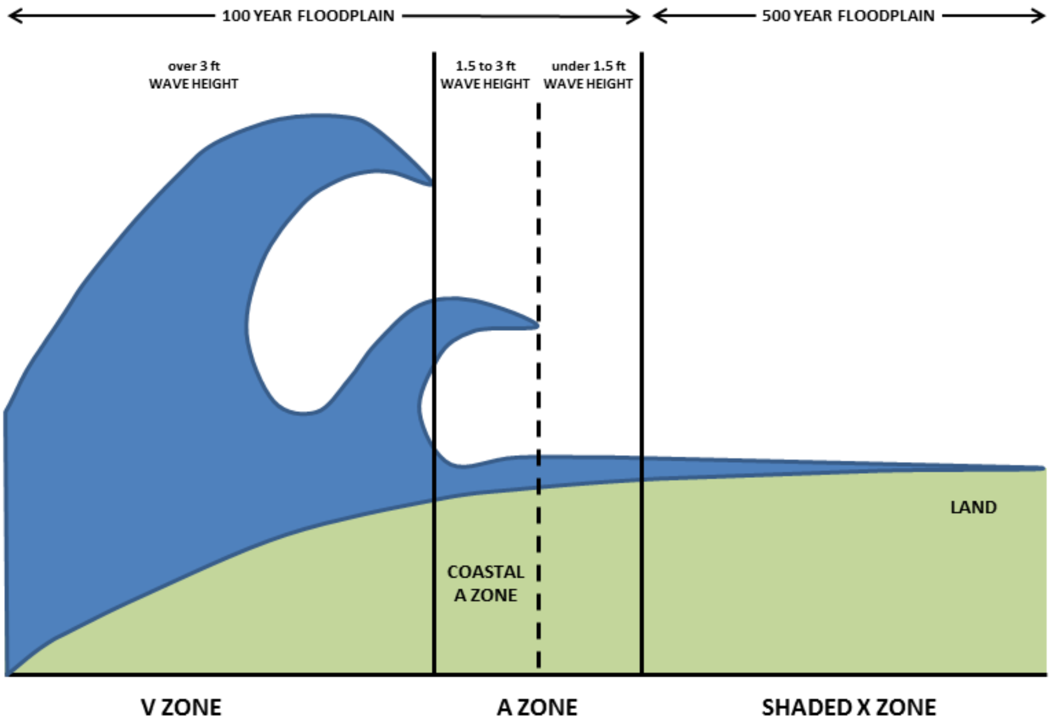

Figure 20. Floodplain zone diagram. Adapted from FEMA (NYC 2013)

NYC has instituted an approach based on adherence to the Design Flood Elevation (DFE), which consists of the BFE plus an additional incremental elevation (above BFE) known as "freeboard" to which a building must be flood-protected, to account for uncertainties and future sea level rise (NYC 2013).

Flood design approaches in PlaNYC include:

- Dry flood proofing – watertight structure (flood shielding)
- Wet flood proofing - allows floodwaters to enter and leave a structure through openings or vents, preventing structural failure (flood venting)
- Elevated structure – structure elevated above DFE (including nonstructural lattice or breakaway walls)

Areas below the DFE have restricted uses depending on zone category and the approach to flood proofing (dry, wet, elevated) – but residential use is not permitted below DFE in any case.

As part of its strategy to strengthen and increase the resilience of the existing building stock through retrofits, PlaNYC introduces a set of Core Flood Resiliency Measures (retrofit requirements which apply to buildings with 7+ stories and 300,000 ft^2 by 2030) (NYC 2013), as well as amendments to current construction codes to protect against utility service interruptions:

- Potable water access in high-rise multi-family buildings
- Exit lighting function during extended blackouts
- Alternative fuel sources and cogeneration systems for emergency power, including solar
- Strategies to limit heating and cooling losses through walls, windows, and roofs.

Utilities

The New York State Public Service Commission (PSC) uses quantitative metrics to assess utility performance:

- System Average Interruption Frequency Index (SAIFI) - average number of interruptions per customer per year
- Customer Average Interruption Duration Index (CAIDI) - average length of each interruption (NYC 2013).

Electricity network and system shutdowns and outages from Hurricane Sandy were caused by:

- Overhead distribution damage
- Transmission System Overload
- Flooded Transmission Substation
- Flooded Area Substation
- Preemptive Shutdown
- Customer equipment flooding (NYC 2013)

PlaNYC notes some of the tradeoffs inherent to utility provision decisions: "…underground network systems are quite robust, suffering outages less frequently than typical above-ground systems – but when outages do occur, they can take longer to address and repair than overhead disruptions" (NYC 2013, p. 111).

PlaNYC also notes some resilience success stories through diversity and redundancy: "…amidst the widespread electric outages, there were some [hospitals and university buildings that] performed well on either backup generators or CHP systems" (NYC 2013, p. 117).

Implementation of resiliency requires an assessment of the criticality of infrastructure components, as "…not all assets need to be protected to the same standard, given that some are more vulnerable or important than others" (NYC 2013, p. 117). The Office of Long-Term Planning and Sustainability (OLTPS) is "developing a risk assessment model that takes into account storm probabilities and future surge heights, quantifying possible customer outages and economic losses, and thereby beginning to identify the system assets that should be prioritized for protection" (NYC 2013, p. 122).

The Electric Sector Storm Surge Risk Model (ESRM) "considering climate change impacts in system planning decisions" (NYC 2013, p. 122) contains three main modules (NYC 2013).

1. Storm surge module: generates inundation scenarios and probabilities for critical electric infrastructure locations in 2013, the 2020s, and the 2050s;
2. Network structure module: maps out dependencies between individual substations and networks, compares the elevations with potential surge height to determine functionality;
3. Customer module: provides a more nuanced understanding of the network's importance - including e.g. the critical customers, economic activity, and vulnerable populations.

Cost-benefit analysis will be used to prioritize resiliency investments and protection strategies in electrical substations modelled to be most responsible for customer losses (NYC 2013, p. 123).

Strategies for utility resilience

1. Redesign the regulatory framework to support resiliency
2. Harden existing infrastructure to withstand climate events
3. Reconfigure utility networks to be redundant and resilient
4. Reduce energy demand
5. Diversify customer options in case of utility outage
6. Seek to harden the liquid fuels supply infrastructure
7. Enhance the ability of the supply chain to respond to disruptions
8. Improve the City's ability to fuel first responders and private critical fleets

Transportation

The New York City transportation network comprises a myriad of different agencies managing different aspects, including the the New York City Department of Transportation (NYCDOT), the state Metropolitan Transportation Authority (MTA), and the Port Authority of New York and New Jersey (the Port Authority) (NYC 2013). The network includes the largest public transportation system in the US, comprising subway networks, bus networks, commuter rail networks, and ferry networks (NYC 2013). It carries 1/3 of all transit passengers and 2/3 of all rail passengers nationwide (NYC

2013). The road transportation network includes nearly 10,000 km of streets, 12,000 traffic signals, and almost 800 bridges (NYC 2013). Nearly all of these networks failed during Hurricane Sandy, including flooded or inundated subway, railroad, and vehicle tunnels, roads, subway stations, airports, maritime terminals, railroads and railway stations (NYC 2013). Sandy was responsible for "…$8 billion in physical damage to the region's transportation infrastructure, including $700 million in damage to NYCDOT's facilities and equipment" (NYC 2013, p. 180).

The damage caused by Hurricane Sandy also highlighted the interconnectedness of the transportation network with other networks:

> …the transportation network in the city depends on the power network to function; electricity is needed to run subways and trains, to switch on traffic signals, and to light tunnels, stations, and terminals. And, in turn, many of the city's other critical networks rely…on the transportation network to run properly; this is especially true in times of emergency…(NYC 2013, p. 175–175).

Much of the damage post-Sandy was attributed to corrosion caused by seawater, exacerbated by the length of time needed to dewater the facilities (NYC 2013). Some facilities took weeks to reopen, while at least one subway station remains closed and under repair (NYC 2013).

The transportation network presents a difficult system to adapt to climate change, especially considering the expected increase in threats over time. Much of the network is built within the 100 year floodplain, including "…12 percent of the roadway network, all of the major tunnel portals other than the Lincoln Tunnel, portions of both airports, a variety of commuter rail assets, all three heliports, and a number of subway entrances and vent structures" , principally in Lower Manhattan (NYC 2013, p. 180).

Transportation strategies:

- Protect assets to maintain system operations
- Prepare the transportation system to restore service after extreme climate events
- Implement new and expanded services to increase system flexibility and redundancy

Other systems

Beyond the four systems highlighted above, initiatives aimed at promoting and increasing resiliency are also introduced for other systems, including healthcare, telecommunications, parks, and wastewater.

Healthcare strategies:

- Ensure critical providers' operability through redundancy and the prevention of physical damage
- Reduce barriers to care during and after emergencies

Telecommunications strategies:

- Increase accountability to promote resiliency
- Enable rapid recovery after extreme weather events
- Harden facilities to reduce weather-related impacts
- Create redundancy to reduce risk of outages

Parks strategies:

- Adapt parks and expand green infrastructure to shield adjacent communities from the impacts of extreme weather events
- Retrofit or harden park facilities to withstand the impacts of climate change
- Protect wetlands, other natural areas, and the urban forest
- Develop tools for comprehensive climate adaptation planning and design

Water and Wastewater strategies:

- Protect wastewater treatment facilities from storm surge
- Improve and expand drainage infrastructure
- Promote redundancy and flexibility to ensure constant supply of high-quality water

Communities

New York proposes specific "Community Rebuilding and Resiliency Plans" for five waterfront areas that were worst hit by Sandy, through a "mix of defenses, built up in layers—defenses at the coastal level, at the building level, and at the infrastructure level" (NYC 2013, p. 236). The community plans consist of a multilayered approach that includes selected measures and initiatives from the host of citywide strategies, as well as site-specific strategies and initiatives "designed to address the area's specific needs and particular vulnerabilities" against current and expected future risks(NYC 2013, p. 255). They address risks in the following waterfront areas (NYC 2013, p. 236):

1. Brooklyn-Queens Waterfront (11 specific initiatives)
2. East and South Shores of Staten Island (12 specific initiatives)
3. South Queens (13 specific initiatives)
4. Southern Brooklyn (17 specific initiatives)
5. Southern Manhattan (9 specific initiatives)

4.7.3 Discussion

Overall, NYC appears to have a solid and well-informed approach to address the threat of climate change. The overall strategy however, as published in the PlaNYC report, is very focused on the failures of Hurricane Sandy. This type of blinkered fixation on obvious threats has been likened to "planning the last disaster" (Ewing & Synolakis 2011, p. 936). The 2010 NPCC report had a host of findings and recommendations, including not only storm surges and flooding, but the threats of heat, heat-waves, drought, and pluvial flooding (NPCC 2010).

NYC would likely be served well by following its immediate goal of recovery and adaptation from Hurricane Sandy, while at the same exploring other potential adaptation pathways. There are likely many opportunities for win-win strategies with co-benefits for other threats and hazards. Some of the strategies being implemented post-Sandy actually do likely provide these co-benefits, but few if any are made explicit in the PlaNYC report. It would be a shame to overlook the low-hanging fruit of adaptation strategies that could provide wide-ranging benefits to inhabitants while addressing more than one climate risk.

Whether the proposed and implemented policies transform into physical actions is easy to assess. NYC has a sound strategy for tracking the policy changes recommended or implemented by PlaNYC. - several online resources are available to track the state of proposals (BRTF 2014; GCTF 2014). Whether these actions result in successful adaptation is more difficult to assess. As noted above, much of the PlaNYC report has a singular focus on the failures of NYC in response to Hurricane Sandy. Successful adaptation comprises a reduction in risk and increased resilience to a host of uncertain events, from an undetermined baseline. As such, successful adaptation generally relies on assessing counterfactuals (what would have happened otherwise cannot be observed in order to be proven or disproven) - unsuccessful adaptation will be easier to assess.

NYC has taken the lead on adaptation in its boroughs, and developed plans, strategies and proposals that are not only citywide, but specific to certain areas. In this sense, NYC has a unified adaptation scheme and a cohesive application of policies across the 5 interconnected and interdependent boroughs. It only needs to widen its threat assessment to the host of possible hazards from climate change, instead of just the last disaster.

4.8 Rio de Janeiro

Rio de Janeiro is a large seaside city in Brazil, with a population of about 6.5 million (IBGE 2014). The city is flanked by the shores of the Atlantic Ocean and Guanabara Bay to the South and East, and hills and mountains to the North and West.

The two documents selected for analysis are the Climate Change Plan (Municipal Policy for Climate Change, Plan for the Reduction of Greenhouse Gases Emissions for Rio de Janeiro) (Camargo 2011), and the Master Plan for Sustainable Urban Development (PCRJ 2011). The documents are chosen because of their legal relevance and scale; they have an impact on the development of the city and their implementation is mandatory.

4.8.1 The Climate Change Plan (CCP)

The Climate Change Plan (CCP) presents a set of initiatives and measures to reduce greenhouse gases emissions. The Plan starts by presenting a range of relevant definitions related to climate change (Camargo 2011, chap. I) such as the definition of adaptation, anthropic, carbon dioxide equivalent, adverse effects of climate change, emissions, source of emissions, greenhouse gases, impact of climate change, inventory of emissions of greenhouse gases, mitigation, climate change, Kyoto Protocol, and processes which remove atmospheric greenhouse gas and vulnerability. In the final provisions chapter (2011, chap. VI) the CCP indicates that environmental licenses from projects responsible for significant GHG emissions will be conditional "upon presentation of a plan to mitigate emissions and countervailing measures, in the form of specific legislation" (2011, para. 25). In Article 26 it is stated that the Government will publish the acts that may be necessary for the regulation of the CCP.

Resilient architecture and infrastructure dimensions are mentioned and taken into account in the goals and strategies described in the CCP. However, the document has a general character that neither clearly specifies how the goals will be achieved, nor how impact would be assessed. The CCP concentrates on mitigation and not on adaptation to climate change. While adaptation to climate change is mentioned several times throughout the document, the plan fails to address local climate hazards to the city of Rio de Janeiro: heavy precipitation, drought, floods, storm, landslides, urban heat island effect and low rainfall.

Potential measures and processes that reduce greenhouse gas emissions and address vulnerability are mentioned in the CCP, but cost assessment of vulnerability and potential measures have not been described. Specific impacts and urban areas are not described in detail in the CCP. The Steelmaking Complex is the only reference to a specific urban area in the document. The CCP is mandatory. The CCP entered into force on the date of its publication in 27th of January of 2011 (Camargo 2011, para. 27).

No clear methodology was found in the document for the assessment of measures for resilience to climate change. However, there is awareness of its relevance. Article 5 of the CCP contains guidelines for climate change and sustainable development of the Municipal Policy. For example, according to the first guideline, measurable, reportable and verifiable goals have to be established to reduce anthropogenic emissions of greenhouse gases in the Municipality. The second guideline states that the municipal inventory of emissions of greenhouse gases has to be prepared, updated and published every four years (Article 5). Nevertheless, how the inventory will be done, what kind of information it might consider and why, are not clearly defined.

4.8.2 The Master Plan

The Master Plan is the law that provides the guidelines for the urban and environmental policy (PCRJ 2011, para. 1). According to Article 2 the urban policy will be formulated and implemented based on principles such as ‘sustainable development, in order to promote economic development, environmental conservation and social equity’ and the ‘recovery, protection and sustainable use of the environment, the landscape and the natural, cultural, historical and archaeological city in the development process’ (PCRJ 2011, para. 2).

Environmental Policy is clearly a major concern in the Master Plan, but the Plan lacks details on how the goals are going to be achieved, when, what the expected costs are, how assessment is going to be performed and what are the expected impacts of the measures implemented in order to achieve the goals – either embedded in the Master Plan or referring to other documents. Due to its generality, the Plan in its current configuration needs a series of complementary plans and laws in order to embrace urban and environmental issues with the detail required for implementation. The Master Plan for Forestation mentioned in Article 183 is an example of such a complementary plan: "The design and implementation of the Master Plan for Forestation, targeting the proper planning and management of urban arboretum" (2011, para. 183). In Article 4 the specific laws that complement the Master Plan are listed. These specific laws establish "general and detailed urban planning concerning the following standards, in compliance with the guidelines established by this Supplementary Act: partition of the urban land; use and occupation; zoning and urban area perimeter; constructions sites and buildings; licensing and supervision of constructions sites and buildings; licensing and supervision of economic activities; municipal code; Regulation of the Environmental Impact Assessment, the EIA and Environmental Impact Report - RIMA; Municipal Plan of Integrated Transportation and regulation of public transport system" (2011, para. 4).

Resiliency dimensions are mentioned and taken into account in the goals and strategies described in the Master Plan. For example in Article 184 structuring actions relating to sustainable practices are presented such as the encouragement and promotion, within the municipality of "the use of solar energy; the energy recovery from solid waste treatment; the use of rainwater collectors and the development of new alternatives to capture and reuse of water for uses that do not require drink water standards; the adoption of materials on the facades of buildings more suited to the climate; the permanent environmental education aimed at reducing the consumption of energy and water, and the use of renewable and clean energy; the mapping and adoption of preventive measures against the formation of heat islands due conurbations" (2011, para. 184).

Neither impacts nor urban areas are specified in detail in the Master Plan. General aims for different kinds of areas are mentioned, but few further details are given. Article 117 does clearly specify sites that are relevant for their natural, scenic, historic and cultural attributes to the landscape of the City of Rio de Janeiro; these areas are subject to specific arrangements for protection and environmental restoration.

Neither cost assessments of vulnerability nor potential adaptation measures have been described in the Master Plan. The Master Plan entered into force on the date of its publication in 1st of February of 2011, and is mandatory.

In Article 1 of the Master Plan it is stated that the Plan will be evaluated every five years and revised every ten years. Assessment is mentioned throughout the entire Plan for each of the concerns considered in the document, but no methodology is specified. Risk assessment of floods, landslides, control of the environmental pollution and urban heat island effect are mentioned as relevant and according to the Plan they will have a significant impact on planning. Regarding to the local climate hazards of landslides and floods, it is mentioned in the Plan that the fragile slope and marshland areas will have their use conditioned to the risk assessment of floods and landslides. Further technical criteria for these assessments are not mentioned in the document, nor referred to. Areas with adverse physical conditions of occupation are considered fragile areas such as: "slopes subject to landslides, mudslides and other geological or geotechnical processes that compromise or may compromise their stability; marshland, subject to flooding, (...) due to their morphological composition" (PCRJ 2011, para. 28).

In Article 119 of the Master Plan the law determines that the control of the environmental pollution considers "the monitoring and evaluation of the quality and vulnerability of the environment, seeking to impose guidelines and goals that enable special protection", among the priorities of: "the vegetation and associated fauna; the water for human consumption; (…) the water bodies, their marginal bands and their sediments, especially groundwater, aquifers and their recharge areas" (PCRJ 2011, para. 119). In Article 120, "in order to achieve the provisions of the preceding Article (119) it shall: carry environmental diagnoses that serve as input to the decision-making process aimed at monitoring, control, remediation and pollution reduction; verify the effectiveness of these actions, to support the revision of the strategies adopted" (PCRJ 2011, para. 120).

4.9 Skopje

4.9.1 Background

Skopje is the capital and most densely populated city of the Former Yugoslav Republic of Macedonia (FYROM). Approximately 20 percent of the total population of the country lives in this capital city. Skopje faces issues of rapid population and slow economic growth –similar to other cities in emerging economy countries rather than the other European case-study cities considered. The policy documents selected for the analysis of resilience in terms of climate change for the city of Skopje are the: (i) Climate Change Communication Strategy and Action Plan (MoEPP 2013); (ii) Climate Vulnerability Assessment: Republic of Macedonia (Glavinov 2012). Both these policy documents are prepared by local institutions or individuals and financially/technically supported by International agencies such as the EU, United Nations Development Programme (UNDP), Global Environment Facility (GEF), and the South East European Forum on Climate Change Adaptation (SEEFCCA).

Both documents were prepared by national level and international level agencies and are expected to be implemented by these agencies; local level involvement in this issue is less evident. Policy document (i) focuses on a key aspect of climate change and disaster risk reduction which is communication with stakeholders at various levels. This is a unique type of document that specifically focuses on building competency toward improving communication in relation to climate change with the target population. This aspect is crucial for successful implementation of climate change related policies – creating awareness and justifying the need for adaptive measures of climate change and disaster risks. Similarly the strength of policy document (ii) lies in a sectoral analysis of climate change – specifically discussing the impact of climate change on health, water resources, energy, agriculture and forestry.

4.9.2 Climate Change Communication Strategy and Action Plan

The Climate Change Communication Strategy and Action Plan (MoEPP 2013) was part of a deliverable of a larger assignment "Consultancy services for development of climate change communication strategy in the country" under the Project "Third national communication to the UNFCCC" implemented by the FYROM Ministry of Environment and Physical Planning (MoEPP) with technical support from the UNDP and financial support from GEF. The primary focus of this deliverable was "to enhance the outreach, action-research and raising awareness agenda in order to raise awareness among and engage key stakeholders at the national and local level on issues pertaining climate change" (MoEPP 2013, p. 3).

According to Macedonians "climate change" is only the third most serious problem currently facing the world following "poverty, lack of food and drinking water" and "a major global economic downturn" (MoEPP 2013, p. 14). Despite various public events and public education activities, communication with specific stakeholder groups is still lacking. There is also a direct correlation between peoples self-perceived information levels and their perception of climate change as "a very serious problem" (MoEPP 2013, p. 14). The Climate Change Communication Strategy and Action Plan is based on a baseline survey of target population which addresses this gap - specifically emphasising communication activities in FYROM related to climate change. The document also outlines implementation, monitoring and review plans for each of its planned activities.

The document is divided into six main sections. Section 1 begins by outlining the development of the strategy processes feeding into the drafting of the "Third National Communication on Climate Change" (MoEPP 2014). Section 2 presents best practice communication principles. Section 3 describes institutional background and Section 4 perceptions and initiatives related to climate change in the country. Sections 5 and 6 form the core of the document with the Climate Change Communication Strategy and Action Plan, and potential implementation arrangements (MoEPP 2013, p. 3).

The document forms part of a broader climate change report; hence the executive summary, introduction and conclusion are quite specific as well, and not all of the resilient architecture and infrastructure dimensions are mentioned in these sections. Similarly the goals and strategies described in this policy document are very specific to the primary purpose of the document: "…providing the communications framework - strategic principles and concrete actions - based upon which the need for action should be communicated to key stakeholders in the Republic of Macedonia'" (MoEPP 2013, p. 3).

Although specific impacts and urban areas are not described in detail, this document does outline three broad levels of engagement: the city (municipal level activities), the workplace (related to businesses), and the household (related to the activities of private citizens). Each of the three levels is further detailed to specific individuals to be targeted as those responsible for making important decisions related to resource consumption:

- The city – Mayors, Deputies, Advisors, Planners and Procurement Officers
- The workplace – Executives, Business and Resource managers, Division Heads
- The household – present and prospective heads of households.

Furthermore, for each target there are three general desired outcomes, which are closely related and constitute ascending levels of engagement and action:

- Knowledge and awareness of the city, workplace and household's impact on and vulnerability to a changing climate.
- The capacity to develop and implement strategies to reduce impact on, and vulnerability to, climate change at the city, workplace and household level.
- The development of a proactive attitude to the mainstreaming of climate change considerations into city, workplace and household routines and processes.

These communication strategies are based on individual interviews, questionnaires and focus groups with over 100 representatives from four groups: public institutions, industry, NGOs and journalists. The methodology of assessment for this policy document is quite clear, specific and detailed.

Although the document does acknowledge cost as a primary factor when dealing with climate change and disaster risk issues, especially in regions with scarce resources, there is not a detailed cost assessment of vulnerability and potential measures nor reference to other documents including these assessments. The policy document is legally binding and is integrated in checklists for project development used by city officials. Although this document does not directly address the local climate hazards that the specific case study city is expected to face, it does address the core issue of communication with target audiences that are directly responsible for the implementation of any plan connected to these key issues.

4.9.3 Climate Vulnerability Assessment: Republic of Macedonia

Policy document (ii) Climate Vulnerability Assessment for Republic of Macedonia (Glavinov 2012) was published under the Instrument for Pre-Accession Assistance (IPA) project South East European Forum on Climate Change Adaptation (SEEFCCA). The IPA is a regional project which established Civil Society Organization (CSO) networks on climate change adaptation in Croatia, Montenegro and Serbia, as well as in FYROM. The project was funded by the EU along with the Austrian Red Cross, the Institute for Economic Promotion of the Austrian Federal Economic Chamber (Wirtschaftsförderungsinstitut - WIFI), and the World Wide Fund for Nature (WWF).

The document is divided into five main parts. Section 1 begins with an introduction to climate change mitigation and adaptation. Section 2 emphasises current and future risks specific for FYROM. Section 3 details impacts of climate change on various sectors such as health, water resources, energy, agriculture and forestry, and a detailed vulnerability and impact assessment of climate change on each of these sectors is discussed along with corresponding potential adaptive measures. Section 4 outlines existing national strategies and platforms for climate change risk reduction, while Section 5 provides recommendations.

Section 1 explicitly states that climate change cannot be prevented and hence argues for the need for adaptation. "For developing countries such as Macedonia…*adaptation is a need and priority*" (Glavinov 2012, p. 29 emphasis in original). The country needs international assistance in order to improve climate change adaptation capacity and corresponding implementation of required strategies. Despite difficult financial constraints, "response is required by the government, the population, non-governmental organizations, the Red Cross, civic organizations, and other actors which feel the impact of climate change" (Glavinov 2012, p. 29). Adaptation responses can be clustered into the following broad categories:

- Technological solutions — (grey measures);
- Ecosystem-based adaptation options — (green measures);
- Behavioural, managerial and policy approaches — (soft measures).

Resilient architecture and infrastructure are mentioned and taken into account in the goals and strategies for this policy document. "The main objective of the project is to enhance the participation of the civic organizations in the efforts for climate change adaptation through national and regional cooperation initiatives" (Glavinov 2012, p. 8). The analysis of this report is expected to help define the actions in the following priority areas:

- Identification, registration and monitoring the risks linked with climate change and their impact on the health of the people;
- Promotion of vulnerability assessment, early warning and timely response for coping with risks from climate change;
- Promotion of adaptation measures in the agricultural sector;
- Promotion of energetic efficiency and renewable energy sources; and
- Identification of the needs of the system for management of water resources (Glavinov 2012, p. 9).

One of the key issues lacking in this document is cost assessment of vulnerability and potential measures, but there is a brief mention of cost in Section 1. There is also no clear indication that this document is legally binding since it was developed primarily by international agencies. The document does not present any technical details about simulations nor refers to it. There were no checklists found for project development.

4.10 Overview and comparison

For this report policy documents from eight cities were evaluated: Antwerp, Bilbao, Bogotá, Hyderabad, London, New York, Rio de Janeiro, and Skopje. These cities comprise a wide assortment of topographies and climates, as well as demographic, economic, and political typologies. They face a wide variety of climate-change related hazards, with a host of varying risks at different levels of uncertainty, confronted by a multitude of pathways and strategies. While the cities could be categorized and compared based on any of these characteristics, the simplest delineation could be one based on size and development level. This should not be construed as an attempt to create a divide between developed and developing countries; merely to recognize that there is a clear difference in terms of responses and approaches to climate change adaptation between cities in developed and developing countries.
Two of the cities (Greater London and New York City), are large cities with populations of about 8.5 million.

Three of the cities (Antwerp, Bilbao, and Skopje) are medium-sized European cities (population 350-550,000). Skopje is an inland river city, while Antwerp and Bilbao are estuarine cities.

Three of the cities (Bogotá, Hyderabad, and Rio de Janeiro) are large cities (6.5-7.5 million) in developing countries. Bogotá and Hyderabad are landlocked, while Rio de Janeiro is situated on the shores of the Atlantic Ocean and Guanabara Bay.

There is a tremendous disparity in the production, dissemination, and availability of policy documentation on the climate resilience of architecture, infrastructure and urban planning within and between the RAMSES case study cities and their national contexts. While a diligent effort was made to obtain the most relevant and up-to-date documentation, it is entirely plausible that gaps exist. This assessment is therefore intended to be indicative of different approaches in different cities, but should not be considered to be a comprehensive assessment of any individual city.

4.10.1 *London and New York*

While London and New York differ tremendously in their spatial and locational aspects, both have an intimate relationship with water. London is a city centred on a river, and New York is a city basically surrounded by the ocean; both cities have been subject to repetivive flooding. The 2007 summer floods galvanized policy action in the United Kingdom and London, while Hurricane Sandy galvanized policy action across the US Eastern seaboard and New York (EA 2007; NYC 2013). The floods had different root causes: In New York the majority of flooding was due to a large storm surge, while in London "virtually all of the 1,400 properties flooded were due to surface water flooding" (EA 2007, p. 14; NYC 2013).

Both cities have crafted thorough, detailed, and routinely updated climate adaptation plans. Both cities have proceeded to implementation of climate adaptation policy, evidenced through the mainstreaming of policy changes into immediate action as well as integration into building and planning codes.

The cities have taken two different approaches, however, with the main difference being the command structure involved in the approach. While the US had no overall Climate Change Adaptation Plan until November 2014, the UK had already implemented legal mandates for climate change mitigation and adaption in 2008 (CCA 2008; EPA 2014b). New York City moved ahead on its own, without any Federal guidance, in an almost "command and control" approach, maintaining authority over the management of the adaptation process from start to finish. London on the other hand, has developed top-level basic policy goals which require compliance from a host of stakeholders, including private infrastructure providers as well as local authorities. These local authorities (from London's 33 boroughs) are given the authority and autonomy to craft and implement policies which they expect satisfy the requirements of greater London policy. New York, on the other hand, is both developing the policy and coordinating implementation for its five boroughs at the municipal, city-wide level.

Both approaches have solid methodological underpinnings, but their execution differs. Both cities grounded their policy proposals on extensive published scientific, environmental, and economic research undertaken by dedicated organizations. London expects that local knowledge of potential impacts and adaptation opportunities in the boroughs will trump the more extensive (but less localised) resources of greater London. New York expects that the distribution and implementation of adaptation options based on citywide needs is a more efficient approach. Both approaches have the potential for success, but the London approach currently seems to be missing a crucial factor. What is likely required is the establishment of a procedure for cooperation between boroughs, including a standardised methodology for coordination of borough policies and adaptation measures. This connectivity appears to be missing from most of the policy documents, which becomes important considering the extreme variation in the level of understanding, as well as capability and desire for local action, between the 33 London boroughs.

The city-level documents assessed for both London and New York included resilience dimensions for architecture, infrastructure and urban planning in almost all categories. The categories where direct reference was lacking (such as explicit inclusion of cost-assessment, modelling, and simulations), likely point more toward an overly narrow design of our question methodology itself, and do not reflect a lack of capacity or understanding. Both London and New York included extensive simulations in the background research and supporting documents that formed the basis for their policies (UKCIP 2002; EA 2009; NPCC 2010; Rosenzweig et al. 2011; UKCIP/ACN 2011; Frontier 2013).

4.10.2 *Hyderabad, Rio de Janeiro and Bogotá*

Hyderabad, Rio de Janeiro and Bogotá are large cities in India, Brazil and Colombia, emerging economy countries that are experiencing not only rapid population and economic growth, but a swift transition from rural to urban life. These transitions add an extra level of complexity to the development of resilience strategies for climate change mitigation and adaptation.

The documents selected for the analysis of resilience policies for these cities include Development Plans, Master Plans, Structural Plans, and Municipal Policy for Climate Change, as well as training modules. For the cities of Rio de Janeiro and Bogotá the selected documents are prepared by local city-level government officials, while for the city of Hyderabad two of the selected documents are training modules prepared in collaboration with international development agencies.

In Hyderabad the main responses to disaster risk and climate change appear to be externally driven. The locally prepared Development Plan does not include issues of disaster risk and climate change adaptation, whereas both of the training modules prepared in collaboration with international development agencies present key crucial issues regarding these concepts. National level institutions such as the National Institute of Disaster Management (NIDM) are clearly aware of the vulnerabilities associated with disaster and climate change in a similar manner to international institutions. There is a clear gap even at the various institutional levels within the country between policy makers and implementers – an issue that the selected training module also addresses and attempts to reconcile.

Rio de Janeiro and Bogotá. do not exhibit the same apparent institutional gap as Hyderabad. In these cities, the local institutions are capable and aware of issues concerning disaster risk and climate change, demonstrated by their active involvement in the preparation of local plans and policies related to this issue. Although the implementation part of the plans and policies in all three cities remains questionable, clear indications of local awareness and capacity for dealing with disaster and climate change are visible. The Structural Plan for the city of Bogotá includes an entire chapter dedicated to risk management and climate change. It is also states that "Colombia is a country that has usually been very aware of environmental conditions over the centuries" (SDP 2013). Similarly the Rio de Janeiro Municipal Law on Climate Change and Sustainable Development (Camargo 2011) and the Master Plan for Sustainable Urban Development (PCRJ 2011) are specific climate change related documents prepared by the municipality, in which environmental policy is clearly the focus. For the city of Rio de Janeiro, urban policy will be formulated and implemented based on principles such as "sustainable development, in order to promote economic development, environmental conservation and social equity" and the "recovery, protection and sustainable use of the environment, the landscape and the natural, cultural, historical and archaeological city in the development process" (PCRJ 2011, para. 2).

All three cities’s selected policy documents lack detailed cost assessment of vulnerability and potential resilience measures, or references to such assessment. Cost assessment is a crucial aspect in relation to resilience thinking for disaster risk and climate change, especially in the context of emerging economy countries where limited financial resources are mostly distributed for other immediate developmental purposes.

A detailed cost assessment of vulnerabilities and potential measures in relation to disaster risk and climate change would be beneficial especially for city officials to plan and distribute the financial resources more effectively, looking for win-win options that promote development as well as resilience.

Most of the documents within the three case study cities of Hyderabad, Rio de Janeiro and Bogotá lack a clear methodology for assessment. The local plans (development, structural, municipal) are generally limited to an overview of goals, without a methodology for implementation. The only document that discusses this is the training module quoted above: "Mainstreaming Climate Change Adaptation and Disaster Risk Reduction, Training Module for the city of Hyderabad" (Gupta et al. 2014). The training module is based on the methodological assessment of a specific case, and attempts to develop a generic approach which could be replicated in other districts of India in order to integrate climate change adaptation and disaster risk reduction concerns into development plans.

The three cities could benefit from exchanging and learning from their collective experiences and qualities in policy making. Rio de Janeiro and Bogotá could attempt to prepare training modules with specific urban areas and impacts in relation to disaster risk and climate change. One of the main limitations for the city of Hyderabad has been the gap between institutions on the local, national and global levels in terms of actually operationalising the policy. This gap is comparatively less in the cities of Rio de Janeiro and Bogotá where the local institutions have the capacity and are aware of resilience thinking in terms of climate change and disaster risk. Hyderabad might benefit fromthe example of local institutional setting within similar cities such as Rio de Janeiro and Bogotá in order to build and strengthen the capacity of local institutions to deal with climate change and disaster risks.

4.10.3 ***Antwerp, Bilbao and Skopje***

Antwerp, Bilbao, and Skopje are relatively small cities in Europe, with fairly static populations and steady economies. The degree, level and scale of complexities in terms of climate change and disaster risk within these cities cannot be directly compared, but each of these cities can learn from the approaches of the other cities.

In terms of referencing characteristics and dimensions of resilience in architecture and infrastructure, most of the selected documents for all three cities have mentioned and taken into account key aspects in the executive summary, introduction and conclusion as well as within their goals and strategies. Except for a few specific policy documents, most of the analysed documents are of a general nature and give an overview of the broad approach in terms of resilient architecture and infrastructure. Specific impacts and urban areas are discussed in detail in only in some of the policy documents.

The methodology of assessment is quite detailed in most of the documents analysed in Antwerp, Bilbao, and Skopje. The documents assessed for Bilbao and Skopje have similarities in terms of their focus on (and outreach to) a target audience (local government to citizens). For example in the Action Plan for Sustainable Energy 2020 Bilbao states, "the goal is to approach from the local institutions to citizens" (Bilbao 2013a, p. 40), while the main objective of the Climate Change Communication Action Strategy for Skopje is development of a proper strategy for reaching out to citizens (MoEPP 2013). This particular document does not specifically describe the impacts and urban areas in detail, but formulates a replicable strategy of focusing on building awareness of issues related to climate change and disaster risk for its target population.

In terms of specific urban areas and impacts, the Strategic Spatial Structural Plan for the city of Antwerp (SA 2012a, 2012b, 2012c) presents a more detailed description of city typologies compared to the plans from the other cities. This plan for the city of Antwerp not only consists of policies at both generic and specific levels to embrace the complexity of the city, but also provides possible measures and actions for each city typology along with an implementation plan. Hence the plan not only states what should be done in terms of policies, but also ways of how to implement them.

An overall comparison between the policy documents analysed in the eight case-study cities and the scientific literature is a difficult endeavour. As noted previously, the analysis is subject to variations and inconsistencies in the public availability of documents, the determination of relevance of potential documents, the selection of documents, individual researcher’s interpretation of the documents, the document target audience, and above all the goal and purpose of the individual documents, including its scale and level of complexity. The main purpose of this comparison is to learn from each of the types of city policy documents, and generalize where possible.

The necessary flow of information between emerging economy countries and more established ones is in most cases unidirectional – cities in emerging economy countries can learn from those in developed countries. The analysis of the eight case-study cities also tends to support this convention - policy decisions and approaches tend to be most refined and explicit in the developed megacities. The smaller European cities include a complex mix of attributes and approaches, some of which could lend concepts to the emerging megacities. The Strategic Spatial Structural Plan of Antwerp, for example, has a number of beneficial aspects that all three of the large cities in emerging economy countries can learn from. The main lesson learnt from Antwerp for the cities of Rio de Janeiro, Bogotá, and Hyderabad is its specificity: while it succeeds in embracing and dealing with the different scales of urban planning and design, it simultaneously manages to consider co-dependent structures of the legal, ecological, functional and social structures (economic and spatial dimensions).

The degree, scale and level of complexities that the three emerging megacities face is different from those in any of the cities in developed countries, however. Policies cannot be generalized and made to fit to various contexts; the specificity of each context must be kept in mind when transferring ideas.

Approaches and methodologies, on the other hand, do have a strong opportunity for transfer and uptake by other cities; careful revision should be expected in order to maintain utility.

Some of the key aspects lacking in many of the analysed policy documents with respect to resilient architecture and infrastructure are:

- Cost assessment. A comparison of the potential costs of the impacts of climate change versus the costs of adaptation is lacking in many of the policy documents. Some form of cost and benefit assessment is a key aspect which should be used as background for any climate change policy, and can provide evidence (and support) for policy implementation. These assessments should be transparent in their assumptions and explicit in their treatment of uncertainty. Incorporating a detailed cost assessment for addressing vulnerabilities and the benefits of potential adaptation measures is especially relevant in the context of resource scarce or emerging economy countries.
- Specific impacts and urban areas. Although some of the policy documents have a clear and detailed description of specific impacts and urban areas, this is lacking in the analysis of many of the other policy documents in the other cities. Policy support and policy implementation can benefit from specificity with regards to the specific hazards faced by specific areas.
- Assessment methodology. Only some of the policy documents present a clear methodology of assessment for climate hazard vulnerability and potential adaptation measures. Proper and effective implementation of policy goals generally requires a clear methodology for assessing the success and failure of both proposed policies and their implementation.
- Simulations. As part of the evidence base, and in tandem with cost assessments, climate simulations should be included or explicitly referenced in policy documents. The simulations and scenarios should be transparent in their assumptions and explicit in their treatment of uncertainty.

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6 Appendix

6.1 Inventory of existing measures by infrastructure type

Blue + Green Infrastructure		
Measure by Implementation Scale	Effect	Examples
General		
"Boosting green infrastructure", but ensuring sustainable water consumption and management (EEA 2012, 31). "A move towards greater use of natural ecosystem services and away from technical and engineered approaches has been observed" (EEA 2012, 92).	Green infrastructure can provide a carbon sink, increased drainage, and a cooling effect, as well as improved human comfort (EEA 2012, 7; 85; 92), water and air quality. Reduced energy use; problems with flooding, peak flows, drought (Demuzere et al. 2014, 142). Can decrease the incidence and severity of natural hazards - particularly landslides, with regards to flood management and slope stabilization. (EEA 2012, 7; 85; 92; 227; EU 2000/60/EC). Can potentially achieve more cost effective/feasible adaptation solutions than grey infrastructure alone. Diminishes the overreliance on grey infrastructure (EEA 2012, 16; 92).	In the UK, "there is declining support for flood defence systems to reduce the impact of flooding in favour of land use planning" (EEA 2012, 92)
Building, Site, Neighbourhood		
Green walls and roofs; private gardens; (EEA 2012, 7; 92). Green façades (Demuzere et al. 2014, 146). Eco-roofs: Green roofs (vegetated), white roofs (cooling), and blue roofs (water managing). (Foster et al. 2012, 5). Use of plants adapted to drought conditions (EEA 2012, 60). Use green urban infrastructure (GUI) to develop sense of well-being, health and restorative benefits, greater coping capabilities, place making, educational opportunities (Demuzere et al. 2014, 151). Good public access to urban green spaces (Demuzere et al. 2014, 152).	"The life-cycle, net present value of green roofs has been estimated to be as much as 40% higher than a conventional roof from storm-water management, reduced electricity costs, and air-quality benefits. A sampling of studies shows energy savings from green roofs at 15-45% of annual energy consumption - mainly from lower cooling costs. Cool or white roofs can save up [to] 65%" (Foster et al. 2012, 4). "...insulating houses against temperature extremes (which leads to reduced domestic energy use), and improving air cooling locally" (Demuzere et al. 2014, 146). "Water conservation; storm-water runoff and water quality management; local and regional cooling; aesthetic value; electricity savings; habitat provision for wildlife; carbon absorption" (Foster et al. 2012, 5) Capture and use of rainwater allows infiltration and groundwater recharge (EEA 2012, 15; 60). "Vegetated areas slow down water run-off, store storm water and allow water infiltration in the soil keeping it available for vegetation or other uses" (EEA 2012, 60). "Green alleys or streets, rain barrels, and tree planting are estimated to be 3-6 times more effective in managing storm-water per $1000 invested than conventional methods" (Foster et al. 2012, iv). "Good access to urban green spaces is associated with: higher use, higher physical activity levels, and a lower likelihood of being overweight or obese" (Coombes, 2010 in Demuzere et al. 2014, 152). Close proximity to green space is linked to disease reduction, less depression and anxiety; encourages active and healthier	"Washington, DC has estimated that installation of green-roofs on most eligible buildings could yield a 6-15% reduction in the number of CSOs into local rivers, with CSO water volume reductions of up to 26%" (Foster et al. 2012, 7). "Toronto estimated that installation of green-roofs citywide could save an initial $313,100,000 and $37,130,000 annually" (Foster et al. 2012, v). "A typical blue roof can store about 50% of the water that falls on it annually. One inch of rain falling on a 1000 square feet of roof generates 623 gallons of water for harvest. Treating 1 million gallons of rainwater instead of reusing it saves 955 – 1911 kWh of electricity" (Foster et al. 2012, v). A study in the Manchester area of the UK "indicated that green infrastructure led to a significant reduction in surface run-off following rainfall" (EEA 2012, 92). "A study in Manchester, England found that adding 10% green cover in high density urban areas and town centres under future climate change projections would keep surface temperatures below local baseline historical levels except under conditions of high emissions" (Foster et al. 2012, vi). Green and blue infrastructure is being used in management of surface water runoff in Malmö, Sweden and Lódź, Poland. (EEA 2012, 49; 92). Examples of bio-retention cells in Maryland and North Carolina have shown that such hydrologic improvements promote groundwater recharge, assist in managing floods and also address channel erosion issues (Demuzere et al. 2014, 149).

Blue + Green Infrastructure		
Measure by Implementation Scale	Effect	Examples
	forms of travel such as walking and cycling; Increases residents' "participation in physical, leisure and social activities, triggering relaxation, comfort and satisfaction"(Demuzere et al. 2014, 152). "…a loss of urban green areas can result in an undesirable outcome from the perspective of climate change mitigation, as urban dwellers have to commute to find recreational services" (Demuzere et al. 2014, 152). "Urban studies have shown that the net economic benefits of mature urban trees range from $30-90 per year for each tree, accounting for all potential benefits with an rate of return (ROR) of $1.50 to $3.00 for every dollar invested" (Foster et al. 2012, v). "A 20-percent tree canopy over a house results in annual cooling savings of 8 to 18% and annual heating savings of 2 to 8%" (Foster et al. 2012, v). "In 2005, total carbon storage in urban trees in the US was approximately 700 million tons with net rate sequestration estimated at around 24 million tons per year (88.5 million tons CO_2 equivalent)" (Foster et al. 2012, v). "Studies have found general increases of up to 37% in residential property values associated with the presence of trees and vegetation on a property" (Foster et al. 2012, vi).	The examples from Berlin, Germany show that "the self-generated social and physical structures" in shared gardens fosters "greater autonomy, information sharing between gardeners", and provides experience with "negotiations and decision making" with other relevant actors within the city (Demuzere et al. 2014, 153). "A case study in Stockholm (Barthel et al., 2010) shows how urban allotment gardens foster sense-of-place, and create and help to maintain social-ecological identities" (Demuzere et al. 2014, 153). North American examples highlight intergenerational learning streams that "included gardening/local ecological conditions, urban politics and the role of civic action" (Demuzere et al. 2014, 154). "The value of street trees in Washington, DC is estimated at nearly $10.7 million annually for all benefits" (Foster et al. 2012, v). "In Houston, Texas trees provide $1.3 billion in stormwater benefits (based on $0.66 /cubic foot of storage)" (Foster et al. 2012, v). "The value from urban forestry in Chicago totals $2.3 billion with total carbon sequestration rate of 25,200 tons/ year equivalent valued $14.8 million/year" (Foster et al. 2012, v).
Neighbourhood, City, Regional/Metropolitan, National		
Bottom up approaches to assess/utilize citywide urban green or all above ground live biomass; soils (Demuzere et al. 2014, 144-145; Satterthwaite 2008). Rain gardens, bioswales, rainwater harvesting, planter boxes, green parking, green roofs, urban tree canopy, etc. (EPA 2013). Network of natural or semi-natural areas in cities; Network of vegetated roadsides; tree-lined roads; forests; rivers, canals, lakes, wetlands, wades and seashores. Linking several ecological corridors, such as gardens, valleys and streams, both in natural and urban areas (EEA 2012, 7; 19; 92; Lugeri et al. 2010). Using "forests, wetlands and floodplains" as "buffers of peak flows and also water purification" (Demuzere et al. 2014, 147-148). "Maintain and manage green areas outside and inside the cities for flood retention including the use of appropriate agricultural and forest practices; Re-naturalization of rivers and wetlands" (EEA 2012, 48), as well as "parks, playing fields and other open spaces" (EEA 2012, 92). "…supplement existing grey infrastructure with natural solutions like beach nourishment, wetlands restoration and sea marsh protections" (EEA 2012, 92)	Carbon sink (Demuzere et al. 2014, 144). GUI "…approaches contribute to the increase of ecosystems resilience and can halt local biodiversity loss, degradation of ecosystem and restore water cycles"; Reduction of vulnerability to floods and landslides (EEA 2012, 16). "The physical properties of GUI play a role in reducing air and surface temperatures by providing shading and by enhancing evapotranspiration, which contributes to the removal of latent heat from soil" (Demuzere et al. 2014, 145). "GUI removes CO_2 from the atmosphere via photosynthetic uptake during the day and releases CO_2 at night via respiration, while additional uptake can occur via below-ground biomass and soils" (Demuzere et al. 2014, 143). Reducing runoff; "…enhancing interflow in the underlying soil" (Demuzere et al. 2014, 148). "Rain water storage in wetlands and water bodies for later use" as well as storm water retention in "natural depressions, rivers and wide shallow water ways" (EEA 2012, 60). "GUI infrastructure has been found to improve the physico-chemical characteristics of the water by removing suspended solids, nutrients, hydrocarbons, and heavy metals. Pollutant removal mechanisms like filtration, adsorption and biological treatment mechanisms combined with runoff reduction results in reduced pollutant loads" (Demuzere et al. 2014, 149).	In Houston, TX trees reduce stormwater runoff, providing "$1.3 billion in stormwater benefits (based on $0.66/cubic foot of storage). In Austin, TX trees provide $122 million in stormwater benefits (based on the U.S. national average of $2/cubic foot of storage) In Atlanta, GA trees provide $833 million in stormwater benefits (based on the U.S. national average of $2/cubic foot of storage)" (Foster et al. 2012, 21). "Philadelphia has been using policies and demonstration projects throughout the city since 2006 to help promote green infrastructure in planning and development. Resulting in drastically reduced combined sewer overflows (CSO), improved compliance with federal water regulations, and savings of approximately $170 million" (Foster et al. 2012, v) "Portland invested $8 million in green infrastructure to save $250 million in hard infrastructure costs. A single green infrastructure sewer rehabilitation project saved $63 million, not counting other benefits associated with green practices such as cleaner air and groundwater recharge benefits. Portland's Green Street projects retain and infiltrate about 43 million gallons of water per year and have the potential to manage nearly 8 billion gallons, or 40% of Portland's runoff annually. Portland estimated that downspout disconnection alone would lead to a reduction in local peak combined sewer overflow (CSO) volume of 20%"

Blue + Green Infrastructure		
Measure by Implementation Scale	Effect	Examples
	"GUI offsets air pollution by directly removing pollutants from the air due to dry deposition and absorption, influencing dispersion conditions" reducing high temperatures and sunlight conditions that can accelerate ozone depletion (Demuzere et al. 2014, 150). "A community in Canada estimated that building more flood control infrastructure to manage probable future climate change impacts would save $10 million" (Foster et al. 2012, vi).	(Foster et al. 2012, v). "New York City's 2010 Green Infrastructure Plan aims to reduce the city's sewer management costs by $2.4 billion over 20 years. The plan estimates that every fully vegetated acre of green infrastructure would provide total annual benefits of $8,522 in reduced energy demand, $166 in reduced CO_2 emissions, $1,044 in improved air quality, and $4,725 in increased property value. It estimates that the city can reduce combined sewer overflow (CSO) volumes by 2 billion gallons by 2030, using green practices at a total cost of $1.5 billion less than traditional methods" (Foster et al. 2012, v) Stuttgart, Germany manages urban heat island effects with urban planning by exploiting "how natural wind patterns and dense vegetation can actively help the city to reduce its problems of overheating and air pollution" via "a series of 'ventilation-corridors' which have been kept open as wide, tree-flanked arteries within the city's street infrastructure" (EEA 2012, 23). "Building a wastewater treatment system using constructed wetlands costs about [half that] of a conventional advanced treatment facility" per unit of capacity (Foster et al. 2012, vi). "Low-lying public spaces, which can be used for temporary water storage during heavy precipitation or flooding events", are being developed in new neighbourhoods in Rotterdam in the Netherlands to "funnel water flow and increase storage and drainage capacity" (EEA 2012, 49) In Singapore, research on "the thermal benefits of a city's natural reserve and a neighbourhood park" indicated "the cooling impact of" GUI through lower temperatures in and around the site of analysis (Demuzere et al. 2014, 146).

Grey Infrastructure		
Measure by Implementation Scale	Effect	Examples
General		
Reduction of "cities' dependency on external services"; Climate proofing key dimensions of the built environment (EEA 2012, 15). "Water resource management can take place on three levels: the catchment area, the urban or neighbourhood scale and the buildings" (EEA 2012, 59).	Infrastructure interdependencies "…are liable to lead to 'cascade failure' where the failure of one aspect of infrastructure, such as flood defences, can lead to other failures. One example of this could be flooded power stations leading to power cuts which thereby affect telecommunications networks, the pumping of drinking water and control systems. The interdependencies in infrastructure therefore need to be managed well. For example, a smart grid will mean energy systems rely more on information and communication technology, and the electrification of transport systems will mean transport is more reliant on the national grid" (EEA 2012, 81).	"With a growing urban population in Europe, city and regional authorities will play an increasingly important role in climate change adaptation in the future. Many European cities have already developed local adaptation strategies, including measures aiming to ensure the future operation of existing urban infrastructure (e.g. cooling in metro-systems or trams) or increasing the share of urban green space" (EC 2013a, 8)

Grey Infrastructure		
Measure by Implementation Scale	Effect	Examples
Building, Site, Neighbourhood		
"Innovative design of buildings and areas such as elevated entrances, building on poles, floating houses, temporary water storage, green roofs" (EEA 2012, 48). Incorporating greater structural wind resistance; green roofs, maintenance of drainage systems, and restricted usage of lower floors in flood-prone buildings (EEA 2012, 50). Energy consumption reduction, passive cooling of buildings "via insulation (thick and well-designed walls, small windows, double glazing and the correct choice of materials) or blinds"; strategies such as white roofs (EEA 2012, 31) "Eco-roofs: Green roofs (vegetated), white roofs (cooling), and blue roofs (water managing)" (Foster et al. 2012, 5). "Increasing water efficiency in buildings; efficiency of water-using products in households, commercial business, industry and agriculture, reducing leakages in water networks" (EEA 2012, 59-60). Implementation of "grey water recycling systems; ground water recharge systems; and rain water harvesting systems" (EEA 2012, 60). "Avoid/remove impervious surfaces wherever possible" (EEA 2012, 48). Temporary rainwater storage - capture and storage for reuse ((EEA 2012, NYC 2014a).	"…medium to long-term measures can focus on the climate-proof design of residential and commercial buildings and new urban developments" to facilitate the reduction of energy demand and greater protection of property (EEA 2012, 50) Reduction of storm/flood damage (EEA 2012, 48) "Water saving technology and devices in households and industry as well as a proper maintenance of the supply system avoiding water loss will reduce overall demand" (EEA 2012, 60). Rain barrels and cisterns capture runoff from roofs and store it for future activities (NYC 2014a).	NYC's Rain Barrel Giveaway Program gave away 2,000 rain barrels to homeowners in Brooklyn, Queens, the Bronx, and Staten Island from 2008 through 2011. Connecting directly to the existing downspout, once the barrel is full, excess rainwater drains normally into the city's sewer systems (NYC 2014a). A study "found that retrofitting 80% of air-conditioned buildings in the United States with white roofs would save $735 million annually in reduced energy bills while achieving an emissions reduction equivalent to removing 1.2 million cars from use" (Foster et al. 2012, 10). "Amsterdam and Almere in the Netherlands have built man-made islands with floating houses which 'naturally' adapt to water levels" and "cope well with sea level rise or high storm surges" (EEA 2012, 49; 85). In Toronto, Canada, and the US cities of Los Angeles, Milwaukee and Portland, downspout programs are being implemented to allow stormwater to better infiltrate into the soil, reduce soil erosion and drought (EPA 2014c). "A study in Los Angeles showed that increasing pavement reflectivity by 10-35% could produce a 0.8°C decrease in UHI temperature and an estimated savings of $90 million per year from lower energy use and reduced ozone levels" (Foster et al. 2012, 5).
Neighbourhood, City, Regional/Metropolitan, National		
Urban planning that includes "public space providing shade and natural ventilation" (EEA 2012, 31). Proper maintenance of the water supply system, as well as maintenance and upgrade of drainage systems (EEA 2012). Optimise existing sewage systems, with "separate treatment of rainwater, disconnected from sewage, improved ground drainage" (EEA 2012, 48). Green railway tracks (EC 2011) "Municipalities can relocate vulnerable urban transport infrastructure and make it climate-proof, improve water use efficiency, reduce losses from the water supply systems and build local water storage facilities and other back-up systems" (EEA 2012, 15). Restoration strategies should include a mix of measures, such as the building of reservoirs, dams and flood defences, and wider development of existing water body corridors. (EEA 2012). "…locating power and communication lines underground or creating multiple supply lines" (EEA 2012, 15). District cooling. (EEA 2012, 31). "Desalination plants and re-allocation of water resources from water-rich regions to water-stressed regions" (EEA 2012, 60).	Avoiding water loss will reduce overall demand (EEA 2012, 60). Can boost the capacity of existing grey infrastructure (EEA 2012, 43). Separating water streams will diminish the potential for cross-contamination. (EEA 2012, 48). Green rail infrastructure reduces runoff volume and attenuates peak flows; reduces heat island effect. The novel gravel turf technique. The subsoil preparation included a high share of recycled building rubble and a high share of compost in the vegetation layer (EC 2011). Decentralization and multiple supply lines can reduce supply system vulnerability (EEA 2012, 15). "District cooling is…an energy-efficient way to prioritize absorption cooling, (which allows the use of excess heat from other processes)" (EEA 2012, 31). Although "desalination and re-allocation of water solutions" can "increase the water supply" of regions in the short term, they are "often expensive and need to be addressed at a national level rather than at a municipality level" (EEA 2012, 60).	A new metro line in Copenhagen, Denmark will feature elevated entrances "to avoid storm water flooding the tracks" (EEA 2012, 49). "Nijmegen, the Netherlands, explores opportunities in which buildings are part of the flood defence." "…structures such as car parks, buildings, dwellings or roads are transformed and redesigned with" flood protection in mind (EEA 2012, 49). "In Vienna, Austria, the sewage system itself provides storage. The loading of the sewer system is monitored continuously in real time and interventions are possible through centrally controlled sluices and pump stations to optimize the full storage capacity of the system and prevent outflows during high precipitation events" (EEA 2012, 49). "Desalination and re-allocation of water resources from water-rich regions" is planned in Spain and Turkey. "However, cities such as Ankara, Barcelona or Istanbul cannot afford such investment on their own. Such solutions run the risk of being poor adaptation measures due to increased energy demand and the fact that the projects themselves may be vulnerable to climate and other stresses" (EEA 2012, 60).

Soft Measures		
Measure by Implementation Scale	Effect	Examples
General		
Soft measures include "behavioural changes, emergency systems and the adequate provision of information to vulnerable groups" (EEA 2012, 7). "Soft measures can include the adjustment of building regulations, financial support for retro-fitting of buildings, insurances to finance repairs and replacements after storm events, [and] preparation or adjustment of emergency response plans" (EEA 2012, 47)	"…awareness raising and communication to a wide audience (Swart et al., 2009) including policymakers, planners, and the public" (EEA 2012, 63). Vulnerability reduction. Can reduce health and property impacts in the event of extreme events such as heat waves, flooding, landslides, etc. (EEA 2012, 8; 43; 89).	"For new infrastructure, examples show that construction codes or planning legislation (e.g. for new residential zones) partially already incorporate climate change parameters" (EC 2013b, 8). "European countries waste between 10% and 25% of their water due to inefficiency, e.g. through losses in public water supply and irrigation networks, appliances in households and inefficient water practices in industry and agriculture" (EEA 2012, 55). Examples of "multi-level, virtual information information hubs"…"include the UK Climate Impacts Programme" "klimatilpasning.dk (Denmark), klimatilpasning.no (Norway), climate-guide.fi (Finland) and KomPass (Germany)" (EEA 2012, 63).
Building, Site, Neighbourhood		
		"House owners in Nijmegen in the Netherlands receive EUR 5 per m^2" of rain water drainage area disconnected from the sewer network (EEA 2012, 52). "Dresden in Germany collects taxes based on the impervious surface of the property" (EEA 2012, 52).
City, Regional/Metropolitan, National		
		"The city of Orléans, the Val de Loire area, and the Loiret departmental council in France are working together on the project 'Flood Resilient City' (FRC) to raise awareness of the potential impact of flooding by the River Loire to the public, among stakeholders and with government and decision-makers" (EEA 2012, 51). Hamburg's Climate Action Plan for 2007-2012 includes "a series of concrete adaptation measures, such as coastal flood defences, water management, inland flood protection, as well as adaptive measures for waterways, urban and landscape planning, transport infrastructure" (EC 2013b, 8). The Zaragoza Water Saving City programme in Spain "included awareness raising campaigns, the implementation of 50 examples of good practice and voluntary public commitments by citizens and businesses." By using revised water tariffs to "ensure a full cost recovery through revenues as well as ensuring affordable access for low-income households" they "provide a disincentive for water consumption and wastewater and an incentive for savings in the form of a water bill for households that reduced their consumption by at least 10%" (EEA 2012, 61). Copenhagen, Denmark's Cloudburst Plan "has been suggested to process the majority of the surface rain water via a system of small canals that can divert the water either

Soft Measures		
Measure by Implementation Scale	Effect	Examples
		to streams, the harbour or areas where it can be stored until being processed into the sewage system. This plan will be implemented in cooperation with neighbouring municipalities that also process their sewage water through Copenhagen." The plan also includes a rescue service plan and warning systems (EEA 2012, 43). In Salford, UK, a document entitled 'Planning Guidance on Flood Risk and Development' was adopted in July 2008, which "specifies that new residential development proposed in high flood risk zone should be designed and built in a way that floor levels for habitable rooms and kitchens would be no more than 600 mm below the flood level predicted for a 1:1000 year extreme flood event, and not below the flood level predicted for a 1:100 year event" (EEA 2012, 89).
Regional/Metropolitan		
		"In Germany the North Rhine-Westphalia region obliges all new development projects to allow for storm water channelling and offers funding to municipalities" (EEA 2012, 52) The Thames Estuary 2100 (TE2100) project "identified a set of decision pathways for flood defences during the next 100 years and mapped out available options. For each option thresholds for responses were calculated together with the required lead times necessary for implementation. These thresholds are related to different sea levels rather than to different time horizons, making them scenario-neutral and thus allowing flexible planning despite large uncertainty in the current climate projections" (EEA 2012, 90). A Green Infrastructure Valuation toolkit has been developed in the UK to rate issues such as economic growth and investment, land and property values, labour productivity, tourism, products from the land, health and wellbeing, recreation and leisure, quality of place, bio-diversity, flood management, etc.. An early release of the toolkit was tested in "Liverpool Knowledge Quarter, where it was demonstrated that a £10m investment in green infrastructure could realize £30m in economic benefits" (NCCP 2011, 11).
National		
		"Several European insurance companies have already included climate change driven wind storms and flood events into their insurance portfolio such as Munich Re in Germany." (EEA 2012, 52) "The 'Warm Front' scheme in England provides heating and insulation improvements to households on certain income-related benefits living in properties that are poorly insulated and/or do not have a working central heating system" (EEA 2012, 85) "Although experiences with monitoring

Soft Measures		
Measure by Implementation Scale	**Effect**	**Examples**
		and evaluation are as yet limited, some countries in Europe (Finland, Germany and the United Kingdom) are experimenting with the development of evaluation methods at a national level" (EEA 2012, 78) "A new national policy in the Netherlands aims to disconnect rainwater drainage from the sewer network in 20% of all urban areas in order to separate rain and wastewater"(EEA 2012, 52).
EU		
		"European Climate Adaptation Platform CLIMATE-ADAPT to assist in selecting assessment procedures and feasible options." "Adaptation Wizard (UKCIP), the Adaptation Decision Explorer (weADAPT) and the Digital Adaptation Compendium (EU ADAM project)" (EEA 2012, 77) "To support the transition from traditional flood defence strategies to a flood risk management approach at the scale of entire river basins in Europe, the European Union has adopted a floods Directive" that "requires Member States to develop and implement flood risk maps and management plans" (EEA 2012, 48). "The cities, provinces and regions participating in the 'GRaBS' project (Green and Blue Space Adaptation for Urban Areas and Eco Towns) went through a specific process when preparing their adaptation action plans. One important step was the development of a high-level policy statement noting the aims and objectives of the adaptation plan, which could be then accepted and signed off by the elected members" (EEA 2012, 75). Critical to GRaBS was "an intensive program of project meetings and mentoring visits … which facilitated the exchange of knowledge and experience between the individuals working for different local and regional authorities" (EEA 2012, 64)
Information & Awareness		
"Forecasting and early warning systems" (EEA 2012, 48). "The preparedness of health and social care system" (EEA 2012, 31). "…preparing evacuation and recovery plans preventively" (EEA 2012, 51). "Municipalities organise public information campaigns, offer technical guidance and financial help" (EEA 2012, 51). "Awareness raising, knowledge, capacity building and training are important tools to enable cities and citizens to cope" (EEA 2012, 52). "Communication with citizens, businesses and public institutions on taking appropriate measures to protect properties and vital systems" (EEA 2012, 43). "…the promotion of walking, cycling and the use of public transport; restrictions for road traffic; use of cleaner emission technology for transport, heating and cooling	"General awareness raising and ensuring broad participation." (EEA 2012, 31). "Identification of vulnerable groups and their distribution as basis for targeted action" (EEA 2012, 31). "Cities have benefied from stakeholder engagement at an early stage in their risk assessments"…as well as from…"development of specific institutional responsibilities for co-ordinating such research from the outset. This involvement has been critical in creating momentum and obtaining resources for subsequent in-depth analysis of sector impacts and adaptation needs" (Hunt and Watkiss, 2011, 13) Information hub initiatives "can increase the support for certain measures that are taken by the government at different administrative levels" (EEA 2012, 63).	

Soft Measures		
Measure by Implementation Scale	Effect	Examples
systems; creation of green areas, such as parks, can absorb and filter dust and other pollutants; and awareness raising and educating vulnerable groups to avoid certain activities during events of high air pollutant concentrations" (EEA 2012, 30).		
Spatial Planning		
"Early integration of climate change adaptation into urban planning"(EEA 2012, 34). "Prohibition of new developments in flood zones"(EEA 2012, 81) Flood risk management plans that map flood risks and take "into account climate change scenarios and information distribution" (EEA 2012, 48). "Appropriate spatial planning"…that includes…"avoiding construction of houses and industrial buildings in current and future flood-prone areas; adapting future developments to the risk of flooding; and appropriate land use, agricultural and forestry practices." (EEA 2012, 48). "Strategic planning in river basins - ban building in flood prone areas; protect flood retention and other green areas" (EEA 2012, 48). "Transport management to reduce air pollutants" (EEA 2012, 31). "Transportation analysis further suggests that it can also be important to avoid commercial or residential development in areas that can often become inaccessible during extreme weather events" (EEA 2012, 81). Using "socio-demographic variables to map sensitive groups in the municipality, e.g. elderly people, people with chronic diseases, children" (EEA 2012, 19). "Mapping of urban heat island as well as cool places" (EEA 2012, 31). "Rain water management (EEA 2012, 48)," Drought and water management plans" "Mapping of drought risks and water availability via climate change scenarios" (EEA 2012, 60).	"The early integration of climate change adaptation into urban planning, such as a network of green areas, Offers a more cost effective and long-term solution than retrofitting the city with less optimal measures" (EEA 2012, 34). "…good land-use planning will not increase vulnerability but will rather decrease it" and is "particularly important for cross-sectorial adaptation" "The way land is developed affects flood magnitudes and losses, water quality, water availability, and local heat island effects" (EEA 2012, 55; 81). Decreases "potential damages to property and improves hydrological conditions, thereby decreasing the severity of flooding" (EEA 2012, 81). "A modelling approach clarifies the magnitude of the effects and allows adaptation strategies to be tested". Model runs can "indicate which types of actions" (blue, green and grey infrastructure combinations) "are likely to be most beneficial and in which locations" (Gill et al. 2007, 130). Regional coordination can help ensure continuity for flood planning (EEA 2012). Better-integrated flood/landslide risk management plans may provide greater damage prevention (EEA 2012, 48). "…to reduce the risk of wealth destruction and human health impact by increasing the resilience of buildings and infrastructures and by preparing evacuation and recovery plans preventively" (EEA 2012, 51; 85). "Drought management plans reduce risk and economic, social and environmental impacts. They emphasise efficient use of existing water supplies and contain guidelines and drought contingency plans for public water suppliers, but also restrictions on water use, rationing schemes, special water tariffs or the reduction of low-value uses" EEA 2012, 60). "Reduce the amount of storm water, which needs to be taken up by the sewage system and thus reduce the necessity to extend and upgrade the existing sewage system" (EEA 2012, 50.)	
Policy Instruments		
"Source control includes further soft measures to change behaviour or force the implementation of measures" (EEA 2012, 50). "Different policy instruments such as insurance, taxes, specific regulations and controls and information campaigns can all be applied" (EEA 2012, 52). "Taxes or incentives, such as concerning the	"National adaptation plans and strategies provide a stimulus for the development of adaptation plans at the city level. However, where there is little or no policy pressure, adaptation planning at the local level tends to be triggered by various influences" (EEA 2012, 74). "If the interest is present, gaining political backing and managerial commitment is essential to progressing the adaptation agenda" (EEA 2012, 74)	

Soft Measures		
Measure by Implementation Scale	Effect	Examples
amount of sealed area per property, amount of waste water used (including rain water)" (EEA 2012, 48). "Adapting building and planning codes to include flood resistance" (EEA 2012, 48), "insulation and shadowing to cope with heat waves" (EEA 2012, 31). "Water pricing as incentive to use water more efficiently"; "Knowledge and capacity building to save water"; "Restriction of water use"; "Organization of emergency water supply" (EEA 2012, 60)	"Promote land use planning, emergency response and other types of risk-reducing behaviour" (EEA 2012, 52). "Spatial planning plays an important role in flood prevention by restricting building in flood plains, conserving flood retention areas and minimizing impermeable surfaces" (EEA 2012, 52). "Inclusion of storm and flood resistance into all building codes can decrease the losses from wind storms and floods" (EEA 2012, 52). Aims to ensure "that no structural damage is done to the property even as a result of an extremely unlikely event and that the damage is minimised for more probable flood events" (EEA 2012, 89). The use of "source control techniques" can potentially "reduce the quantity and improve the quality of storm water at or near its source by using infrastructure or natural physical resources" (EEA 2012, 50). "…the price of water can be temporarily raised to suppress demand" (EEA 2012, 60). "Insurance can be seen as a consequence of the economic aspect of adaptive capacity since it is predominantly an instrument used by wealthier nations and individuals. Insurance can be very important in terms of coping capacity for example in the aftermath of extreme weather events." Depending on use, "it can also guide long-term development in adaptive capacity (i.e. the total withdrawing of insurance coverage from the riskiest locations)" (EEA 2012, 69).	
Monitoring		
"Good practice states that evaluation and monitoring is carried out by an organization independent from stakeholders involved in adaptation implementation" (EEA 2012, 78).	"Monitoring enables the adjustment and refining of the adaptation options where necessary thus eliminating maladaptation" (EEA 2012, 78).	