WP 5: Development of a cost assessment framework for adaptation

D5.1: Review of climate change losses and adaptation costs for case studies

Reference code: RAMSES – D5.1
**Project Acronym:** RAMSES  
**Project Title:** Reconciling Adaptation, Mitigation and Sustainable Development for Cities  
**Contract Number:** 308497

**Title of report:** D5.1: Review of climate change losses and adaptation costs for case studies  
**Reference code:** RAMSES – D5.1

**Short Description:**  
This report provides a review of climate change and adaptation costs for European cities, including a range of case studies and stakeholder surveys.

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**Made available to:** Public

**Versioning**  
<table>
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<tr>
<th>Version</th>
<th>Date</th>
<th>Name, organization</th>
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<tbody>
<tr>
<td>0.1</td>
<td>31/3/14</td>
<td>Graham Floater, London School of Economics</td>
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**Quality check**  
Internal Reviewers: Jürgen Kropp, PIK; James Kallaos, NTNU
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1 Executive Summary

The aim of this Review was to provide an overview of climate change losses and adaptation costs in cities, particularly in the RAMSES case study cities: London, Antwerp, Bilbao, Bogota, Hyderabad, Rio de Janeiro and New York. The Review formed part of Work Package 5 of RAMSES which has the overarching goal of developing a cost assessment framework for cities.

The aim of RAMSES is not to deliver detailed cost assessments for different cities, but to provide standardised and transferable tools for cost assessments with regard to different climate threats on an intermediate scale of complexity. Nevertheless, the field of urban climate costs is relatively young, and there are few standardised data and analytical methods. Consequently, one of the main objectives of this Review was to act as a scoping exercise for assessing both the existence and gaps in evidence that could be targeted by further analysis in the RAMSES project. A second major objective was to engage city stakeholders in the RAMSES case study cities to understand and assess their expectations.

A range of climate-related threats, including both extreme weather events and slow onset events, have potentially substantial costs for cities (though not all threats, extreme weather events, and “loss and damage” are faced by all cities). The main extreme weather events identified were: sea and tidal flooding, inland flooding (fluvial and pluvial), storms (strong winds), heatwaves, drought, air pollution, coldwaves and snow. Further extreme threats included landslides and wildfires. In addition, “slow onset events” were identified that are associated with mean temperature changes as opposed to extreme events.

Following this initial review, the research team focused on four threats where a larger evidence base of costs existed, both for the case study cities and in the wider literature. These four threats are: flooding, storms, heatwaves and drought. For other threats, evidence was gathered and reported where available for individual case studies. It should be noted that some of the threats (particularly slow onset events) where evidence is scarce and that are consequently not included in detail in this Review could nevertheless have substantial costs to cities in the future and could constitute areas of further research by RAMSES.

Under the Review, the following were completed:

- review of historical costs for different extreme events in Europe;
- review of historical costs for events in RAMSES case study cities and gaps identified;
- review of climate adaptation measures and costs for RAMSES cities and gaps identified;
- review of economic sectors of RAMSES cities that may be vulnerable to climate-related events;
- analysis of stakeholder (city official) perceptions of the future costs of extreme events due to climate change.

The results of the Review suggest that costs of different extreme weather events in the case study cities follow a similar pattern to total European level costs. Examining the events with the highest losses across the case study cities, costs were highest for flooding followed by storms, with heatwaves and drought having much lower market costs.

The Review also found that the evidence for historical costs of extreme events in cities is highly incomplete and often estimated using different assumptions (e.g. different sectors, different cost accounting, market or non-market effects, and inclusion or exclusion of
network and indirect effects). Furthermore, evidence for the costs of slow onset events was not available. This makes a rigorous comparison of costs across types of climate-related event and across sectors highly challenging. For Antwerp and Bogota, no historical costs were recorded in the literature or were known to exist by the city authorities and local stakeholders. The most comprehensive data reviewed were for London. However, even for London, some of the data used and provided by the city authorities are sourced from anecdotal references such as news reports rather than academic or official analyses.

Where quantitative estimates have been produced, the climate risks most frequently examined are associated with either market costs or health costs. Almost no studies have been conducted on other non-market and indirect costs at the city level, where uncertainties are even higher than for market impacts. One of the reasons for this lack of research is the deficit in urban metrics that can be used for cost assessments. Unlike national governments, there is no standard accounting methodology at the municipal level for indicators such as wealth, economic growth, carbon emissions and employment. Outside Europe, many cities collect no standardised data at all.

While there is a paucity of data on historical costs of extreme events, there is almost no published evidence for the costs of adaptation measures sector by sector for the case study cities. One exception is New York City where, following Hurricane Sandy, the authorities commissioned an adaptation plan, and this plan focuses on one threat in particular – sea flooding.

The results of the Review have implications for the RAMSES project over the next three and a half years. The large gaps in historical data for climate-related events in case study cities suggest that standardised and transferable tools for cost assessments cannot be developed solely through extrapolation from bottom-up historical data. It will also require top-down methodologies.

In terms of the costs of adaptation measures, very few cities have attempted comprehensive cost-benefit analyses. This is partly due to the complexity of urban systems (both in the large number of sectors and the potential cascading effects within and across sectors) as well as the uncertainty of climate impact levels and frequency. The very high degree of uncertainty that this creates overall suggests that any cost assessment framework will need to consider thresholds and option spaces for policy makers rather than simple deterministic projections based on bottom up accounting methods.

Finally, stakeholder engagement and analysis in this Review suggest that the expectations of city officials with regard to the costs of different types of climate-related impacts do not necessarily match the actual costs incurred by historical events. Whatever the reasons for this mismatch, it will be important that RAMSES continues to engage with stakeholders proactively to ensure that the ongoing research is not only policy-relevant, but also provides decision makers with a stronger evidence base than currently exists.
2 Introduction

2.1 Objectives of this Review

The aim of this Review was to provide an overview of climate change losses and adaptation costs in cities, particularly in the RAMSES case study cities: London, Antwerp, Bilbao, Bogota, Hyderabad, Rio de Janeiro and New York. The Review formed part of Work Package 5 of the EU FP7 project RAMSES which has the overarching goal of developing a cost assessment framework for cities.

The aim of RAMSES is not to deliver detailed cost assessments for different cities, but to provide standardised and transferable tools for cost assessments with regard to different climate threats on an intermediate scale of complexity. Nevertheless, the field of urban climate costs is relatively young, and there are few standardised data and analytical methods. Consequently, one of the main objectives of this Review was to act as a scoping exercise for assessing both the existence and gaps in evidence that could be targeted by further analysis in the RAMSES project. A second major objective was to engage city stakeholders in the RAMSES case study cities to understand and assess their expectations.

The Review is presented in two broad parts. The first part reviews the costs associated with four types of extreme weather event that may increase in some cities due to climate change:

- flooding (including sea, tidal, fluvial and pluvial flooding);
- storms;
- heatwaves (including air pollution); and
- drought.

The first part also includes the results of stakeholder surveys, including a summary of evidence from each of the RAMSES case study cities. The surveys include historic costs of extreme weather events in the cities based on local knowledge and published sources. The stakeholder surveys also include a survey of city officials on their perceptions of the future costs of extreme weather events due to climate change; these include sea and tidal flooding, inland flooding (fluvial and pluvial), storms, heatwaves, air pollution, cold and snow, drought, and humidity.

The second part of the Review provides a review of major historic extreme events for each of the RAMSES case study cities over the last 10 to 50 years, and their associated costs where these were available.

Under the Review, the following were completed:

- review of historical costs for different extreme events in Europe;
- review of historical costs for events in RAMSES case study cities and gaps identified;
- review of climate adaptation measures and costs for RAMSES cities and gaps identified;
- review of economic sectors of RAMSES cities that may be vulnerable to climate-related events;
- analysis of stakeholder (city official) perceptions of the future costs of extreme events due to climate change.
2.2 **Scope and methodology of the Review**

2.2.1 **Case study cities**

The Review covers climate-related costs in cities in Europe and other parts of the world. Given this geographical breadth, the intention is not to provide a comprehensive analysis of costs in all cities, but to focus primarily on the RAMSES case study cities: London, Antwerp, Bilbao, Bogota, Rio de Janeiro and New York. The other RAMSES case study city, Skopje, is intended to be used for the analysis of health costs under Work Package 6 of RAMSES and is not included in this Review. In addition to the RAMSES case study cities, an analysis of flooding in Genoa was also undertaken to expand the evidence base further. The evidence from case study cities is also supplemented with reviews of climate-related costs in other cities in Europe and the rest of the world.

2.2.2 **Climate-related events**

An initial review of evidence showed that a range of climate-related threats have potentially substantial costs for cities (though not all threats and extreme weather events are faced by all cities). The main extreme weather events identified were: sea and tidal flooding, inland flooding (fluvial and pluvial), storms, heatwaves, drought, air pollution, coldwaves and snow. Further extreme threats identified included landslides and wildfires. Wherever possible, the costs of storms were limited to those costs related to strong winds (see Prahl et al., 2012 for a discussion of assessing storm costs). For example, the major costs of Hurricane Sandy were categorised as flooding rather than storm damages, as the vast majority of damages were due to the storm surge that led to extensive flooding.

In addition, incremental impacts were identified that are associated with mean temperature (gradual changes, slow onset events) changes as opposed to (singular) extreme events. These included impacts of rising mean temperatures on energy demand and associated rises in energy prices and socio-economic costs (e.g. costs of installation and operation of cooling systems), impacts of incremental coastal erosion, impacts of increased mean humidity which is a potentially substantial cost in high latitude cities (e.g. in Scandinavia) where wooden building stock is threatened, and impacts of reduced mean precipitation levels that can also lead to wooden building damage through drying (e.g. in Amsterdam). It is also important to recognise that climate-related events can have cascading effects – these are discussed in the RAMSES Report D2.1.

Following this initial review, the research team focused on four threats where a reasonable evidence base of costs existed, both for the case study cities and in the wider literature. These four threats are: flooding, storms, heatwaves and drought. For other threats, evidence was gathered and reported where available for individual case studies.

It should be noted that some of the threats where evidence is scarce and that are consequently not included in detail in this Review could nevertheless have substantial costs to cities in the future. As a consequence, the research team recommends that research is targeted on some of these other areas beyond the scope of the RAMSES project.

Where costs of events have been reported in the local currency, an estimate in euros has been provided in this Review based on the currency exchange rate on 1 January of the year in which the event occurred.

2.2.3 **Literature review and stakeholder surveys**

The evidence for this Review has been drawn from three main sources. First, an extensive literature review was undertaken on historical costs of different climate-related threats for regions/nations and cities. The review included both the seven case study cities and other cities where relevant information provided additional insights. Second, city officials and
relevant local stakeholders were interviewed to gain further insights into climate and adaptation costs in case study cities. Third, a survey of city officials (including case studies and non-case studies) was undertaken to assess how officials perceived the relative costs and likelihoods of various climate-related threats.

The published evidence for climate-related costs – and particularly adaptation costs – for the case study cities is extremely patchy. In many cases, no evidence was found for the costs of certain climate-related events. In other cases, the only evidence available to the researchers (either through literature searches or directly through the municipal government) was unsubstantiated, based on news reports or unreferenced. Given the scarcity of data, the research team decided to include the more anecdotal evidence in the review. However, it should be noted that in these cases, the evidence should be recognised as being, at best, a potential indicator of the magnitude of costs, not a rigorous analysis of the costs.

The survey of stakeholder perceptions covered three RAMSES case study cities: London, Antwerp, Bogota; and 14 other cities: Amsterdam, Dresden, Gibraltar, Paris, Shanghai, Barcelona, Bologna, Bratislava, Brussels, St. George, Blantyre, Helsinki, Stockholm and Rotterdam. Officials were asked to determine the likelihood of a threat (sea flooding, inland flooding, heatwaves, air pollution, drought, cold and snow, strong winds and humidity) increasing or decreasing with climate change and the associated costs on a scale of 1 to 10. The results were analysed using ANOVA and Principal Component Analysis to determine whether particular threats were perceived as being significantly higher than others, and whether particular cities shared common threats.

2.3 Categorising climate costs

The assessment of costs due to climate change impacts, together with the net positive or negative benefits of adaptation or mitigation, is complex. Cost assessments require the monetisation of potential impacts in areas that range from the easily quantifiable to the highly speculative. These potential impacts can be classified into market impacts and non-market impacts, or into direct and indirect impacts (Hallegatte et al., 2011). These are discussed below.

2.3.1 Market and non-market impacts

Market impacts (described as tangible, i.e. damage to capital or resource flows that can be easily specified in monetary terms) can be assessed through prices that the market sets to a particular good or service. The value of physical assets or costs associated with repair and replacement are examples. The total loss or damage to real estate assets from extreme weather events can be calculated, based either on the market value of the building lost or its costs to repair.

Non-market impacts (described as intangible, i.e. damage to assets that are not traded in a market and are difficult to transfer to monetary values) are more challenging to quantify as they tend to affect goods and services that are not traded and thus not valued in the same way (Reilly et al., 2013). Examples include the value of landscape amenity or biodiversity. Another example is the cost of climate-related impacts on health, including mortality and morbidity (see reports under Work Package 6 of RAMSES on health costs). The practice of valuing these non-market elements is growing, with models that can translate the value of, for example, environmental goods and services. Techniques for valuing non-market impacts are generally classified into methods that are derived from 'revealed preferences' and values that are based on 'stated preferences' (EEA 2007). Revealed preference methods can calculate values indirectly by using the relationships between environmental goods and expenditures on market goods. Methods for undertaking this analysis include hedonic pricing and averting behaviour method.
Stated preference methods ask individuals about their willingness to pay (WTP) for the environmental good directly, usually through structured questionnaires. The contingent valuation method (CVM) is one technique belonging to this category (EEA, 2007). Methods such as WTP are somewhat subjective and vary by circumstance related to, \textit{inter alia}, time, income, social or cultural norms. Consequently, unit values for non-market impacts need to be ‘normalised’ to demographic or socio-economic factors to allow their transfer to models in different regions or those that are global.

\section*{2.3.2 Direct and indirect impacts}

Another framework for classifying climate change costs is to differentiate between direct and indirect costs. Direct costs are costs that are directly associated with an extreme weather event or changing mean climate such as higher temperatures or humidity. Examples include the costs of repairing physical damage to buildings and infrastructure following a storm, or the costs associated with hospital admittances or deaths attributable to an extreme heat wave.

Indirect costs are those that impact the wider economy. These costs can be borne by sectors of the economy that are not directly impacted by the extreme weather event and can also be longer term costs. The boundaries between direct and indirect impacts are subject to interpretation. As a result, different definitions can lead to substantially different cost estimates for the same event; this represents a major challenge when comparing costs in the literature.

No consistent relationship between indirect costs and direct costs has been described. Consequently, the overall costs of an extreme weather event cannot be estimated accurately based solely on an estimate of the direct costs. Research undertaken following Hurricane Katrina suggested that when direct losses are relatively low, indirect losses may in fact be negative when capturing the value of reconstruction (Hallegatte et al., 2011). This suggests that the response of the economic system may dampen the shock of the event and limits the economic damage. However, when direct losses are above a certain threshold, the economic system may no longer able to react or function efficiently and indirect losses start to scale.

The interplay of these economic effects, termed the Economic Amplification Ratio (EAR) - the ratio of indirect (systemic) losses to direct (sectoral) losses - increases with the size of the event (see Figure 2.1). For an event such as Katrina, with around USD 100bn of sectoral losses, the EAR was estimated at 1.44. For a disaster with USD 200bn sectoral losses, this ratio is estimated to reach 2, with systemic losses being double the sectoral costs (Hallegatte et al., 2011).

In a study of economic damages from floods (Merz et al., 2010), the interplay between market and non-market (tangible and intangible), and direct and indirect, show the plausible range of factors within costs assessments:

- Direct, tangible: damage to private buildings and contents; destruction of infrastructure such as roads, railroads; erosion of agricultural soil; destruction of harvest; damage to livestock; evacuation and rescue measures; business interruption inside the flooded area; clean-up costs.
- Direct, intangible: loss of life; injuries; loss of memorabilia; psychological distress, damage to cultural heritage; negative effects on ecosystems.
- Indirect, tangible: disruption of public services outside the flooded area; induced production losses to companies outside the flooded area (e.g. suppliers of flooded companies); cost of traffic disruption; loss of tax revenue due to migration of companies in the aftermath of floods.
- Indirect, intangible: trauma; loss of trust in authorities.
Figure 2.1: An adaptive regional input-output model and its application to the assessment of the economic cost of Katrina. The curve shows indirect losses as a function of sectoral losses, for a disaster with the same sectoral structure of Hurricane Katrina. The equation in black is the polynomial regression of indirect losses to sectoral losses for this case study modelled. Source: reproduced from Hallegatte et al., 2011 using data from Hallegatte, 2008.

2.3.3 Long term costs

Cost estimates of climate change impacts, and assessments of the value of adaptation and mitigation efforts, are further complicated by the intergenerational aspects of climate change, i.e. the consequences of action or inaction now may not be revealed until several decades in the future, as well as differences as to where or whom the impacts will be revealed. Discounting and equity weighting are means through which these temporal and spatial relationships can be accounted.

On matters of uncertainty, modelling climate change impacts and costs (from damages, and for adaptation and mitigation) faces complexity due to the long-term nature of the problem. Models should embed any number of factors that influence these values over several decades: rate of technological change and economies of scale, movement of populations, macroeconomic growth, specific and locally relevant climatic changes, and many more. A number of socio-economic scenarios have been created by the climate change research community and several are commonly used in many large-scale models.

Assumptions on risk also create differences in outcomes. Low probability but high impact events (the ‘long-tail’ in probability distribution curves, such as the melting of the Greenland ice sheet) will have dramatic costs associated with them, but the likelihood that they will eventuate (as assumed by the modeller) may significantly minimise the economic justification for action. It has been argued that these risks and costs have been overly discounted in most models (Weitzman, 2009). However, altering the assumptions around these events can make even discounted damages very large. The long temporal build-up of 

CO₂ concentration and the potential irreversibility of some impacts mean that mid-course corrections may not be available. Addressing these probabilities is a form of social insurance against unexpected and perhaps unmanageable consequences, and present action can have valuable impacts on future welfare.
2.3.4 Quantitative methodologies for cost assessment

Determining costs and priorities for action needs to balance information sets that reveal current baseline conditions, project scenarios on future climate changes within socio-economic and environmental frameworks, and determine levels of either planned or autonomous adaptation, if any. This modelling may range from assessments that: target a single-sector, individual countries, or regions; capture the totality of sectors and interactions – referred to as Integrated Assessment Models (IAMs), or; are global in their nature. Input factors can include direct or indirect costs, and those that are market or non-market valued. Outcomes can refer to total or average costs, or marginal costs. In summary, modelling can be used to determine whether the costs of adaptation are net positive, either through accrued benefits, avoided costs, or some combination thereof. The following, taken from the 2007 EEA report *Climate change: the cost of inaction and the cost of adaptation*, lists relevant metrics and methods for understanding costs and benefits:

- **Total social costs** - the total (social) costs of climate change reflect the total economic costs of the baseline scenario, either in a given future year (e.g. 2100), or as a total net present value over, e.g. the next 100 years or longer. By dividing by the total emissions of carbon, it is possible to assess the average cost of Greenhouse Gas (GHG) emissions.

- **Marginal social costs** - the marginal social costs of climate change are usually estimated as the net present value of all climate change impacts over the next 100 years (or longer) of one additional tonne of carbon or other GHG emitted to the atmosphere today. They are the marginal global damage costs of carbon emissions. The marginal social costs are usually estimated by assessing the economic costs of climate change under the given baseline, and then rerunning the analysis with an additional pulse of carbon emissions (e.g. an additional tonne). The difference between the two scenarios (over all future years) provides the marginal social cost.

- **Marginal abatement costs** - the marginal abatement cost (MAC) reflects the marginal technology and represents the cost of abating an additional tonne of carbon. This metric is often used for the assessment of mitigation policy costs.

- **Cost-benefit analysis (CBA)** - CBA is designed to help policy makers choose the best option by calculating the net benefits as the balance of total benefits and total costs of alternative projects or policies. It quantifies costs and benefits in monetary terms, including values not captured by markets (i.e. the full social or economic costs). CBA also has the capacity to determine the optimal policy, i.e. where net benefits are maximised: this occurs when marginal abatement costs are equated to marginal abatement benefits. However, researchers and policymakers face major challenges in estimating comparable costs for climate threats on the one hand and adaptation measures on the other.

- **Cost-effectiveness analysis (CE)** - CE analysis compares the costs of alternative ways of producing the same or similar outputs. It is therefore a relative measure, i.e. it only provides comparative information between choices and cannot show whether the chosen project will have a net benefit to society, as CBA theoretically does. It is typically used in one of two ways — it can be used to identify the highest level of achievement given available resources, or it can be used to assess the least-cost approach of reaching a given target (e.g. a threshold level). It is worth noting that cost-benefits and cost-effectiveness analyses are not necessarily mutually exclusive.

---

1 Planned adaptation are programmed actions taken by public or private sector actors based on policy decisions or clear market signals supported by economic or social analyses. Autonomous adaptation refers to the more subtle and less strategically planned actions that humans or natural systems make based on external stimuli.
Economic modelling, principally as practised in cost-benefit analyses for long-term assessments, necessarily embeds many assumptions around the uncertainties on magnitude and timing of climate damages. Decision makers need to understand the precision attached to such monetary estimates and make judgements on priorities accordingly (Kunreuther et al., 2013). Shorter term analyses may yield more accurate values but may only offer a partial solution against the scale of the problem. Cost-effectiveness studies to calculate the least-cost strategies for achieving a range of potential carbon reduction or climate adaptation targets can be a valuable alternative and well suited to political processes. Options can be produced and assessed that are aligned with society’s collective willingness to pay (Ackerman and Finlayson, 2006).

2.3.5 Multi-criteria analyses

In addition to the formalised cost-benefit and cost-effectiveness tools, decision-makers may also employ multi-criteria analyses (MCAs) which may be less quantitative but more instructive for integrating questions of social preferences, ethical fairness and political realities. While most of the insights and techniques of CBA can be incorporated into the market (monetised) criterion in MCA, MCAs can more transparently integrate non-monetised factors and risks and uncertainties that influence choices and decisions.

MCAs can be particularly valuable for revealing priorities for action and preferences towards certain adaptation pathways or directions (Bell et al., 2003). MCA processes tend to be more participatory and stakeholder oriented than CBA or CE modelling. While this creates a risk that vested interests may over-influence the review and findings, it allows for particular features of ‘local’ conditions to emerge, which is ultimately where adaptation decisions are enacted. It can help circumvent problems with economic modelling approaches which are subject to wide assumptions and uncertainties, and that have been shown to ignore specific issues of equity and the distribution of wealth. It is this latter which has proven particularly challenging for climate change economics as the costs tend to be met disproportionately by those who cannot afford insurance, re-location or adaptation investments (Barker, 2008).

2.3.6 Adaptation costs and assessment

Policy decisions for delivering adaptation measures are driven by the need to reduce vulnerability to climate change, and can be assessed by the costs of implementation and the socio-economic benefits they yield. The IPCC (2001, p.6) has defined vulnerability as “the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of variation to which a system is exposed, its sensitivity and its adaptive capacity.” In simple terms, assessing sensitivity reveals information about what is impacted by climate change and how frequently and intensively, whereas adaptive capacity is about the resilience of the impacted system. Reducing vulnerability can be accomplished by addressing both functions.

Adaptive capacity is generally believed to be determined by technological options, economic resources and their distribution, human and social capital, and governance. (Tol, 2005) In a study on the vulnerability of Australian cities to climate change prepared for the Australian Greenhouse Office in 2005-06, the following key determinants of adaptive capacity were developed from a range of public health and social science literature sources and refined specifically for an urban-centric approach to assessing climate change vulnerability and prioritising adaptation:

• Diversity of Critical Systems (is the impacted area reliant on single or multiple resource sets and solutions?)
• Awareness (have climate change impacts been studied and made available to decision-makers and stakeholders?)

• Wealth (are financial resources available to address the need?)

• Sensitive Populations and Ecosystems (are higher-risk sub-groups, eg. elderly, highly drought-sensitive species, etc. present, in large numbers and have they been recognised?)

• Available Technology (are adaptation and mitigation solutions ready and implementable?)

• Urban Design Standards (have analyses of what the existing infrastructure was designed to withstand and its condition been undertaken?)

• Vested Interests (do existing organisations and structural conditions inhibit change?)

• Appropriate Decision Making / Governance and Jurisdiction (are institutions and governance structures available and configured to fashion a response to the impact?)

• Ability to Manage Information (can large and complex sets of data inputs be organised so that information is available and actionable?)

• Monitoring and Surveillance (is there an effective system to track climate change effects and responses; is the feedback loop functioning?)

• Human Capital (are there skilled people available to contribute to and manage climate change adaptation?)

• Social Capital (what is the capacity of people to pull together in the time of crisis?)

• Psychological Capital (what is the capacity of people to withstand multiple and at times lasting impacts and adapt to change?)

Utilising these determinants in a vulnerability assessment (for example, a multi-criteria assessment to determine priorities) may reveal significant variances in adaptive capacity depending on the system, sector or geography being studied. The list shows that adaptation can target both ‘hard’ (e.g. flood defences, or robustly engineered infrastructure) and ‘soft’ (e.g. institutional preparedness, appropriate skills, management capacity) measures. Research into adaptation has revealed a general bias towards hard measures, driven by the fact that these are easier to cost and more visible when delivered. However, acting on this bias may yield actions that ultimately prove less cost-effective than addressing human and institutional capacity (Fankhauser and Burton, 2011).

In addition to distinguishing between hard and soft approaches, adaptation can be characterised further by how it addresses:

• timing (are the actions anticipatory versus reactive);

• scope (do they apply locally versus regionally, are they short-term in application and impact or long-term);

• purposefulness (are the actions autonomous versus planned); and

• adapting agent (are the actions revealed in natural systems versus human systems, undertaken individually or collectively, led by private actors or the public sector).

(OECD 2008)

Urban-focused impact assessments, if holistic, need to deal with the complex and somewhat unbounded nature of cities. As an example, climate impacts that are not directly revealed in a particular urban system may nonetheless create effects due to that nature of supply chains. Food and materials sourced from distant locations for local consumption
mean that system stresses in other regions may create local consequences. Whilst adaptation decisions made by the affected city may not be able to address those source stresses (e.g. introducing drought tolerant plant species in distant agricultural regions that face water supply issues), they can address the nature of the local resiliency to those stresses (e.g. promoting city-based or regional agricultural production to strengthen the link between local supply and demand).

Hallegatte et al. (2011) offer a methodological roadmap to assess local economic impacts of climate change in cities (see Figure 2.2). It shows how the process can be iterative and capture influences from both mitigation and adaptation. It further allows for sensitivity testing of how various responses will produce different outcomes for the system or city being assessed. However, it should also be recognised that, given the uncertainties inherent in climate change and adaptation costs in cities, using deterministic single trajectories is less useful for policy makers that the use of an options space.

For understanding and quantifying the impacts on physical assets, different approaches and data sources may be used. Insurance records offer an evidence base of losses from weather events and are often the most comprehensive data sets that aggregate information
over long time periods and multiple assets. However, there are limitations to insurance data. For example, the data only address insured assets, may only capture insured losses (i.e. damages paid out rather than total damages sustained), and are based on historical weather patterns that may change substantially with climate change in the future. The data remain important, however, for statistical assessments, providing key inputs to future projections. Typically, extrapolations can be made against the universe of assets - existing and predicted to be present in the future - to gain perspective on the likely scale of future damages. ‘What if’ scenarios can also be run from these data sets, for example by estimating the damages of a future flood by scaling up historical costs of past flooding events.

Another approach is for the assessment to be engineering-based. In this case, the design and robustness of physical assets are assessed against variable parameters such as wind speed, water flow and velocity and ground saturation to understand how climate conditions will lead to damages or underperformance. Assessors tend to rely on a small number of detailed investigations that are then imposed over a larger number of units based on generalised typologies. Acero et al. (2013) provides a database of physical and cost typologies for buildings and infrastructure which covers storm, flood and heat impacts on various building typologies, and on water and wastewater, transport and energy systems. In the case of utilities, climate change impacts include not only direct damages but also impacts on supply and demand. For example, temperature changes can increase the demand and reduce the supply of water, or increase demand for energy but create supply bottlenecks.

Models or scenarios can be used to produce reviews in specific sectors or tied to specific climatic variables. There are various reasons for these more narrowly tailored investigations, including an acknowledgement of the boundaries or organisational capacity of stakeholders and decision-makers, or simply to produce a refinement of larger integrated models based on a prioritisation exercise. For example, studies of the urban heat island effect show that ‘cool’ or ‘reflective’ surfaces such as roofs and roadways and the planting of urban trees are cost-effective measures for moderating temperatures. (Akbari, 2005) The results demonstrate a direct contribution in temperature reduction that leads to decreased energy demand. In practical terms for cities, this means less reliance on mechanical air conditioning, which creates a circular benefit as mechanical cooling generates external (city-wide) heat gains in order to produce the desired internal comfort. The fact that trees and vegetation sequester carbon means that the strategy delivers a direct mitigation benefit, though in this case the indirect mitigation improvement of reducing energy consumption and thus CO\(_2\) emissions from the power sector is greater than the direct. Indirect benefits can also be calculated in health measurements, with shade trees and lower temperatures reducing particulate and ozone concentrations that influence the prevalence of respiratory morbidity and mortality.

Costs of hard protection, regulation and governance (e.g. dykes, land use planning to avoid overbuilding in flood prone areas, and information and preparedness actions) will be substantial. But they may be exceeded in the aggregate by individual private measures such as insurance and building-level precautionary measures. The precautionary measures may include any number of actions to raise the building, seal or shield against water ingress, building without basements and / or using flood resilient materials in basements and lower floors, and moving furnishings to upper floors during flood events.

Many of these precautionary measures will only be cost-effective during time of renovation or rebuilding, and costs will vary widely based on building design and construction. While studies show that precautionary measures are more effective in smaller-scale floods, benefits are clearly significant in major events. Social factors such as sharing information amongst neighbours, community-level engagement and planning can also be significant determinants in reducing damage costs. A review of the 2002 flood from the Elbe River in
Germany (a 1 in 200 year event) showed the cost-effectiveness of these precautionary measures, even for this major event. Damages to buildings and for contents were consistently lower when adaptation measures were taken (see Figure 2.3).

Figure 2.3: Building and contents damage ratios for households with and without flood adapted use and measures (bars=means, points=medians and 25–75% percentiles). Source: reproduced from Kreibich et al., 2005 p. 124.
3 Flooding

3.1 Definition of flooding

The EEA defines a flood disaster as a result of both societal and hydro-meteorological factors (EEA, 2011). Consequently, the areas most heavily damaged by flooding are highly populated urban areas.

Coastal flooding occurs due to storm surges induced by winds, where seawater is driven towards the coast, resulting in the inundation of low-lying areas. Other flooding disasters tend to occur further inland, most commonly as a result of rainfall (pluvial flooding) or due to river overflows (fluvial) and other general flooding. Flash floods are rapid inland floods caused by intense rainfall, with the fast flow of water resulting in high destructive potential (EM-DAT, 2014b). Floods can also occur from snowmelt or glacier lake outbursts.

3.2 Economic costs of flooding

3.2.1 Flooding events in Europe

The EEA reports that between 1998 and 2009, a total of 213 flooding events were recorded across Europe, resulting in 1,126 fatalities and EUR 52.17bn of damages (EEA, 2011). The trends they report are of increasing economic costs over the past decades (see Figure 3.1), with some evidence suggesting that this increase is due to increasing population and assets in exposed areas. However, it should be noted that the improvements in data collection over time may have introduced bias to the cost estimates.

No major sea flooding events unrelated to storms have been reported on the Emergency Events Database (EM-DAT) for Europe in the past 10 years. For storm-related sea flooding events, refer to Section 4 Storms. Inland flooding across 210 reported events in Europe resulted in damages of EUR 24.4bn between 2003 and 2013, as well as an estimated 887 fatalities (EM-DAT, 2014a). The large majority of European countries experienced some form of flooding, with around 30 listed on EM-DAT with recorded events.

Five major flood events were recorded in the UK in 2007, resulting in total estimated damages of EUR 2.23bn, 8 fatalities and 3,785 people affected (EM-DAT, 2014a). The months of May, June and July in England and Wales were the wettest in over 200 years, with some areas experiencing more than a month’s rainfall in 24 hours (EEA, 2011). Particular examples include Pershore in Worcestershire receiving rainfall of 143 mm and Brize Norton in Oxfordshire recording 126 mm, both in periods of 24 hours.

Flash flooding events in Romania killed 14 people on the 20th June 2006, while there were five more general flooding events that year, resulting in another 37 fatalities and two injuries, as well as leaving 5,000 people homeless (EM-DAT, 2014a). This followed flooding in 2005, which killed 79 people and cost almost EUR 970m.

Bulgaria experienced five separate flooding events in 2005, leading to 39 fatalities and an estimated EUR 337m of damages, affecting over 12,000 people (EM-DAT, 2014a).

Flash flooding in the Czech Republic and Poland occurred twice in 2010 resulting in 10 fatalities, with even more flooding occurring that year resulting in an additional 20 fatalities, and an estimated total damage of EUR 2.39bn across all events that year (EM-DAT, 2014a). The Czech Republic was also particularly affected in 2013, when Prague and its surroundings were flooded, killing 7 people and costing an estimated EUR 786m. Over 7,000 people had been evacuated in the Czech Republic, with flooding causing the disruption of water supplies and flushing raw sewage onto the streets. Throughout Europe that year damages amounted to over EUR 1.3bn, affecting around 1,300,000 people and killing 28 (EM-DAT, 2014a).
3.2.2 Flooding events in the rest of the world

A total of 1,817 major flooding events have been recorded by EM-DAT worldwide between 2003 and 2013 (including Europe), resulting in an estimated EUR 204bn of damages over 10 years, and almost 65,000 fatalities.

Research suggests that damages from sea flooding in the world’s major coastal cities may exceed USD 1 trillion a year by 2050 (Hallegratte et al., 2013). The study is based on data for the 136 largest coastal cities around the world. In 2005, the average global losses for coastal cities have been estimated at USD 6bn per year, with the increase to 2050 predicted to be USD 52bn per year. This takes account of the socio-economic changes only. Climate change and subsidence account for the rest of the projected rise of costs.

The most costly sea flooding events between 2003 and 2013, excluding storm events, both economically and in terms of fatalities, have occurred in Southern and South-East Asia. Six events in 2007 resulted in over 220 reported deaths and estimated damages of EUR 549m, with a population of almost eight million affected (EM-DAT, 2014a). Vietnam alone
experienced losses of around EUR 364m, while India experienced around EUR 208m of damages. Other coastal flooding events are discussed in the Storms section of this report.

Fluvial and pluvial flooding has affected over one billion people outside of Europe between 2003 and 2013. These events killed over 63,000 people, left over 13 million homeless and injured over 200,000 (EM-DAT, 2014a). Damages are estimated at a cost of almost EUR 190bn.

The most economically costly inland flooding events occurred across South-Eastern Asia in 2011, with a total damage estimate of EUR 31bn, and killing over 1,700 people (EM-DAT, 2014a). Recent events in Eastern Asia have resulted in substantial losses: EUR 12.6bn of damages and 1,921 fatalities in 2010; EUR 8bn of damages and 754 fatalities in 2011; and EUR 11.4bn of damages and 746 fatalities in 2012.

### 3.3 Damages by sector

#### 3.3.1 Buildings

The Association of British Insurers (ABI) estimated losses from storms and floods in the UK to have exceeded GBP 6bn (EUR 8.5bn) during 1998-2004 (Dlugolecki and Catovsky, 2004). ABI estimates future claims will be two or three times higher than today’s level unless action is taken to reduce the impacts of climate change (Dlugolecki and Catovsky, 2004; ABI, 2004). Table 3.1 shows estimates of future costs of insurance claims due to flooding across the UK. Costs from inland floods are expected to double by 2050 on an annual average basis and triple during an extreme year (Dlugolecki and Catovsky, 2004; ABI, 2004).

<table>
<thead>
<tr>
<th></th>
<th>Today</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Annual average</td>
<td>Extreme year</td>
</tr>
<tr>
<td>Inland flood</td>
<td>400 [570]</td>
<td>1,500 [2,000]</td>
</tr>
<tr>
<td>Coastal flood</td>
<td>-</td>
<td>5,000 [7,100]</td>
</tr>
</tbody>
</table>


Table 3.2 shows data from the ABI on insurance claims from general flooding events in the UK between 2002 and 2012. Although claims represent only a proportion of overall losses, it provides an indication of relative order of magnitude of events across years.

<table>
<thead>
<tr>
<th>Year</th>
<th>Gross Claims Incurred (GBP million)</th>
<th>Number of Claims</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>115</td>
<td></td>
</tr>
<tr>
<td>2003</td>
<td>61</td>
<td></td>
</tr>
<tr>
<td>2004</td>
<td>60</td>
<td>22,000</td>
</tr>
<tr>
<td>2005</td>
<td>155</td>
<td>16,000</td>
</tr>
<tr>
<td>2006</td>
<td>62</td>
<td>11,000</td>
</tr>
<tr>
<td>2007</td>
<td>973</td>
<td>68,000</td>
</tr>
<tr>
<td>2008</td>
<td>273</td>
<td>17,000</td>
</tr>
<tr>
<td>2009</td>
<td>150</td>
<td>9,000</td>
</tr>
<tr>
<td>2010</td>
<td>102</td>
<td>6,000</td>
</tr>
<tr>
<td>2011</td>
<td>52</td>
<td>8,000</td>
</tr>
<tr>
<td>2012</td>
<td>335</td>
<td>26,000</td>
</tr>
</tbody>
</table>

*Table 3.2: Domestic flood damage in the UK. Source: ABI, 2013.*
The most costly events occurred during 2007 where GBP 973m (EUR 1.44bn) of insured losses occurred across the UK (compared to a total estimate on EM-DAT of EUR 2.23bn) (ABI, 2013). Another estimate for the cost of the 2007 floods has been estimated at a total of GBP 3.3bn (EUR 4.9bn) in insurance claims (The Kitemark, 2014).

The 2002 London Climate Change Partnership (LCCP) report, The Impacts of Climate Change on London, studied the associated insurance costs of flooding (2002b). According to the ABI in 2002, 25% of households choose not to insure their contents, with this number rising to 50% for low-income groups due to the price (GLA, 2002). Furthermore, an informal study in East Sussex revealed that many households and business are underinsured by between GBP 5,000 (EUR 8,000) and GBP 20,000 (EUR 32,000) (around 15% of residents in Lewes where the study was undertaken, which had been flooded in November 2000). Typical flood claims per household were around GBP 15,000 (EUR 24,000) to GBP 30,000 (EUR 48,000) at the time of the report.

In cities such as London, where property values are high, there are many basement flat conversions, which are particularly vulnerable to flooding (LCCP, 2002b). This is especially due to the fact that often these flats are rented-out, thus protection measures are less likely to have been taken by the owner, and the residents are likely to be amongst the less affluent- often with less insurance cover.

The US National Flood Insurance Program, (NFIP), has estimated costs for the flooding of an average US household. These are based on a home built on a slab foundation (thus no basement flooding costs are taken into account) and containing typical items, with costs estimated for a floor space of 93m$^2$ and 186m$^2$ and for varying levels of flooding (NFIP, 2014). Table 3.3 provides a summary of the costs. In another study, the costs of flooding for a two storey building were estimated to be 37% less on average than for a one storey design, provided that the flood waters do not reach levels above 1.2m (the height of the first storey) (Acero et al., 2013).

The residential property losses in New Orleans alone following Hurricane Katrina in 2005 have been estimated at USD 16bn (IPET, 2007), while across the United States, insurance claims have been estimated to total USD 66.9bn from The American Insurance Services Group (AISG) and the NFIP (Knabb et al., 2011).

<table>
<thead>
<tr>
<th>Height of flood (mm)</th>
<th>Total cost (USD) for 93m home</th>
<th>Total cost (EUR) for 93m home</th>
<th>Total cost (USD) for 186m home</th>
<th>Total cost (EUR) for 186m home</th>
</tr>
</thead>
<tbody>
<tr>
<td>25.4</td>
<td>10,600</td>
<td>7,690</td>
<td>20,240</td>
<td>15,170</td>
</tr>
<tr>
<td>50.8</td>
<td>10,670</td>
<td>7,740</td>
<td>21,000</td>
<td>15,230</td>
</tr>
<tr>
<td>76.2</td>
<td>11,450</td>
<td>8,310</td>
<td>22,590</td>
<td>16,380</td>
</tr>
<tr>
<td>101.6</td>
<td>15,150</td>
<td>10,990</td>
<td>29,650</td>
<td>21,510</td>
</tr>
<tr>
<td>127.0</td>
<td>17,310</td>
<td>12,560</td>
<td>33,870</td>
<td>24,570</td>
</tr>
<tr>
<td>152.4</td>
<td>20,150</td>
<td>14,620</td>
<td>39,150</td>
<td>28,400</td>
</tr>
<tr>
<td>304.8</td>
<td>27,150</td>
<td>19,690</td>
<td>52,220</td>
<td>37,880</td>
</tr>
<tr>
<td>609.6</td>
<td>33,700</td>
<td>24,440</td>
<td>62,880</td>
<td>45,610</td>
</tr>
<tr>
<td>914.4</td>
<td>36,600</td>
<td>26,550</td>
<td>68,100</td>
<td>49,390</td>
</tr>
<tr>
<td>1,219.2</td>
<td>39,950</td>
<td>28,980</td>
<td>74,580</td>
<td>54,090</td>
</tr>
</tbody>
</table>

Table 3.3: Total estimated costs of a typical US home. Source: NFIP, 2014.
3.3.2 Transport

Between 1999 and 2004 flooding events on the London Underground metro system caused more than USD 12m (EUR 9.5m at 2004 exchange rates) of costs due to passenger delays (Arkell and Darch, 2006). In another example, the disruption to rail services caused by a flooded rail line, which affected a London bound train in December 2000, led to estimated costs more than GBP 1m (EUR 1.6m) (LCCP, 2002b).

3.3.3 Energy

Urban flooding can have a substantial impact on energy and utilities. As a result of Hurricane Sandy in New York in 2012, a third of the electricity generating capacity was lost with five major electric substations being flooded, causing their temporary shutdown (City of New York, 2013). Parts of the natural gas distribution network were also flooded, and four out of six steam plants in the city were made inoperable. An estimated 2 million New Yorkers were left without power and around 80,000 households had their natural gas supplies cut off. One third of New York City’s buildings were without heat or hot water due to the disruption of the steam system—also affecting several major hospitals. Service was mostly restored within four days of Sandy’s departure from the city; however, some power outages lasted for two weeks, as electricians and plumbers had to repair flooded equipment door-to-door. While no comprehensive cost estimates have been conducted on these impacts, the overall socio-economic costs to the city would have been considerable.

3.3.4 ICT and finance

Flooding and storms can also impact on the information and communications technology (ICT) and financial sectors. For example, Hurricane Sandy caused The New York Stock Exchange to close trading for two days. Originally only floor trading was intended to be closed. However, as the scale of the potential storm surge increased, the authorities decided to halt electronic trading as well. This was the first weather-related unscheduled market-wide shut down since Hurricane Gloria in 1985. According to Shaefer (2012), the previous weather-related event where trading was closed for more than a single day was in 1888.

3.3.5 Water and waste

While storm surge is normally the cause of sewage discharge during hurricanes, it is also likely to occur due to high rainfall. For example, in Washington D.C. the rainfall from Hurricane Sandy released 475 million gallons of untreated sewage (Kenward et al., 2013). Examples of damage costs to sewage systems occurring from Hurricane Sandy include: the Passaic Valley Sewage Commission in Newark, N.J. which expected over USD 200m (EUR 154m) in repairs; the sewer system in Westchester County, N.Y. which had a total damage cost of USD 14.5m (EUR 11.2m); and South Monmouth County, N.J. which experienced USD 10m (EUR 7.7m) in damages to sewer equipment.

Overall New York State estimates USD 1.9bn (EUR 1.5bn) of system repair and recovery costs to sewage and wastewater systems. The New Jersey Department of Environmental Protection had plans to allocate USD 2.6bn (EUR 2.0bn) on water infrastructure following the damage caused by Sandy, with USD 342m (EUR 264m) going towards recovery, USD 553m (EUR 426m) on repairs, and the rest of the money going towards building resilience into the system.
3.4 Adaptation costs

Few cities have undertaken comprehensive estimates of the costs of adapting to increased flooding due to climate change. The New Jersey Department of Environmental Protection is currently spending USD 1.7bn (EUR 1.3bn) on building resilience into the wastewater and sewage system, following the damages caused by Hurricane Sandy (Kenward et al., 2013). In the UK, a permanent flood barrier has been installed in Tewkesbury in order to protect a water treatment work. The barrier cost GBP 5.5m (EUR 6.2bn) (Acero et al., 2013).

In another example, all properties in Seattle (with the exception of city streets and state highways) are charged a drainage fee based on percentage of impervious surface area and land parcel size (Seattle, 2014). For example a small residential parcel of under 280 m$^2$ would be charged USD 180.96 in 2014 (EUR 131.25), while a larger one of between 650 m$^2$ and 930 m$^2$ would have a charge of USD 403.70 (EUR 292.81) (Seattle, 2014). This money is used for storm water management services.

One of the few cities to have a costed cross-sector adaptation plan is Copenhagen. A summary of the adaptation measures and costs is set out in Table 3.4.
<table>
<thead>
<tr>
<th>Measure</th>
<th>Costs</th>
<th>Total estimated costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stormwater</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduction of the hydraulic watercourses</td>
<td>DKK 200,000</td>
<td>DKK 1,101,850,000</td>
</tr>
<tr>
<td>Passing on knowledge to the public/businesses on options for climate-proofing</td>
<td>DKK 100,000</td>
<td></td>
</tr>
<tr>
<td>Planning and implementation of the plan B solutions in the city of Copenhagen</td>
<td>DKK 500,000</td>
<td></td>
</tr>
<tr>
<td>Opening of piped watercourses</td>
<td>DKK 1,100,600,000</td>
<td></td>
</tr>
<tr>
<td>Disconnection of stormwater from the sewer</td>
<td>DKK 150,000</td>
<td></td>
</tr>
<tr>
<td>Quantification of the effect of different suds elements</td>
<td>DKK 300,000</td>
<td></td>
</tr>
<tr>
<td>Coordinated wastewater planning in the whole catchment of Lynettefællesskabet</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Seawater</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surveying of coastline</td>
<td>DKK 100,000</td>
<td>DKK 200,000</td>
</tr>
<tr>
<td>Selection of instruments</td>
<td>DKK 100,000</td>
<td></td>
</tr>
<tr>
<td>Soil and Groundwater</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Risk of infiltration to the drinking water resource</td>
<td>DKK 75,000</td>
<td>DKK 200,000</td>
</tr>
<tr>
<td>Calculations of effects of increased infiltration of stormwater</td>
<td>DKK 75,000</td>
<td></td>
</tr>
<tr>
<td>Possibility of putting surplus soil to use in climate adaptation</td>
<td>DKK 50,000</td>
<td></td>
</tr>
<tr>
<td>Monitoring of groundwater level</td>
<td>DKK 150,000</td>
<td></td>
</tr>
<tr>
<td>Buildings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Registration of buildings in areas at risk</td>
<td>DKK 100,000</td>
<td>DKK 300,000</td>
</tr>
<tr>
<td>Upgrading of qualifications/training</td>
<td>DKK 200,000</td>
<td></td>
</tr>
<tr>
<td>Emergency Preparedness</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Warning systems</td>
<td>DKK 100,000</td>
<td>DKK 100,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>DKK 1.102bn</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Around EUR 148m)</td>
</tr>
</tbody>
</table>

Table 3.4: Adaptation measures and costs. Source: Copenhagen, 2011.
4 Storms

4.1 Definition of storms

A storm is a meteorological event characterised by strong winds, and often accompanied by heavy precipitation such as heavy rainfall, hail or snow (EEA, 2011). Direct economic damage normally occurs due to wind loading of structures such as buildings, vehicles, boats, scaffolding, cranes and overhead power networks (Barredo, 2010).

Europe experiences its large storms mainly from October to April, and according to annual reports by reinsurance companies their impact in terms of insured losses is second only to the hurricanes which occur in the Caribbean and southern United States (EEA, 2011). Worldwide losses incurred from storms in 2012 amounted to around 63% of total natural catastrophe losses, i.e. around USD 100bn (EUR 77bn) lost worldwide due to storm damage (Munich Re, 2013a).

4.2 Economic costs of storms

4.2.1 Storm events in Europe

The EEA reports that between 1998 and 2009, a total of 155 storm events were recorded across Europe, resulting in 729 fatalities and EUR 44.34bn of damages (EEA, 2011).

The five of the most severe storms in Europe between 1999 and 2011 have been estimated to be Lothar, Martin, Kyrill, Klaus and Xynthia (Munich Re, 2013b). Lothar and Martin hit many countries in Europe in December 1999, affecting France, Switzerland, Germany, Denmark, Sweden, Poland, Lithuania, Austria and Spain (EEA, 2011). The widespread damage resulted in 151 fatalities and a population of about 3.5 million people who were affected. Overall losses amounted to EUR 15.5bn, of which EUR 8.4bn was insured. Most damage was to housing and transportation systems, as well as damage to the forestry sector.

Kyrill caused 46 deaths in 2007 and overall losses of almost EUR 8bn, of which EUR 4.5bn was insured, after hitting the UK, Denmark, Germany, Poland and the Czech Republic, with maximum wind speed of 212 km/hour recorded in its path from Poland to the Czech Republic (EEA, 2011).

Klaus occurred in January 2009, affecting France, Spain and Italy, with 28 fatalities and EUR 4bn of overall losses (EUR 950m of which were insured) (EEA, 2011), while figures from Munich Re show losses of USD 3.8bn (EUR 2.7bn) with USD 2.3bn being insured (EUR 1.6bn) (Munich Re, 2009).

Xynthia affected most of Western Europe (Belgium, France, Germany, Luxembourg, The Netherlands, Portugal, Spain, Switzerland and the UK) in 2010, with an estimated EUR 4.2bn of damage and 64 fatalities (EM-DAT, 2014a).

In 2013, Europe was affected by hailstorms in Germany on the 27th and 28th July (Munich Re 2014a). The losses estimated from this were EUR 3.6bn overall, with around EUR 2.8bn being insured. Winter storm Christian (St. Jude) then went on to cause widespread damage between the 27th and 30th of October. Estimates for insured losses from this event range between EUR 1.5bn and EUR 2.3bn (Alert Worldwide, 2013).
4.2.2 Storm events in the rest of the world

The largest overall losses for 2011 were recorded in the United States, where severe storms and tornadoes between the 22nd and 28th April caused an estimated USD 15bn (EUR 11.2bn) in losses, about USD 7.3bn (EUR 5.5bn) of which were insured losses, and some 350 fatalities (Munich Re, 2012).

Hurricane Irene caused a lot of devastation between 22nd August and 2nd September, hitting the USA and the Caribbean, with estimated losses of USD 15bn (11.2bn), of which roughly USD 7bn (EUR 5.3bn) was insured, along with 55 fatalities (Munich Re, 2012).

The largest fatalities occurred when tropical storm Washi hit the Philippines and resulted in an estimated 1,257 fatalities (Munich Re, 2012).

The following year, 2012, saw widespread storm damage worldwide also. South Africa was hit severely by hailstorms in October, while the largest typhoons in Asia hit in August and December. Typhoon Haikui hit China from 8th until the 9th of August. Typhoon Bopha hit the Philippines from the 4th to the 5th of December, resulting in around 1,100 fatalities, and an estimated USD 600m (EUR 460m) in losses (Munich Re, 2013a).

North America experienced extensive damage in 2012. Storms and tornadoes hitting the USA in March resulted in 41 deaths and USD 2.5bn (EUR 1.9bn) of insured losses. Further events in April led to 350 deaths and USD 2.5bn (EUR 1.9bn) of insured losses, and again in July when there were 18 fatalities and USD 2bn (EUR 1.5bn) of insured losses. Hurricane Isaac affected the USA and Caribbean in August, followed by Hurricane Sandy in October. Canada also suffered losses in August when it was hit by hailstorms and severe storms in August (Munich Re, 2013a).

Typhoon Fitow hit China and Japan in October of 2013, causing 12 fatalities and losses of USD 5bn (EUR 3.9bn), around USD 750m (EUR 580m) were insured (Munich Re, 2014a). Typhoon Haiyan then struck the Philippines, Vietnam and China in November, leading to 6,095 fatalities and overall losses of USD 10bn (EUR 7.7bn) (of which around USD 700m (EUR 540m) were insured).

North America was also affected in 2013, with severe storms in March killing 2 people and resulting in USD 2.2bn (EUR 1.7bn) in overall losses (USD 1.8bn (EUR 1.4bn) insured) and with severe storms and tornadoes causing extensive damage on two occasions in May, the more severe of which caused 28 fatalities and overall losses of USD 3.1bn (EUR 2.4bn) (USD 1.8bn (EUR 1.4bn) insured) (Munich Re, 2014a). Then, in September, Hurricanes Ingrid and Manuel hit Mexico (Munich Re, 2014b).

The USA is generally heavily affected by tornadoes, with the top three years by number of tornadoes being 2008 with almost 2,200 tornadoes, 2011 with almost 1,900 and 2010 with almost 1,500.

4.3 Damages by sector

4.3.1 Buildings

Buildings are particularly vulnerable to storm damage. Table 4.1 shows data from the ABI on losses from storm events in the UK between 2002 and 2012, much of which is property damage. Damages range from GBP 140m (EUR 215m) in 2003 to GBP 547m (EUR 811m) in 2007.
<table>
<thead>
<tr>
<th>Year</th>
<th>Gross Claims Incurred (EUR million)</th>
<th>Number of Claims</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>765</td>
<td></td>
</tr>
<tr>
<td>2003</td>
<td>215</td>
<td></td>
</tr>
<tr>
<td>2004</td>
<td>311</td>
<td>352,000</td>
</tr>
<tr>
<td>2005</td>
<td>423</td>
<td>424,000</td>
</tr>
<tr>
<td>2006</td>
<td>294</td>
<td>253,000</td>
</tr>
<tr>
<td>2007</td>
<td>811</td>
<td>603,000</td>
</tr>
<tr>
<td>2008</td>
<td>380</td>
<td>344,000</td>
</tr>
<tr>
<td>2009</td>
<td>180</td>
<td>194,000</td>
</tr>
<tr>
<td>2010</td>
<td>167</td>
<td>209,000</td>
</tr>
<tr>
<td>2011</td>
<td>333</td>
<td>250,000</td>
</tr>
<tr>
<td>2012</td>
<td>344</td>
<td>369,000</td>
</tr>
</tbody>
</table>

Table 4.1: Domestic storm damage in the UK. Source: Association of British Insurers

HomeAdvisor (2014) has estimated costs of repairs to the US homes post storm and wind damage, with a range of between USD 840 and USD 11,000 (approximately EUR 600 – EUR 7,900 at current exchange rates). Their findings are shown in Figure 4.1.

![Figure 4.1: Repair Storm or Wind Damage Costs. Source: reproduced from HomeAdvisor, 2014.](image)

FM Global (2008) has reported that the insured wind losses averaged USD 400m (EUR 300m) per year between 1998 and 2007, with 80% of these being related to roofing system failures, and approximately 1,128 roof-related events reported during this period, totalling USD 1.7bn (EUR 1.3bn) (2007 value).

4.3.2 Transport

High speed winds on October 20th 2000 caused trees to be blown on railway tracks between London and the south east, which led to three separate train crashes (LCCP, 2009). Engineers had to work overnight to clear the trees. Overcrowding and disruptions of public transport during the rush hours followed, and the damage costs were estimated at around GBP 2bn (EUR 3.2bn).
Hailstorms, for instance those affecting parts of Germany in 2008, can potentially cause substantial damages to cars. The total impact of hailstorms in 2008 was estimated at over EUR 1bn (EEA, 2011).

### 4.3.3 Energy

Winter storm Klaus, 2009, in Europe caused power cuts in over 1 million households, with disruption to supply affecting 1.5 million homes in France alone (EEA, 2011).

Kyrill in 2007 caused major disruptions across Germany, Austria, Poland and the Czech Republic, leaving 2 million households without electricity and cutting off communications networks (EEA, 2011).

Winter storm Andrea in 2009 caused disruptions to power supply as it passed over the United Kingdom, affecting almost 1,000 homes in Nottingham (Alert Worldwide, 2012). As it passed over Austria it caused further disruptions to power supplies, most significantly affecting Tyrol, with about 10,000 households losing power.

The Irish Independent reported that network repairs and equipment replacement has cost over EUR 2m for Eircom, an Irish telecommunications company, following storms at the start of 2014, where both broadband and telephone services had been impacted (Weckler, 2014). However the figures in this report have not been independently verified.

### 4.4 Adaptation costs

Measures for reducing the impact of storms tend to focus on prevention, emergency planning and post-disaster relief (EEA, 2011). The EEA states that perhaps one of the best storm management options to reduce losses from storms is prevention by the building of strong infrastructure capable of withstanding strong gusts of wind. Emergency planning and management has already been well developed in Europe, with storms and their paths having been successfully predicted in the past, for example Kyrill and Klaus, which has meant that the population has been accurately alerted. The most widespread option remains post-disaster aid and insurance to cover the damage and destruction of both public and private assets. However, information on costs for rehabilitation of non-insured public infrastructure and services is scarce.

FM Global (2008) reports that the most economically effective way to reduce windstorm loss in commercial roofing is to attach additional fasteners to the small edge areas of the roof. For example, a quote they provide for the reinforcement of 3m edges of a 9.1m high building of up to 30.5m in width is “most of the time, less than USD 5,000” (EUR 3,800) (FM Global, 2008).

It should be noted that little rigorous evidence is available on the adaptation costs of measures for reducing the impact of strong winds and storms in cities. This is an area that should receive more attention for research.
5 Heatwaves

5.1 Definition of heatwaves

A range of definitions exist for heatwaves, which can make standardised comparisons challenging. The EEA (2011, p.41) define heatwaves as being “a prolonged period of excessively hot, and sometimes also humid weather relative to normal climate patterns of a certain region”. The European Climate Assessment and Dataset project (ECA&D 2010 cited by EEA 2011) define heatwaves more specifically as “a period of at least six consecutive days on which the mean daily temperature exceeds the 90th percentile of the baseline temperature (average daily temperature in the 1961–1990 period).” Meanwhile, the WHO (2009) defines a heatwave as “a period when maximum apparent temperature and minimum temperature are over the 90th percentile of the monthly distribution for at least two days”.

5.2 Economic costs of heatwaves

5.2.1 Heatwave events in Europe

The EEA (2011) reports that between 1998 and 2009, a total of 101 heatwaves and coldwaves were recorded across Europe, resulting in 77,551 fatalities and EUR 9.96bn of damages. Between 2003 and 2009, 23 of the 32 EEA member countries (EU 27 and Iceland, Liechtenstein, Norway, Switzerland and Turkey) were affected by heatwaves and coldwaves (EEA, 2011). The vast majority of fatalities – over 75,000 – were due to heatwaves, and in particular the European heatwave of 2003.

The most extreme heat wave events occurred in 2003, 2006 and 2007 (EEA, 2011). The 2003 heatwave caused more than 70,000 deaths in excess of the average for the five preceding summers across 12 European countries (Robine et al., 2008). The 2006 heatwave caused the biggest number of fatalities in Belgium, France and the Netherlands. Temperatures exceeded records held for the month of July 2006 in the Netherlands, Belgium, Germany, Ireland and the United Kingdom (EEA, 2011). The 2007 was very disruptive for most of southern Europe and the Balkans as well as Turkey (EEA, 2011). Temperatures in Greece, Italy, Bulgaria, Romania, Serbia and Croatia exceeded 45 °C during that summer (EEA, 2011).

The EEA (2011, p.9) has described heatwaves as “the most prominent hazard with regard to human fatalities” (see Table 5.1). This is partly because of their surprise effect (Mairie de Paris, 2007). Heatwaves and hypothermia is most likely to affect the elderly and the already ill and the economically disadvantaged (CDC, 2005)
Heatwaves lasting more than four days long are thought to lead to a mortality 1.5–5 times higher than during short heatwaves (Matthies et al., 2008). If night-time temperatures remain high then the effect of heatwaves on health are greater. This means health effects of heatwaves are highest in cities, because of the Urban Heat Island effect and its limitation of night-time cooling (Doick and Hutchings, 2013). The Climate Change Risk Assessment (CCRA) included modelling of fatalities due to heatwaves and heat stress and predicted a 60% increase in fatalities by the 2020s and a 200% increase by the 2050s (DEFRA, 2012). The 2003 hot summer in Europe is thought to have led to more than 70,000 additional fatalities. In addition to the very high number of fatalities the 2003 heatwave and hot summer caused across many European countries, it has been estimated to have cost EUR 10bn of economic losses because of damage to farming, livestock and forestry (EEA-JRC-WHO, 2008). The hot weather in 2006 and 2007 combined is thought to have led to an excess of almost 3,000 deaths (EEA, 2011).

In the UK, 1,100 premature deaths per year are estimated to be due to heat stress (Doick and Hutchings, 2013). Summer heatwaves in the UK are estimated to lead to 8-11 deaths for each degree increase in air temperature (Doick and Hutchings, 2013). In the 2006 heatwave in England, each degree increase in air temperature led to an estimated 10.7 extra deaths (Department of Health, 2008). The three-day-heatwave of 2009 caused 299 excess deaths in England and Wales (Andrews et al., 2010).

### 5.2.2 Economic costs of air pollution

Major heatwaves have an exacerbating effect on air pollution which increases mortality (WHO, 2009). For example, high temperatures can increase the rate of ground-level ozone formation (EPA, 2014). When ozone or PM$_{10}$ levels are high, the daily death rate during heatwaves is higher, particularly among the elderly (75-84 years) (EEA, 2011). Daily deaths in this age group “increase by 16.2 % on heatwave days with high ozone levels, and by 14.3 % on days with high PM$_{10}$ levels, respectively, compared to an increase of 10.6 % and 10.5 % on days with low levels of ozone and PM$_{10}$” (EEA, 2011).
The economic costs of air pollution can be substantial. The World Bank (2007) examined the cost of air pollution in China and estimated the total costs at CNY 157.3bn in 2003, or 1.16% of GDP. If the adjusted human capital approach is replaced by the value of a statistical life (VSL) based on studies conducted in Shanghai and Chongqing, the cost increases to around CNY 780bn, or around 5.8 percent of GDP (World Bank, 2007).

The UK Department for Environment Food and Rural Affairs (DEFRA, 2013b) estimates that air pollution is expected to reduce life expectancy of people in the UK by 6 months on average, imposing a cost of around GBP 16bn (EUR 19.6bn) per year.

Air pollution is thought to have cost Singapore USD 3.7bn (EUR 3.2bn) (4.31% of Singapore’s GDP) in 1999 alone (Quah and Boon, 2003).

Lee et al. (2011) estimate that PM$_{2.5}$ inhalation during a year in Seoul leads to 2,181 deaths for acute exposure and 18,510 premature deaths for chronic exposure. PM$_{2.5}$ inhalation is thought to cost about USD 1.06bn (EUR 0.79bn) per year for acute exposure, and USD 8.97bn (EUR 6.72bn) per year for chronic exposure (Lee et al., 2011).

### 5.3 Damages by sector

#### 5.3.1 Buildings

In 2002, the ABI stated that their members incurred costs of nearly GBP 1m (EUR 1.6m) every day on average from subsidence (LCCP, 2002a). The 2003 heatwave caused GBP 400m (EUR 613m) in subsidence claims across the UK (City of London, 2010). The last 30 years have seen subsidence claims rise after summer droughts and account for GBP 3.3bn (EUR 3.7bn) of insurance claims over the 1990s.

The ABI anticipates household insurance costs to rise across the UK between GBP 3bn (EUR 3.4bn) to GBP 12bn (EUR 13.5bn) by 2080s as a result of climate change (City of London, 2010). Table 5.2 indicates the estimation of costs of subsidence insurance claims by the ABI.

<table>
<thead>
<tr>
<th></th>
<th>Today</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Annual Average</td>
<td>Extreme year</td>
</tr>
<tr>
<td></td>
<td>300 [425]</td>
<td>600 [850]</td>
</tr>
</tbody>
</table>


#### 5.3.2 Transport

The 1995 hot summer in the UK lead to an extra GBP 1.2m being spent on domestic flights, and GBP 12m less being spent on international tourist flights (see Table 5.3) (LCCP, 2002a). Rail travel also benefited from this domestic wave of tourism, and had an increased revenue from holiday and leisure trips of GBP 11.6m that year (see Table 5.3) (LCCP, 2002a). Car travel also added to domestic travelling increases (LCCP, 2002a). Hot weather is also thought to increase the use of bicycles, and correspondently hot summers have been thought to bring increased cases of bicycle-related accidents. In 1995 pedal cycle accident is thought to have cost GBP 14m (see Table 5.3) (LCCP, 2002a).
<table>
<thead>
<tr>
<th>Transport Mode</th>
<th>Benefits</th>
<th>Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Transport</td>
<td>Increased internal holiday flights (GBP 1.16m)</td>
<td>Loss of overseas holidays (GBP 11.6 m)</td>
</tr>
<tr>
<td>Rail Transport</td>
<td>Increased revenue from holiday and leisure trips (GBP 11.6 m)</td>
<td>Rail buckles (GBP 1.16m) Speed restrictions (GBP 1.16m) Lineside fires (GBP 1.16m)</td>
</tr>
<tr>
<td>Road transport</td>
<td>Reduced maintenance costs (GBP 9.4 m)</td>
<td>Increase in pedal cycle accidents (GBP 14m)</td>
</tr>
<tr>
<td>Water transport</td>
<td>Reduced delays to offshore shipping (GBP 1.16m)</td>
<td>Closure of canals - loss of income (GBP 1.16m)</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td>Benefits GBP 23.32m</td>
<td>Costs GBP 41.84m</td>
</tr>
</tbody>
</table>

Table 5.3: Estimated costs and benefits of the weather of 1995 on air, rail, road and water transport (GBP million). Source: LCCP, 2002a.

Heatwaves and high temperatures also affect rail transport negatively. If temperatures reach between 39 degrees C (Dobney et al. 2009 cited by Acero et al., 2014) and 43 degrees C (TRB 2008 cited by Acero et al., 2014) railway tracks can buckle and deform. The impact of heatwaves on railways lead to costs because of accidents, damage-repair, delays and cancelation (Acero et al., 2014). Dobney et al. (2009) estimate that railway damage costs on average GBP 50 (EUR 52) per delay minute. A higher use of cars is likely to occur during heatwaves. However an increased usage of urban motor vehicles during high temperatures can lead to higher levels of air pollution and therefore additional health problems. Following the 2003 heatwave in France, the city of Paris has recommended that urban motor vehicle traffic be reduced during heatwaves (Mairie de Paris, 2007).

In high temperatures the asphalt used in roads can soften resulting in ruts or it can come off the road surface or form bubbles (Mills and Audrey, 2002). Under high temperatures, pavement plates can expand and “hit neighbouring plates and either first arch up or break immediately” (Acero et al., 2014). The costs of repairing road and pavement damages are hard to determine as they depend on a variety of factors such as for example what materials have been used (Acero et al., 2014).

### 5.4 Adaptation costs

Hallegatte et al. (2007) consider Paris, and present the following four adaptation measures for the city to better cope with heatwaves.

The first adaptation measure proposed by Hallegatte et al. (2007) is to install air conditioning (AC) in sensitive places such as hospitals, subways and apartments for elderly people. This could be implemented within months but depends on the availability and production of the necessary equipment (Hallegatte et al., 2007). This measure generates short term moderate costs and necessitates small investments in the electric supply system to adapt to an energy increase in summer (Hallegatte et al., 2007).

The second adaptation measure proposed is to provide AC in all dwelling places, Hallegatte et al. (2007) declare that this could be undertaken within one or two decades and would need to be combined with the development of new electric-production capacities. In the warmest European countries AC facilities increases very regularly with GDP (EECCAC, 2002). The impact of having widespread AC on the energy grid has been calculated in the US – where 64% of households have some type of AC – and been estimated to increase
energy demand by 10 TWh/year (Hallegatte et al., 2007). In Paris the cost of such an increase of energy demand would require an investment of EUR 7bn, and additional costs of EUR 400m a year (Hallegatte et al., 2007).

A third measure is to adapt building infrastructure and urban planning regulation to make new buildings less vulnerable to high temperatures and/or enable low cost AC (Hallegatte et al., 2007). The timescale required for this strategy is about 150 years, and “the permanent capital cost […] would be small since the ratio of the construction costs of a low-class building to an upper-class one is only one to two” (Hallegatte et al., 2007, p.53). Hallegatte et al. (2007) calculate that this would cost Paris about EUR 1.2bn per year.

The fourth measure is to adapt buildings rapidly to warmer temperatures - this would be necessary in case of drastic and rapid warming. Such a measure would be substantial: “assuming a mean rehabilitation cost per apartment of 25,000 € yields 80 G€ for Paris-IDF”. It would also take approximately 20 years to complete but would prevent the higher energy demand expected with the first two adaptation measures (Hallegatte et al., 2007, p.54).

In the United States, fatalities due to heatwaves have declined, in part because of the increasing number of households with air conditioning facilities (Davis et al., 2003). The number of houses with air conditioning is expected to increase, having a considerable impact on the energy grid. It is thought that by 2100 California will need at least 10% more electricity for air conditioning alone during peak demand days in summer (Miller et al., 2005 cited by Cayan et al., 2006).

Public health warnings can also help to reduce fatalities. The state of Philadelphia has implemented a “Hot Weather Health Watch/Warning System”. Between 1995 and 1998 the system issued warnings on 21 days and has been estimated to have saved 117 lives. If every life saved is estimated at USD 4m, then the Philadelphia heat health warning system led to a gross benefit of USD 468m, or USD 117m per year. The costs of the Philadelphia Warning System are due to the heatline and additional emergency medical services. Between 1995-1998, these costs amounted to around USD 300,000, or USD 75,000 per year (Koppe et al., 2004). The costs of the Philadelphia Warning System were estimated in 2002, and indicate total costs of USD 115,000 (see Table 5.4), and additional system costs ranging between USD 50 000 and USD 60 000 (Kalkstein, 2002 cited by Koppe et al., 2004).

<table>
<thead>
<tr>
<th>Intervention measure</th>
<th>Cost per unit (USD)</th>
<th>Total summer 2002 (USD) [EUR]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heatline</td>
<td>2,950 (weekend)</td>
<td>25,000</td>
</tr>
<tr>
<td></td>
<td>1,220 (weekdays)</td>
<td></td>
</tr>
<tr>
<td>Insurance of fans</td>
<td>13 (per fan)</td>
<td>7,000</td>
</tr>
<tr>
<td>Extended hours of senior centres</td>
<td></td>
<td>3,000</td>
</tr>
<tr>
<td>Mobile teams</td>
<td>357–476 (weekend)</td>
<td>4000</td>
</tr>
<tr>
<td></td>
<td>156 (weekday)</td>
<td></td>
</tr>
<tr>
<td>Extended hours of the emergency medical services of the Fire Department</td>
<td>4,000</td>
<td>76,000</td>
</tr>
<tr>
<td><strong>Total per year</strong></td>
<td></td>
<td><strong>115,000 [128,900]</strong></td>
</tr>
</tbody>
</table>

Table 5.4: Total costs of single intervention measures in 2002 in Philadelphia. Source: Koppe et al., 2004 using data from Kalkstein, 2002.

Trees can reduce road and pavement damage from heatwaves. Their presence lowers the air and surface temperatures and irradiance (Mcpherson and Muchnick, 2005). Mcpherson and Muchnick (2005) have estimated that over a 30-year period the shade from a Crape
myrtle on a street reduces road damage repair costs by USD 2.04 (EUR 1.50) per m² and the shade from a Hackberry by USD 7.13 (EUR 5.25) per m². Shading from trees has been found to reduce pavement maintenance costs by 15 to 60% depending on the type of shade the trees provided (McPherson and Muchnick, 2005).

Direct shade provided from trees and vegetation can also reduce energy used for cooling buildings. These cooling energy savings can range between 7 and 47 percent (Akbari et al., 1993 cited by EPA, 2008). Another study has demonstrated that when an average of three trees are planted within 3 metres of a house, annual cooling energy savings were 1 percent per tree, and annual heating energy use decreased by almost 1 and 2 percent per tree (Simpson and McPherson, 1998). Trees are thought to provide net benefits even in winter because the positive wind shielding effect outweighs the negative effect of added shade (EPA, 2008). A study in the United States has shown that in Sacramento, CA, a 25% increase in urban tree coverage can save 40% of annual cooling energy and 25% in Phoenix, AZ and Lake Charles, LA (Huang et al., 1987).

In their study of the positive effect of trees in London, Doick and Hutchings (2013) found that green spaces in London “prevent 2°C of additional UHI warming and may be saving 16–22 lives a day during spells of hot weather”. London’s green spaces are collectively valued at GBP 26.4 - 36.4m (EUR 32.4 – 44.6) because of their role in averting heat stress and therefore excess deaths (Doick and Hutchings, 2013).

Planting trees does come with costs but cost benefit analyses have shown that the benefits mostly outweigh the costs when it comes to planting trees. A cost and benefit analysis in Tucson, Arizona showed that planting 50,000 trees over 40 years resulted in costs of USD 9.61 per tree versus total benefits of USD 25.09 per tree (McPherson, 1991). This tree planting project is projected to have a 7.1% rate of return (Koppe et al., 2004).
6 Drought

6.1 Definition of drought

According to the EEA (2011, p.54): “Drought is a natural phenomenon, which is defined as sustained and extensive occurrence of below average water availability, caused by climate variability”. It should not be confused with aridity, or water scarcity. Droughts can be of various durations (from months to years) and be spread across parts of the territory of some countries or only specific regions. Vulnerability to drought is thought to vary and be defined by social factors such as “increases in population and regional migration trends, demographics, urbanization, land use changes, natural resources policies, water use trends, environmental awareness and degradation, technology and the like” (World Bank, 2006, p.1).

6.2 Economic costs of drought

6.2.1 Drought events in Europe

The EEA reports that between 1998 and 2009, a total of eight drought events were recorded across Europe, resulting in no fatalities and EUR 4.940bn of damages (EEA, 2011). Over the past 30 years, droughts are estimated to have cost EU countries EUR 100bn (EC 2007 cited by EEA, 2011). In the period 1991-2006, droughts are thought to have cost EUR 6.2bn/year, this is double the costs from 1976–1990 (EEA, 2011). In Europe the 2003 drought is estimated to have cost EUR 8.7bn (EEA, 2011). The bulk of these costs are due to agricultural losses rather than direct impacts to cities.

In Europe droughts are easier to manage than in many regions of the world because of the region’s financial resources and relatively high water availability – Europe uses only 13% of its available resources each year (EEA, 2009).

European cities generally rely on their surrounding regions for water. In drier regions, cities draw on water supplies from further afield. For example, Athens, Paris and Istanbul have all developed wide water networks (often over 100-200 km) to ensure the circulation and transportation of water into the city (EEA, 2011). However, the growth of urban populations, improving lifestyles, and drinking water quality standards mean that large cities are increasingly at risk of droughts.

6.2.2 Drought events in the rest of the world

Droughts are thought to be among the most devastating natural hazard given their impact on food and water availability (FAO, 2013b, 2014). The FAO suggests that droughts cause more deaths and force the displacement of more people than cyclones, floods and earthquakes combined. Droughts can lead to substantial economic, environmental and social impacts (World Bank, 2006). More than 11 million people have died as a consequence of drought since 1900 (FAO, 2013a).

The health risks due to droughts mainly include increased risks of diseases, malnutrition and famine (Logar and van den Bergh, 2011). Loss of lives due to drought can also be exacerbated because of the migration of people, usually from rural to urban areas, social conflicts can arise, crime rates can increase, income distribution can change and social welfare can be expected to change (Logar and van den Bergh, 2011).

The large costs associated with drought are generally due to impacts on food and water availability – particularly in rural areas. However, drought also leads to impacts in cities. Direct costs of droughts are the costs due to their biophysical impact - direct physical
damages to buildings, infrastructure, stemming from subsidence and fire – and include losses in resource-based sectors (Logar and van den Bergh, 2011). These include damages to the agricultural sector – such as “land value reduction, failure of perennial crops (e.g., orchards, groves, vineyards) – soil degradation by wind erosion and/or damage to any productive capital damaged as a direct consequence of water shortages” the energy sector (if it is dependent on hydro-power), water navigation, and water-intensive manufacturing and households (Markandya and Mysiak, 2010).

Indirect costs of drought represent the impact of the natural hazard on the economy as a whole. They are the costs due to changes in resource based sectors on the rest of the economy (Logar and van den Bergh, 2011). For example when drought induces damage to crops and yields production can become limited, unemployment can increase, revenues can decrease, trade can be diminished, national, regional or local government tax revenues can be expected to be smaller because of a lower tax base, there can be increased pressure on financial institutions (higher credit risks, capital deficits), and investments may be postponed (Markandya and Mysiak, 2010; Logar and van den Bergh, 2011). Furthermore, impacts of severe drought can lead to large migrations of people from affected rural areas to the nearest cities and other urban areas. Tourism and electricity prices may also be impacted. Health care costs may increase, especially because of respiratory problems due to an increased concentration of dust particles in the air (Logar and van den Bergh, 2011). These indirect costs of droughts can have long term effects.

### 6.3 Damages by sector

#### 6.3.1 Buildings

A direct impact of droughts on buildings is subsidence (Logar and van den Bergh, 2011). Dlugolecki (2007) has reported that drought-induced subsidence has cost insurers in the UK and France billions of dollars in recent decades. Damages to buildings due to subsidence of the ground in France is estimated to have cost EUR 237m per year for the period 1989-2002 (Corti et al., 2009). Furthermore, the damage costs of subsidence have doubled since the 1961-1990 period – when subsidence damage costs to buildings equated to EUR 115m. Logar and van den Bergh (2011) argue that the increase in costs indicates a causal relationship between subsidence and climate change, because the increase corresponds with temperature increases and a higher incidence of drought (see Figure 6.1).

![Figure 6.1: Correlation between UK household buildings subsidence damage and drought (1988-2006)](image)

Legend: Subsidence damage measured in £2003 million. Data supplied by the ABI. Drought intensity measured in accumulated precipitation over the 18 months prior to September of the corresponding year (in mm). Source: reproduced from Logar and van den Bergh, 2011 using data from Dlugolecki, 2007.
6.3.2 Energy

Droughts in areas that rely on hydropower can have a ripple effect on energy prices and air pollution levels. For example, the 2002-2003 drought in Norway, Sweden and Finland reduced hydropower production and led to a substantial increase in electricity prices (Kuusisto, 2004; Silander et al. 2006; NVE 2003 cited by EEA 2011). Hydroelectric power stations on the Meuse, Nederijn and Vecht were forced to run on limited capacity (10-25% of normal) for several weeks because of water shortages (EEA, 2011).

In the United States, in an average year, California sources 10 - 25% of its electricity from hydropower. Johnson (2014) has suggested that if California experiences more severe droughts in the future, the state will need to substitute hydropower with energy from natural gas, thereby increasing prices and reducing air quality.

The drought in 2004-2005 was one of the most severe recorded in the Iberian Peninsula, with only half of the average precipitation (EEA, 2011). Hydroelectric power production in the region was reduced by 40% and thermoelectric power plants had to be used to meet energy demands (García-Herrera 2007 cited by EEA, 2011).

In 2005 in Portugal, low hydroelectric production due to drought cost the country EUR 883m (Demuth 2009 cited by EEA, 2011). The country had to use fossil fuels costing EUR 182m in order to compensate for the low hydroelectric production (EEA, 2011).

If river water is used to provide the cooling water in electricity generation plants then droughts have a further negative impact (EEA, 2011). This is a risk for nuclear and other forms of power production. In 2003 power stations in the Netherlands and France were forced to reduce their production capacity because of high water temperature levels and low river levels (EEA, 2011).

6.3.3 Water and waste

In 2008 in Barcelona, water had to be shipped into the country by tankers because of water scarcity and drought. This is thought to have cost an estimated 18m EUR (EEA, 2011). The drought cost Barcelona EUR 450m for emergency measures to increase water supply (EEA, 2011).

Water supply services in Cape Town face a number of challenges in order to become more efficient. This is particularly important as water demand has been predicted to exceed the total potential yield for the area, if the economic and population growth scenarios are realised and if the predicted impacts of climate change on water supply and demand materialise themselves (DWAF, 2004 cited by Mukheibir and Ziervogel, 2007).

Southern Africa has been impacted by extensive droughts over the past 20 years. These have altered the water resources and dam levels in Western cape and added pressure on the future adaptability of water resources and induced demand-side management responses (Mukheibir and Ziervogel, 2007). Because of climate change and the expected increase in the frequency of droughts, the current water management practices will have to be adapted and a long term plan will have to be implemented to ensure demand and water supply match even in times of reduced availability (Mukheibir and Ziervogel, 2007).

6.3.4 Tourism

Droughts in the Southeast Mediterranean coincide with the largest demands from tourists (Hunt and Watkiss, 2011). If heatwaves and droughts are to increase, tourists may be dissuaded from visiting parts of southern Europe during summer. Droughts cost the French tourist industry an estimated EUR 144m during the winter of 2006-2007 in the Alps-Savoie (EEA, 2011).
6.4 Adaptation costs

Due to the incremental effects of drought, few studies have been undertaken to assess the costs of adaptation measures for example in reducing the future impacts of subsidence on building and infrastructure damages.

The World Bank (2006) has suggested that a risk-based approach to droughts would be more cost effective than the reactive response which has historically been the common response. For example, a study by Hensher et al. (2006) indicated that households and businesses in Canberra, Australia were more willing to endure drought water restrictions than to pay higher water bills. Hensher et al. (2006) argue this has implications for policy makers. The findings indicate that implementing permanent low-level restrictions may be justified and easily accepted by the public. Logar and van den Bergh (2013) also argue that the social impacts of droughts depend on how willing people are to live with less water during a drought period, and their willingness to change their habits. In order to be successful, drought mitigation and adaptation policies will need to expand over a 20 or more year period. This is because the effects of drought are difficult to observe in the short term, so in order to not lose momentum or incentives for mitigation or adaptation a long term initiative would be necessary (Logar and van den Bergh, 2013).
7 Climate-related costs in case study cities

7.1 Losses from extreme events and adaptation costs

7.1.1 Costs at the European level

In this section, we summarise the evidence from our review on the costs of different historical climate-related events, both for the RAMSES case study cities and for other cities where evidence has been gathered. We also examine the adaptation costs under New York City’s adaptation plan, A Stronger, More Resilient New York – the only RAMSES case study city where a cost assessment of this type has been undertaken (following Hurricane Sandy).

The evidence for historical costs of extreme events in cities is incomplete and often estimated using different assumptions (e.g. different sectors, different cost accounting, market or non-market effects, and inclusion or exclusion of network and indirect effects). This makes a rigorous comparison of costs across types of extreme weather event and across sectors highly challenging. This should be borne in mind when regarding the available information. The conclusions here are not definitive, but provide an illustration of the areas where further research may be conducted most effectively.

Before considering the costs of extreme events in cities, it is worth examining the evidence for costs more generally at the national and international levels. According to the EEA, flooding led to the highest weather-related costs between 1998 and 2009 in Europe (see Table 7.1; Figure 7.1a). Flooding damages totalled EUR 52.2bn, followed closely by storm damages of EUR 44.3bn. Heatwaves, coldwaves, forest fires and drought caused substantially lower market costs, between EUR 4.9bn and 10bn.

In contrast, heatwaves and coldwaves were responsible for many more excess fatalities, and the health costs of these extreme events are most likely to be substantial (see Table 7.1; Figure 7.1b). Between 1998 and 2009, 77,551 recorded excess deaths were attributed to heatwaves and coldwaves – the vast majority of these being due to the heatwave in the hot summer of 2003.

<table>
<thead>
<tr>
<th>Hazard</th>
<th>Recorded events</th>
<th>Number of fatalities</th>
<th>Economic losses (EUR billion)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flooding</td>
<td>213</td>
<td>1,126</td>
<td>52.17</td>
</tr>
<tr>
<td>Storms</td>
<td>155</td>
<td>729</td>
<td>44.34</td>
</tr>
<tr>
<td>Heatwaves &amp; coldwaves</td>
<td>101</td>
<td>77,551</td>
<td>9.96</td>
</tr>
<tr>
<td>Forest fires</td>
<td>35</td>
<td>191</td>
<td>6.92</td>
</tr>
<tr>
<td>Drought</td>
<td>8</td>
<td>0</td>
<td>4.94</td>
</tr>
<tr>
<td>Snow avalanche</td>
<td>8</td>
<td>130</td>
<td>0.74</td>
</tr>
<tr>
<td>Landslide</td>
<td>9</td>
<td>212</td>
<td>0.55</td>
</tr>
</tbody>
</table>

7.1.2 Costs at the city level

The climate-related events for which costs were sourced for the RAMSES case study cities between 1900 and 2013 ranged between EUR 1.1m (London heatwave in 2003) and EUR 14bn (floodings from New York City’s Hurricane Sandy in 2012). In terms of economic output at the city level, the costs of events ranged from 0.0002% to 3% of municipal Gross Domestic Product (GDP) (see Table 7.2). The costs of different extreme weather events in the case study cities follow a similar pattern to total European level costs estimated by the EEA. Examining the events with the highest losses across the case study cities, costs were highest for flooding followed by storms, with heatwaves and drought having much lower market costs (see Figure 7.2a).

Table 7.2 also shows the lack of historical data on costs for many of the RAMSES case study cities. For Antwerp and Bogota, no historical costs were recorded in the literature or
were known to exist by the city authorities and local stakeholders. The most comprehensive data found were for London. However, even for London, some of the data used and provided by the city authorities are sourced from anecdotal references such as news reports rather than academic or official analyses.

<table>
<thead>
<tr>
<th>RAMSES CASE STUDY CITIES</th>
<th>London</th>
<th>Antwerp</th>
<th>Bogota</th>
<th>Hyderabad</th>
<th>New York</th>
<th>Bilbao</th>
<th>Rio de Janeiro</th>
<th>Total range (EUR)</th>
<th>Total range (% GDP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea flooding</td>
<td>EUR 1.2bn (0.0002% GDP) – EUR 2.6bn (0.37% GDP)</td>
<td>EUR 40.5m (0.2% GDP)</td>
<td>EUR 930m (3% GDP)</td>
<td>EUR 14bn (1.6% GDP)</td>
<td>EUR 930m – EUR 14bn</td>
<td>1.6 – 3%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inland flooding</td>
<td>EUR 1.2m (0.0002% GDP) – EUR 2.6bn (0.37% GDP)</td>
<td>EUR 40.5m (0.2% GDP)</td>
<td>EUR 358.5m (1.2% GDP)</td>
<td>EUR 1.2m – EUR 2.6bn</td>
<td>EUR 1.2m – EUR 2.6bn</td>
<td>0.0002 – 1.4%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Storms</td>
<td>EUR 1.2m (0.0002% GDP) – EUR 2.6bn (0.37% GDP)</td>
<td>EUR 40.5m (0.2% GDP)</td>
<td>EUR 224.6m (1.4% GDP) – EUR 358.5m (1.2% GDP)</td>
<td>EUR 139m – EUR 2.6bn</td>
<td>EUR 139m – EUR 3.2bn</td>
<td>0.06 – 0.4%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heatwaves</td>
<td>EUR 1.1m (0.0002% GDP) – EUR 119m (0.021% GDP)</td>
<td>EUR 139m (0.06% GDP)</td>
<td>EUR 139m (0.06% GDP)</td>
<td>EUR 1.1m – EUR 119m</td>
<td>EUR 1.1m – EUR 119m</td>
<td>0.0002 – 0.021%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drought</td>
<td>EUR 437m (0.064% GDP)</td>
<td>EUR 437m (0.064% GDP)</td>
<td>EUR 437m (0.064% GDP)</td>
<td>EUR 1.1m – EUR 3.2bn</td>
<td>EUR 1.1m – EUR 3.2bn</td>
<td>0.06%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL COST RANGE (EUR)</td>
<td>EUR 1.1m – EUR 3.2bn</td>
<td>-</td>
<td>-</td>
<td>EUR 40.5m</td>
<td>EUR 14bn</td>
<td>EUR 224.6m – EUR 358.5m</td>
<td>EUR 139m</td>
<td>EUR 1.1m – EUR 14bn</td>
<td></td>
</tr>
<tr>
<td>TOTAL COST RANGE (% GDP)</td>
<td>0.0002 – 0.43%</td>
<td>-</td>
<td>-</td>
<td>0.2%</td>
<td>1.6%</td>
<td>1.4 – 3%</td>
<td>0.06%</td>
<td>0.0002 – 3%</td>
<td></td>
</tr>
</tbody>
</table>

Table 7.2: Summary of absolute and relative costs from historical extreme events in the RAMSES case study cities. No recorded costs were found for coldwaves, mean warming, humidity, coastal erosion, wildfires or landslides.
Figure 7.2a: Highest cost extreme weather events in RAMSES case study cities, 1900-2013

Figure 7.2b: Perceived costs of extreme events due to future climate change (responses from municipal officials averaged across 20 cities)

Figure 7.2c: Estimated costs of adaptation measures by sector in New York City. Averages of ranges from City of New York 2013. Conversion of USD to EUR based on 1 January 2013.
While there is a paucity of data on historical costs of extreme events, there is almost no published evidence for the costs of adaptation measures sector by sector for the case study cities. One exception is New York City where, following Hurricane Sandy, the authorities commissioned an adaptation plan under *A Stronger, More Resilient New York*. As Figure 7.2c shows, the estimated costs of adaptation measures to increase New York City’s resilience to a similar hurricane are highest for upgrading the water and waste water systems (EUR 3.45bn – 4.02bn) and coastal protection (EUR 2.66bn – 3.06bn), with healthcare, transport and parks each requiring over EUR 500m.

The PlaNYC resiliency report states that while Sandy caused around USD 19bn (EUR 14bn) in losses, a storm of the same magnitude could cause an estimated USD 90bn (EUR 68bn) (in current value) in losses by the 2050s, a cost almost five times higher, due to the effects of climate change on sea level rise (City of New York 2013).

If the first phase of coastal protection measures as well as power and building protections are taken into account, the projected losses for the 2050s are reduced by up to 25% (around USD 22bn; EUR 17bn), which would result from the USD 10-12bn (EUR 7.5-9bn) investment in adaptation measures (City of New York 2013). The analysis assumes the city as it is today. If all of the other measures are also taken into consideration this would result in a larger reduction in damage costs, and other investments by State-led transportation authorities and others could reduce future costs even further.

This cost benefit analysis only quantifies value of losses avoided from any future coastal storms. However, the measures that are going to be implemented will also protect NYC from damage due to other extreme events such as heavy downpours and heatwaves which are also predicted to increase in likelihood with climate change (City of New York, 2013).

### 7.2 Stakeholder engagement: perceived costs of climate change in cities

#### 7.2.1 Perceived costs of different climate-related impacts

The research team undertook a survey of city stakeholders to assess which events were perceived by city officials to be the most costly in a future of climate change. The survey aimed to (a) assess whether particular climate-related events were regarded as more or less important by city officials which could affect their expectations for the RAMSES project, and (b) engage city stakeholders more broadly in the RAMSES project. The surveys were conducted during the 1st RAMSES Stakeholder Dialogue in October 2013 and through further one-on-one surveys with officials from additional cities. In total, 20 cities were surveyed included three RAMSES case study cities – London, Antwerp and Bogota.

The climate-related threats with the highest perceived costs were (in order of rank averaged across 20 cities) inland flooding, heatwaves and air pollution and drought (see Figure 7.3; Table 7.3). The costs of sea flooding were perceived to be high in coastal cities. In contrast, humidity, storms and coldwaves and snow were perceived to have a low or negative likelihood of increasing with climate change as well as being relatively lower cost than other threats.

Figures 7.2a & b show that perceived costs of flooding, storms, heatwaves and drought differ substantially from the highest historical damage costs in the case study cities. Flooding is the highest perceived climate-related cost, which is similar to the historical data. However, storms (strong winds) while being the second most costly historical impact recorded for the case study cities (the 2000 storm in London costing EUR 3.2bn) was perceived to be the least costly of the four threats.
Furthermore, heatwaves and drought both scored very highly as perceived future costs. This may be partly because officials assess health-related costs of heatwaves to be high while these non-market costs are rarely quantified in the cities. The high costs of drought may be due to views that costs will increase substantially as the likelihood of drought events increases (see Figure 7.3). However, the mismatch between historical costs and perceived future costs may also be due partly to the lack of a strong evidence base for policy makers to draw on. Further research should be undertaken to test this.

![Figure 7.3: Perceived likelihood and cost of extreme events due to future climate change (0 – 10 range, averaged across 20 cities). The minus value for coldwaves and snow denotes a hazard that is perceived on average to decrease in likelihood with climate change.](image)

<table>
<thead>
<tr>
<th>Challenge</th>
<th>Inland flooding</th>
<th>Heatwaves</th>
<th>Air pollution</th>
<th>Drought</th>
<th>Coldwaves and snow</th>
<th>Sea flooding</th>
<th>Storms</th>
<th>Humidity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inland flooding</td>
<td>0.110</td>
<td>0.057</td>
<td>0.017</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Heatwaves</td>
<td>-</td>
<td>0.761</td>
<td>0.454</td>
<td>0.031</td>
<td>0.003</td>
<td>0.001</td>
<td>0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Air pollution</td>
<td>-</td>
<td>-</td>
<td>0.662</td>
<td>0.064</td>
<td>0.008</td>
<td>0.004</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>Drought</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.144</td>
<td>0.021</td>
<td>0.010</td>
<td>0.004</td>
<td>-</td>
</tr>
<tr>
<td>Coldwaves and snow</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.407</td>
<td>0.234</td>
<td>0.159</td>
<td>-</td>
</tr>
<tr>
<td>Sea flooding</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.678</td>
<td>0.548</td>
<td>-</td>
</tr>
<tr>
<td>Storms</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.875</td>
</tr>
<tr>
<td>Humidity</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 7.3: Results of Fisher LSD tests showing p values. P values below 0.05 (5% level) suggest a significant difference in perceived cost between hazards. For example, the perceived costs of inland flooding are significantly higher than the perceived costs of coldwaves and snow, sea flooding, storms and humidity across the 20 cities.
### 7.2.2 City clusters

Using the survey data on perceived costs, a cluster analysis using k means was performed to identify four broad clusters of cities with similar perceived characteristics under future climate change. The highest cost impacts (inland flooding, sea flooding for coastal cities, heatwaves, air pollution and drought) were included in the cluster analysis.

Cities in Cluster 1 tend to have high perceived costs of inland flooding. These cities include: Amsterdam, Antwerp, Bogota, Dresden, Gibraltar, Paris and Shanghai (see Table 7.4). Cities in Cluster 2 tend to have high perceived costs of heatwaves and drought. They also have the highest perceived costs from air pollution (higher levels of which are associated with heatwaves) of any of the clusters. These cities include: Barcelona, Bologna, Bratislava, Brussels and St. George, Romania. Cities in Cluster 3 have high perceived costs of sea flooding and inland flooding. These coastal cities include: London and Rotterdam. Finally, cities in Cluster 4 have low perceived costs from future climate-related events. These cities include: Blantyre, Helsinki and Stockholm.

The results of the cluster analysis display some anomalies – and limitations with this type of information collection from officials. For example, officials in Antwerp consider that costs of future sea flooding events are low as they are confident that adaptation measures (even very costly ones) will be put in place to prevent sea surges. However, London and Rotterdam consider that the risk is remains high. Nevertheless, the cluster analysis provides some indications of where city officials are most interested in researchers focusing when undertaking work on adaptation strategies and policy measures in their municipality. This will allow researchers on RAMSES to understand the expectations of officials in terms of the most important impacts to focus on. Where expectations and evidence diverge, RAMSES will be able to target those areas for further discussion with stakeholders.

<table>
<thead>
<tr>
<th>Mean perceived cost</th>
<th>Cluster 1 Inland flooding</th>
<th>Cluster 2 Heat &amp; drought</th>
<th>Cluster 3 Sea/inland flooding</th>
<th>Cluster 4 Low impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air pollution</td>
<td>5.19</td>
<td>5.36</td>
<td>4.30</td>
<td>1.57</td>
</tr>
<tr>
<td>Drought</td>
<td>3.09</td>
<td>8.26</td>
<td>6.65</td>
<td>1.63</td>
</tr>
<tr>
<td>Heatwaves</td>
<td>4.66</td>
<td>7.10</td>
<td>4.00</td>
<td>3.57</td>
</tr>
<tr>
<td>Inland flooding</td>
<td>7.99</td>
<td>5.56</td>
<td>8.30</td>
<td>2.00</td>
</tr>
<tr>
<td>Sea flooding</td>
<td>0.90</td>
<td>1.08</td>
<td>7.35</td>
<td>2.50</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cities</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Antwerp</td>
<td>Amsterdam</td>
<td>London</td>
<td>Blantyre</td>
<td></td>
</tr>
<tr>
<td>Bogota</td>
<td>Barcelona</td>
<td>Rotterdam</td>
<td>Helsinki</td>
<td></td>
</tr>
<tr>
<td>Brussels</td>
<td>Bologna</td>
<td>Stockholm</td>
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<td>Dresden</td>
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<td>Gibraltar</td>
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<td>Shanghai</td>
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</table>

Table 7.4: Results of cluster analysis of perceived costs of climate-related threats across 17 of the 20 cities surveyed. The three remaining cities – Burgas, Copenhagen and Trondheim – did not provide sufficient responses to cover all threats. Numbers represent means of perceived costs for each event, with higher means representing higher perceived costs. Cities fall into four groups: Cluster 1 have high perceived costs of inland flooding; Cluster 2 have high costs of heatwaves and drought; Cluster 3 have high costs of sea and inland flooding; Cluster 4 have low predicted costs from future climate change.
8 Review of case study cities

8.1 London

8.1.1 London’s economy

London is a global megacity, with a strong economy underpinned by one of the largest financial services industries in the world. London’s metropolitan population was 14.1 million in 2012, and is expected to increase by 1.3 million in the 25 years to 2031 (Brookings Institution, 2012b; GLA, 2013).

In 2012, London’s metropolitan GDP was GBP 470.34bn (EUR 563.9bn), or 31.9% of the UK’s GDP (Brookings Institution and JPMorgan Chase, 2014). This equates to around EUR 40,085 per capita (Brookings Institution, 2012b). According to Brookings, London had an employment rate of 48% in 2012. Business and finance dominates London’s economy, representing 48% of the economy, with trade and tourism representing 12% (see Figure 8.1).

![Figure 8.1: Share of London’s metro output by industry. Source: Brookings Institution, 2012b.](image)

8.1.2 Climate impact costs

The impact costs arising from extreme weather events and climate change in London are not well understood and there has been no comprehensive cost analysis undertaken to estimate the costs of projected climate change. The following cost estimates from historic and projected events in London give some indication of the scope and costs of potential damages.

8.1.2.1 Flooding

The most severe impacts due to tidal flooding in recent history occurred in 1953 when floods caused the deaths of 300 people in the East of England. Due to this extreme event, a
large scale construction of flood defences was established to reduce future tidal flood risk. The potential area affected by tidal flooding is 11,600 ha which includes 20 London boroughs. Protection from tidal flooding in London is currently very high and risk of flooding by 2030 is 1 in 1000 years (0.1% chance per year) (GLA, 2009d). The Thames Barrier has been closed 119 times (up to September 2010) to prevent tidal flooding.

In the period from 1992 to 2003, over 1,200 flooding incidents and 200 station closures were recorded by London Underground Limited (LCCP, 2005). Flooding of the London Underground between September 1999 and March 2004 cost approximately GBP 14.6m (EUR 20.7m) in passenger delays. Flood related traffic disruptions during peak periods are estimated to cost at least GBP 100,000 (EUR 116,000) per hour delay on each main road affected, excluding the costs of infrastructural damage (UKCIP, 2011). The potential losses resulting from river, coastal and urban flooding are the greatest source of costs for insurers of properties (GLA, 2009a).

The worst pluvial flood in recent years was the July 2007 heavy rainfall event in London which caused major disruptions to public services and damages to the infrastructure of the city (The Pitt Review, 2008). The damage cost of the flood is estimated at GBP 1.8bn (EUR 2.7bn) and the total cost for UK taxpayers through relief and subsequent investment in the recovery process is estimated at around GBP 87m (EUR 129m). Costs for the UK economy were estimated to be GBP 3.2bn (EUR 4.7bn) (Catovsky, 2011). The flood affected seven police buildings in Kensington, Putney and other parts of West London, electricity infrastructure in the London Underground, the closure of hospitals, major disruptions to Wimbledon 2007, disruptions to the London Underground, social and health care infrastructure, road networks, 500 properties, 80 schools and several hospitals (LCCP, 2009; City of London, 2010).

Heavy rainfalls caused signal failures on the Underground, and caused commuters to be stranded and roads to be flooded on 14th of September 2006 (City of London, 2010). The flooding on the 3rd of August 2004 flushed more than 600,000 tonnes of raw sewage into the Thames at Brentford, Kew and Isleworth which killed tens of thousands of fish (LCCP, 2009).

On the 4th of August 2004, flash floods left commuters stranded due to failing of the Underground network and other major route closures (City of London, 2010). The London Underground, bus, rail and road routes were damaged, and homes and offices in West London were flooded. The media was also affected as the Television Centre in the West End of London was flooded.

The LCCP estimated some of the costs of recent London floods since 2002 in their report *Wild Weather Warning* (2009). The flood on the 7th of August 2002, in which 22mm of rain fell, caused disruptions and tunnels being closed at Green Park, Kilburn, Chalk Farm, Finchley road, Aldgate and Wembley Park underground stations. There were damages to residential buildings, parks, streets and water pipes across the city. The flooding is estimated to have cost approximately GBP 0.74m (EUR 1.2m) (City of London, 2010). Passenger delays were estimated at GBP 14.6m (EUR 23.8m) (Arkell, 2006). Flood related traffic disruptions and delays on each main road as well as infrastructural damage are estimated to have cost over GBP 91,100 (EUR 148,700) per hour.

The flood event in 2000 had major effects on the UK, with secondary effects on London (GLA, 2002). The rail link between Oxford and London was closed due to flooding between the 13th and 18th of December 2000. Economic losses included rail passengers losing time and losses incurred due to the repair of rail infrastructure. Financial losses that resulted from this event are estimated to be GBP 1.2m (EUR 1.9m) (LCCP, 2002b). The defences on the River Roding at Wanstead and Woodford in Redbridge in Northeast London were overtopped and 230 properties were flooded as a result. A total of 75 properties at
Edmonton in Enfield and 15 at Teddington in Richmond were flooded. Overall, 320 properties were flooded as a result.

8.1.2.2 Storms

High speed winds on October 20th 2000 caused trees to be blown onto railway tracks between London and the Southeast which led to three separate train crashes (LCCP, 2009). A train also crashed on the Piccadilly Line of the London Underground. Overcrowding and disruptions of public transport during the rush hours followed as a result. The cost for this weather event was estimated to be GBP 2bn (EUR 3.2bn) in losses.

8.1.2.3 Heatwaves

In London, average daily maximum temperature varies from 23°C in July to 8°C in the coolest months of January and February. However, it has been suggested that London is vulnerable to increases in temperature due to the urban heat island effect (LCCP, 2002b). This could have an effect on air quality, summer electricity demand, and comfort in the city’s buildings and transport network. A study that analysed historic data of temperature and heat related deaths in London found that a relatively low mean daily temperature of 20-23°C had significant effects on mortality in London (Hajat et al., 2002). The study furthermore found that episodes of high temperatures over long durations have the largest effect on mortality.

Considering London as a whole, DEFRA estimates that the costs associated with heat-related mortality could reach GBP 7m to 78m (EUR 8.6m to 95m) by the 2030s (473-712 deaths), with this figure rising to GBP 13m to 149m (EUR 15.9m to 182.7m) by the 2050s (1,200-1,838 deaths). These figures are not discounted and do not take into account existing adaptation and acclimatisation (DEFRA, 2013a).

High temperatures have frequently led to costs in a number of sectors including public transport, health and water supply (City of London, 2010). The heatwave in July 2006 was especially severe and lasted for five days. Road tarmac started to melt, rail sections buckled, and serious health risks were posed to passengers using the London Underground. London Transport suffered enforced speed restrictions and bridges did not close after metal parts expanded. Temperatures on buses were recorded at 52°C on buses and 47°C on the Underground system. Hospitals were not equipped with cooling systems to deal with the high temperatures and public health services were affected. Hospitals were put under the hot weather plan by the Department of Health and GPs were asked to identify the people most at risk from the heatwave for regular check-ups. Ten schools in central London closed early.

Due to the loss in productivity, businesses in the UK were also affected. An estimated GBP 154m (EUR 224m) was lost a day by UK employers according to the Centre for Economics and Business Research. Work levels dropped by a third when the temperatures increased to over 30°C and Active Health Partners (AHP) estimated a loss to UK businesses of GBP 119m (EUR 173m) due to absenteeism when temperatures rose above 35°C.

The heatwave in August 2003 caused disruptions to London transport, damage to roads and strikes at London airports (LCCP, 2002b). The same heatwave caused an estimated 600 deaths in London. The temperatures exceeded 35°C in Southeast England and a heatwave plan was drafted in response (City of London, 2010; LCCP, 2011). The economic cost of the delays in 2003 in four of the railway sections around London was estimated at GBP 95,169 (EUR 145,900) (Arkell, 2006). The high temperatures in July 2002 led to an estimated 4000 calls to the London Ambulance Service (LCCP, 2009).

Heatwaves can also exacerbate the effects of air pollution. The heatwave in 2006 led to asthma sufferers being particularly badly affected (City of London, 2010). Asthma attacks were potentially triggered through higher pollution levels and thunderstorms. Asthma is a
severe health risk which costs the NHS GBP 898m (EUR 1.31bn) annually and could further increase if air quality worsens with climate change.

8.1.2.4 Drought

The prolonged period of drought from November 2004 to January 2007 led to falling groundwater, affecting 13m people across Southern England (including London), with water consumption having to be reduced by 8 per cent (LCCP, 2009).

The 2006 summer heatwave was especially severe and led to hosepipe bans across London (City of London, 2010). London suffered the worst drought in 70 years due to the very low levels of rainfall. This affected both individuals and businesses. IT businesses and data centres were affected during July 2006 as power supply was interrupting the cooling systems. Local authorities were forced to turn off non-essential servers and media firms suffered from air conditioning failure. The Horticultural Trades Association estimated that the drought cost its members up to GBP 300m (EUR 337m) in lost sales. The prolonged drought during this period led to conditions which sparked fires in the Southeast of England. Fires led to traffic delays as smoke was blown across major roads.

Subsidence remains a major risk in parts of London. The alternation between wetting of clays during the winter time and the drying of the clay during the summer can cause additional ground movements which result in damage to buildings, roads, underground pipes and cables. The 2003 heatwave caused GBP 400m (EUR 448.9m) in subsidence claims across the UK.

8.1.2.5 Coldwaves and snow

Snow has often caused disruptions to public transport in London (LCCP, 2009). According to one news broadcaster, the snowfall in 2009 was estimated to cost the economy around GBP 3bn (EUR 3.1bn) (CNN, 2009). Every fifth worker took a day off work and thousands of schools in the south of England were closed. The loss in productivity was estimated to be GBP 1bn (EUR 1.03bn). There were travel disruptions on London buses, eight separate tube lines and trains (Stacey et al., 2009). Gatwick and London City airports were also affected. The websites of National Rail, South West Trains and Transport for London crashed due to the high number of visitors.


The snowfall in January 2003 led to two to three hour travel delays for tens of thousands of commuters. The Victoria and Waterloo and City line were the only Underground lines running and sections of the M25 outer London orbital motorway and the M11 London to Cambridge motorway were blocked, with motorists and lorries stranded overnight. Snow and ice at airports caused air traffic delays.

8.1.3 Adaptation costs

The main responsibility for strategic climate change adaptation policy for the London urban region lies with the GLA (GLA, 2011a). The 33 Boroughs of London and the UK Government also play important roles in adaptation policy development, and infrastructure delivery. The GLA’s Managing risks and increasing resilience, The Mayor’s Climate Change Adaptation Strategy (2011a) outlines health, environment, economy and infrastructure as key focus areas. The overall approach is focusing on extreme weather events and to increase the resilience for the economy, quality of life, social equality and the environment.

At the national level The Climate Change Act 2008 requires the UK Government to conduct a climate change risk assessment every five years. The UK Government’s Climate Change
Risk Assessment sets out the main threats of climate change for the country across agriculture, forestry, business, health and well-being, infrastructure and natural environment sectors (HM Government, 2012). The complementary National Adaptation Programme 2013 suggests a mix of adaption policies to tackle these issues across the UK (HM Government, 2013). The local borough level is responsible for planning measures within their own area to address challenges posed to local transportation, housing, education and minimising the flood risk in their own area.

8.1.3.1 Current infrastructure and resilience

London has extensive infrastructure in place to protect the city from tidal floods (GLA, 2012). The Thames Barrier is the key piece of infrastructure, protecting 125 sq. km of central London from tidal surges. It stretches 520 metres across the River Thames near Woolwich and was opened in 1982. The combined tide and surge had to be of a 1 in 1000 (0.1 per cent chance in any given year) to overtop the Thames Barrier. Additionally, there are eight other flood barriers across the London urban region, 36 industrial flood gates, 400 smaller movable structures and 330 km river walls and embankments to protect the city from tidal floods.

Fluvial flood protection is currently provided by bridges, tunnels, culvert structures, raised river walls and widened river channels (GLA, 2009d). Additional GBP 52bn (EUR 77.1bn) would be needed compared to the initial GBP 22bn (EUR 32.6bn) estimated to manage flood risk by both flood defences and urban drainage and additionally a number of non-engineering measures (GLA, 2007). These figures were revealed by research into the use of hard engineering.

Thames Water is currently working on a London Tideway Improvements programme, with upgrades taking place to all five major sewage treatment works in London, costing GBP 675m (EUR 809m), as well as construction of two tunnels to combat the problem of regular emergency sewage discharges into the River Thames and River Lee, which can be caused by as little as 2mm of rainfall (Thames Water, 2012). The construction of the Lee Tunnel has been allocated GBP 635m (EUR 761m), and should prevent the more than 16m tonnes of sewage mixed with rainwater overflowing into the River Lee annually. The Thames Tideway Tunnel is estimated to cost a total of around GBP 1.6bn (EUR 1.9bn), and prevent the average annual overflow of 39 million tonnes of untreated sewage into the Thames (Thames Water, 2014).

Heatwaves affect public transport systems - particularly the London Underground due to very limited cooling systems (Transport for London, 2013). The Metropolitan line trains are air-conditioned; and new air-conditioned trains are now being rolled out on the Hammersmith & City and Circle line. There are 6,100 double decker buses which have air conditioning in driver’s cabs, automatic heating and ventilation, opening windows, tinted windows, white roofs, and insulated roofs. Station cooling systems are available for the tube stations at Green Park and Oxford Circus.

The Heatwave Plan for England (2012), a public health plan for England which was first published in 2004 in response to the heatwave in 2003 informs the NHS, local authorities, social care, and other public agencies as well as professionals, and individuals how to reduce the risks from exposure to prolonged severe heat (NHS, 2012).

The GLA’s Securing London’s Water future, The Mayor’s Water Strategy (2011) outlines how London can ensure water security and tackle water scarcity problems in London (GLA, 2011b). As a result, water companies are now required to produce Water Resource Management Plans (WRMP) every five years to set out how they will balance the supply of water with customer demands over a 25-year period. At the national level the Government’s recognition for the importance of having an integrated approach to water management is laid out in the Water Act (2003). Future Water (2008) by DEFRA sets out the nationwide Government strategy until 2030 (DEFRA, 2008).
8.1.3.2 Future adaptation costs

No comprehensive adaptation cost analysis has been undertaken for London and there is no specific budget line allocated for London climate change adaptation measures within the city’s budget. However, there have been some attempts to evaluate the adaptation costs to climate change, particularly with regard to flooding.

The GLA (2009c) emphasises the importance of adaptation measures by suggesting new trees for shade, green roofs for substations; and source heating pumps as well as equipping the Underground with sustainable adaptation measures. The Local Transport Act 2008 placed new duties on Local Transport Authorities to regard the government’s adaptation policies and encourage them to improve climate change resilience measures for flooding and deterioration of roads (The Local Transport Act, 2008).

The Environment Agency’s Thames Estuary 2100 Plan (2012) is a comprehensive plan to secure the city from tidal flooding (Environment Agency, 2012). The Plan was the first attempt to estimate tidal flood risk and to set out a proactive management plan for long-term future flood risk (Environment Agency, 2012). The Environment Agency estimated the adaptation costs at GBP 1.5bn (EUR 1.8bn) over the first 25 years, and a further GBP 1.8bn (EUR 2.2bn) over the following 15 years (Environment Agency, 2012). The costs cover major renewals and replacement of the Thames tidal defences and floodplain management.

The Drain London Forum has developed a surface water management plan for each London Borough as well as a London wide overview (GLA, 2011b). Drain London is the key agency responsible for London’s drainage and is seeking to improve the surface water drainage networks and reduce the risk of surface water flooding by identifying the areas with the greatest risk of flooding and planning improvements to the current sewage system (LCCP, 2005; GLA, 2013).

At the national level, the Flood and Water Management Act 2010 was passed in response to the summer 2007 flooding (Loudiyi, 2010). It defines responsibilities for managing surface water flood risk, giving DEFRA the overall national responsibility on flood and coastal erosion risk management and provides funds through grants to the Environment Agency and local authorities.

The Pitt Review (2008) gives an indication of the costs of flood defences implemented in response to surface flooding. The Government spent about GBP 600m (EUR 815m) on flood and coastal erosion risk management in the year 2007-2008 (The Pitt Review, 2008). DEFRA increased funding to GBP 800m (EUR 929m) in 2010-2011. The total amount of spending has increased overall. According to Evans et al. (2008) an increased spending of GBP 30m (EUR 42.6m) a year in real terms would be needed to contend with the best predictions of the effects of climate change on flooding. Table 8.1 summarises the split of funding among the agencies overseeing coastal and flood risk from 2007 to 2011. The majority of the funding is allocated to the operating authorities, the Environment Agency and the Capital Programme.
The GLA has developed an urban greening programme to tackle the losses in vegetation and manage the climate risks from overheating and pluvial flooding (Nickson, 2010). It includes a target of 10 per cent by 2050 and London wide tree cover by five per cent which amounts to an additional two million trees by 2030. *Living Roofs and Walls* describes a scheme by the GLA which focuses on creating green roofs and recreational living roofs and green walls to help London adapt to the risks of climate change through flooding, overheating, drought and reducing the urban heat island effect in the city (GLA, 2008). The Mayor of London made funds available to green the city and upgrade a number of parks in London with about GBP 10m (EUR 11m) until 2012 and the GLA planned to continue these efforts by creating a revolving fund for green roofs (Mees, 2010).

### 8.1.4 Cost benefit analysis

The costs and benefits of implementing climate change adaptation measures are currently estimated as cost benefit estimates by individual sectors. The UK Government and the GLA have not undertaken any comprehensive cost and benefit analysis for all sectors combined.

#### Flood risk management

The ABI (Dlugolecki and Catovsky, 2004) suggests that building climate change into flood risk management policies and plans today could reduce the costs of annual flood damage from GBP 21bn to GBP 2bn (EUR 29.8bn to EUR 2.8bn. DEFRA noted that there is an average return of around 27 per cent per annum in capital investments into flood risk management (The Pitt Review, 2008). This is substantially higher compared to other investments such as road or rail capital schemes.

An analysis by Future Foresight for the *Pitt Review* found that in order to manage the risk of floods, flood investments need to rise on average between GBP 1bn and GBP 2bn (EUR 1.4bn and EUR 2.7bn) per annum in real terms for rivers and coasts in England, and GBP 400,000 to 800,000 (EUR 543,000 to EUR 1,086,000) per annum for intra-urban systems to hold flood risk at around its present-day value (Evans et al., 2008). An increase in spending of GBP 30m (EUR 40.7m) a year in real terms would be needed to contend with the best current predictions of the effects of climate change across the United Kingdom.
Greening the city

The GLA have estimated that an average of 32 per cent of roof area could potentially be greened in London (GLA, 2008). Two different proposals have been suggested (see Table 8.2) (GLA, 2009b). The first option is to install green roofs in four inner city areas: Cannon Street, Oxford Street, Tottenham Court Road and Canary Wharf. This would comprise a total area of 226,750m$^2$, would cost around GBP 4m (EUR 4.1m) and provide environmental benefits worth GBP 4m (EUR 4.1m) (see Table 8.2). The second option is a wider scheme that would cover the City of London, part of the London Borough of Hackney, part of the London Borough of Tower Hamlets and part of the West End. This option would comprise 3.2 million m$^2$ of roof space and would cost around GBP 55.5m (EUR 57.3m) with additional environmental benefits. Grants for green roofs could be jointly administered with councils.

<table>
<thead>
<tr>
<th>Area</th>
<th>Potential roof area that could be greened (m$^2$)</th>
<th>NPV of Environmental benefits</th>
<th>Size of scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td>Option 1</td>
<td>Four small inner city areas</td>
<td>GBP 4m (EUR 4.1m)</td>
<td>GBP 4m (EUR 4.1m)</td>
</tr>
<tr>
<td>Option 2</td>
<td>Four larger areas in London</td>
<td>GBP 55.5m (EUR 57.3m)</td>
<td>GBP 55.5m (EUR 57.3m)</td>
</tr>
</tbody>
</table>

Table 8.2: Total Environmental Benefits and Size of Scheme. Source: GLA, 2009b.

Water management

A five year project was originally proposed in 2009 in order to adapt London water fittings (GLA, 2009b). The first proposal was an increase in the penetration of water efficient toilets from 2-9% with the help of a subsidy of GBP 44 (EUR 45) to every consumer who bought water efficient toilets and could therefore potentially save 9,200 ML over the expected lifetime of the product (16.5 years) (GLA, 2009b). This amounts to an average of about 557ML each year. The value of this scheme is about GBP 6.5m (EUR 6.7m) to (GBP 8m (EUR 8.3m) (including administration costs) over five years providing subsidy to the purchase of 148,000 toilets.

The second proposal targets water efficiency through a 100% subsidy of showerheads with a value of GBP 10 (EUR 10.3) each which could increase the penetration to 80% of replacement showerheads in 2013. This could lead to potential savings of 67,000ML over the next 10 years, which would amount to a saving of 6,700 ML on average each year. The entire cost of this scheme would be GBP 9m (EUR 9.3m) over 5 years provided for 916,000 showerheads. Over five years this could save 202,500 tonnes of carbon (on average 40.5 tonnes per year) due to the energy savings with reduced use of hot water. Customers could save approximately GBP 41 (EUR 42) per year.
8.2 Antwerp

8.2.1 Antwerp’s economy

Antwerp is located in the Flemish region of northern Belgium. The city, a major seaport, lies on the banks of the River Scheldt. The River Scheldt and its tributaries form an international tidal river system over 250km long. Antwerp’s surface is estimated at 205km², and the port area surfaces at 13.06 hectares (DP World, 2013).

Antwerp is a small, open economy with a high level of prosperity. In 2012, the population of the City of Antwerp was 502,604. In 2007, Antwerp’s Gross Domestic Product (GDP) was EUR 57.3bn, representing 17% of Belgium’s GDP (Stad Antwerpen, 2013). In 2008, Antwerp had an employment rate of 59.8% (Stad Antwerpen, 2013).

Antwerp’s economy relies on the activities of its port, which is the second largest in Europe and fifth largest in the world (Port Integration, 2014). In 2010 Antwerp’s port handled over 178 million tons of international maritime cargo traffic (Port Integration, 2014). The service sector in Antwerp accounts for 75% of business in the city (Internations, 2013). The most important sectors of employment in Antwerp in 2007 were industry (13.5%), administrative services (12.8%), retail (11.8%), health services (10.9%), and transport (10.5%) (Stad Antwerpen, 2013).

8.2.2 Climate impact costs

Little evidence exists for historical costs of extreme weather events in Antwerp. The sections below highlight some of the events that are most likely to have had high impact costs due to the quantity of physical damage or fatalities.

8.2.2.1 Sea flooding

The City of Antwerp does not hold records of damage costs from sea flooding for the city. Antwerp’s flood defences are already strong, and there are few recent examples of flooding in the city. However, Antwerp was impacted by the 1953 flood that affected a range of European countries. In Belgium, several dykes were breached, and the Ostend and Antwerp area flooded. In total, 18 people died in Antwerp. However, there are no known details on the economic costs.

In 1976, Flanders was struck by a storm tide that flooded almost 900 houses, and one fatality was recorded in Antwerp. Other impact costs of sea and tidal flooding include the restoration of dykes, consequences of overflow and wave overtopping, burst pipes, and dykes’ sliding inner slopes (Marchand, 2008).

8.2.2.2 Inland flooding

The City of Antwerp does not hold records of damage costs from inland flooding for the city. However, fluvial flooding from the Scheldt not only represents a risk to Antwerp’s real estate, infrastructure and heritage, but also increases the risk of toxic waste deposits left over by the spread of polluted sediment (Marchand, 2008).

According to the Green Plan of Antwerp, an estimated 63.9% of Antwerp’s surfaces (buildings and roads) are sealed, increasing the risk of river and pluvial flooding due to the reduced capacity to absorb excess water (VMM, 2009). This risk is predicted to increase with climate change (ProSes, 2013).

8.2.2.3 Heatwaves

Based on work by Buekers et al. (2012) for Flanders, Lauwaet et al. (2013) have extrapolated the impact of heatwaves on health costs in Antwerp, with an average annual
loss of life due to heat in Antwerp estimated at over 80 DALYs (Disability-Adjusted Life Years) annually. As each DALY has an estimated cost of EUR 40,000, they estimate that the social cost of premature deaths due to heatwaves in Antwerp is around EUR 3.2m per year. However, as the authors point out, there remains considerable uncertainty about the assessment of the number of years lost due to mortality as a result of temperature change, as many external factors such as insulation, air conditioning and healthcare provision also play a role.

Air pollution, and its associated health costs, is influenced by heatwaves. Due to the Antwerp’s highly industrial zones, including its port, Antwerp experiences relatively high levels of air pollution. Although policies have been implemented to counter this trend, air pollution rates still remain higher than the European Air Quality Directive standards, including the annual threshold for NO\textsubscript{2} (which is set at 40µg/m\textsuperscript{3}), and SO\textsubscript{2} daily limits (Environment, Nature and Energy Department, 2012).

8.2.3 Adaptation costs

8.2.3.1 Sea (tidal) flood protection

Belgium has no law regulating tidal flood protection, but the Flemish government sets the security standard that the whole coastline should be able to withstand a storm with a return period of 1000 years (Policy Research Corporation, 2013).

The Sigma Plan is a Flanders-wide action plan for protecting the Scheldt region from flooding. The Plan was first created in 1978, in reaction to the 1976 storm which hit the Flemish banks of the Scheldt leading to major flooding. It was updated in 2005, and a review of the Sigma Plan may be expected in the future.

The 1978 Sigma Plan mirrored the Dutch Delta Plan, and aimed to protect against a 1 in 10,000 year storm tide. It included the construction of a tidal storm surge barrier downstream of Antwerp and dyke heightening (ProSes, 2013). By 1982 the barrier was ready for construction, however the barrier was found not to be economically viable and the project was postponed indefinitely. The Sigma Plan then consisted of dyke heightening and the construction of controlled inundation areas (CIAs).

Controlled Inundation Areas (CIAs) are areas designated to be flooded in case of a storm surge. The storm tide of the estuary flows over an overflow dyke into the CIAs, thus preventing uncontrolled flooding (OURCOAST, 2007). The CIA in Kruibeke, Bazel and Rupelmonde (FCA KBR), is 580 hectares in areas - the largest CIA constructed under the Sigma Plan (OURCOAST, 2007). The target date for completion of the FCA KBR was 2013 but has yet to be completed.

While the FCA KBR will be an effective storm surge barrier downstream of Antwerp (ComCoast, 2007), it has been suggested that it is not a long term solution for flood protection because of the increased risks from climate change (ProSes, 2013).

In 2005 the Sigma Plan was updated by the Flemish Waterways Administration. The updated Sigma Plan considers the amounts of adaptation needed in function of the amount of risk in the area. Therefore numerous cost-benefit analyses are undertaken as part of the Plan in order to decide which actions are worth investing in (ProSes, 2013). The Sigma Plan has different protection standards for different sized agglomerations.

The cross-border nature of the Scheldt estuary means that in order for national policy to be effective there needs to be a cross-border cooperation. As a result, Flanders and the Netherlands set up the Vlams Nederlandse Schelde Commissie (VNSC) in an attempt to synchronise policies and objectives (ProSes, 2013).

In 2005 the Scheldt Development Outline 2010 (OS2010) was drafted. OS2010 is a cross-border plan between Flanders and the Netherlands aimed at harmonizing both countries
visions of safety, environment protection and accessibility of the Scheldt (TIDE, 2013). These include widening and deepening of the Scheldt, the creation of CIAs and raising of dykes (Meine and Maris, 2008), and were implemented by using strategic environmental reports, public hearings, and various cost benefit analyses and measuring for the development of the natural environment (ProSes, 2013).

Since the creation of the VNSC both Flanders and the Netherlands have been subject to long term monitoring (MONEOS), which measures the advance and assesses the success of each objective (Meine and Maris, 2008). ProSes2010 was also put into action in order to ensure the coordination of activities in the Scheldt region under OS2010 (ProSes, 2013).

The Hydrological Information Centre (HIC) provides Flanders with forecasts of water levels and discharges for the following 48 hours (Hydrological Information Centre, 2011). These data permit local waterway managers to assess future needs and provide high water reports, which are provided to crisis centres (Hydrological Information Centre, 2011).

Four dyke rings lead to the entrance of the port of Antwerp, and a large number of dunes and other constructions have been implemented to reduce flood risks (Rajabalinejad et al., 2009). As of 2005 under the 1978 Sigma Plan, 80% of the total dyke length in Flanders (or 405km) had been strengthened (LCCP, 2006). The dykes in Ring 32 (the ring closest to Antwerp) currently have a failure probability of one in eleven events a year, however failure does not always mean flooding (Marchand, 2008).

In 2001 The Flemish Parliament agreed to a common vision for the development of the Scheldt estuary looking out to 2030, the Long Term Vision 2030 for the Scheldt Estuary (LTV2030). The vision includes safety against flooding, protection of the environment and health, and accessibility to the port of Antwerp (TIDE, 2013). The different aspects of LTV2030 have been integrated into the 2005 updated Sigma Plan (Meine and Maris, 2008).

Future adaptation measures in Belgium have to take into account the increased risk of flooding anticipated with climate change. Sea level is expected to rise by at least 60 cm between 2000 and 2100. As a consequence, in 2100 Belgium's current coastal infrastructure will only be able to protect against a 1 in 20 year (5% of occurring in any given year) flooding event. (LCCP, 2006).

The expected total cost of the Sigma Plan at completion in 2030 is estimated at EUR 830m, with an additional 49m euros for possible accompanying measures (Marchand, 2006).

According to one estimate, the Belgian Government will have spent EUR 419m on coastal protection and climate adaptation over the period of 1998 to 2015 (Policy Research Corporation, 2013). The Belgian Government spends around EUR 18m annually on coastal maintenance (Policy Research Corporation, 2013).

**8.2.3.2 Air quality**

European Directive 2008/50/EC defines limit values for air quality. In order to comply with the PM$_{10}$ limit value, Antwerp will apply 39 measures. Twelve of these measures focus on improving the air quality zone of Antwerp, and the rest focus on air quality in different areas (Castell and Guerreiro, 2013). The types of measures include economic and fiscal, technical, educational and other measures and affect the transport, industry (including heat and power production), agriculture and commercial and residential sectors.

**8.2.4 Cost benefit analysis**

In order to define the strategies to be used in the updated 2005 Sigma Plan, a cost-benefit analysis was undertaken for adaptation measures in Flanders considering climate change impacts. Impacts were considered under four different climate change scenarios: low, medium, high, and extreme. The results suggested that a combination of CIAs and dyke
heightening would represent better value for money than the building of a flood barrier (ProSes, 2013).

Under the models, the annual costs of climate change were estimated at EUR 1.7bn in the low scenario, EUR 2.5bn in the medium scenario, EUR 4.2bn in the high scenario and EUR 9.9bn in the extreme scenario. These costs correspond respectively to 0.66%, 0.93%, 1.61% and 3.81% of the GDP of Flanders in 2030 (TECHNUM, 2012). These impacts include health (salmonella, depression, heat stress, cold stress), agriculture, river water, coastal water, tourism, energy (TECHNUM, 2012).

As well as the costs of climate change, there are also benefits, including tourism (which is expected to increase substantially) and reduced fatalities due to a lower incidence of cold stress (TECHNUM, 2012). Energy savings in households are also a negative cost of climate change. In total about EUR 600m in the low scenario, EUR 1bn in the medium scenario, EUR 2bn in the high scenario and EUR 3.6bn in the extreme scenario. However, these benefits would need to be weighed against any increased energy demand required for increased cooling measures in summers.
8.3 Bilbao

8.3.1 Bilbao’s economy

Bilbao is the capital of the Basque region, with a traditionally strong economic base. The city covers an area of 41.6km$^2$ (Bilbao Turismo, 2013). In 2011, the population in the city of Bilbao was calculated at 350,558 inhabitants (EUSTAT, 2014), while the greater Bilbao area has more than a million inhabitants (Akademy, 2013). The population density of the city of Bilbao is 8,486 inhabitants/km$^2$ (Olazabal and Pasual, 2013). Bilbao’s population has declined by 2.28% since 2011 (Udalmap, 2014). In 2012, the registered unemployment rate for the population aged 16-64 was 13.6% (Udalmap, 2014).

Bilbao is a city of high wealth levels relative to the rest of Europe. In 2012, Bilbao’s metropolitan GDP was EUR 30.82bn, representing 2.95% of Spain’s GDP (Brookings Institution and JPMorgan Chase, 2014a). In 2012, Bilbao’s GDP per capita was EUR 31,753 (Brookings Institution and JPMorgan Chase, 2014a). As Figure 8.2 shows, the largest sectors of employment in Bilbao in 2012 were the business and financial sector (21%), the trade and tourism sector (18%) and the manufacturing and local/non-market sector (both 17%) (Brookings Institution, 2012b) (see Figure 8.2).

![Figure 8.2: Sectors of employment in the metropolitan area of Bilbao. Source: Brookings Institution, 2012b.](image)

8.3.2 Climate impact costs

8.3.2.1 Inland flooding

Rainfall between December and February in the Basque country is expected to increase by between 5% and 20% as a consequence of climate change (Basque Government, 2008). In summer, rainfall is expected to decline by between 30% and 50%; however, the largest disruption is expected to be the seasonal distribution of rainfall rather than the percentage change itself (Basque Government, 2008).

In the last 600 years, Bilbao has experienced 39 major flood events (Ibisate et al., 2000). Floods in Bilbao were traditionally due to the works of defence and channelling of the Ria de
Bilbao which were completed late last century (Basas, 1983). In the first half of the twentieth century there were only two notable flooding events, the Nerbioi floods of December 1908 and May 1913. Floods then continued to affect Bilbao in October 1953, June 1975, June 1977 and August 1983 (see Table 8.3). These floods are thought to be due to the combination of rapid urbanisation and industrialisation of the city and the absence of maintenance work in the estuary.

The “Bilbao Plan de Emergencia Municipal” (Emergency Plan for the Municipality of Bilbao – PEMU) carried out an analysis of risk to determine the probability of occurrence and the severity with which floods can occur in traditionally flood-prone areas. Even though the severity index is classified based on the material damage and fatalities caused by the risk, costs prediction are not detailed. The PEMU details the previous floods that took place in Bilbao. Out of this list, the most devastating floods were in August 26-27th, 1983, roughly corresponding to a 500 year return period, and costing around EUR 360m in damages (1983 costs, corresponding to about EUR 930m in 2005 value) (Ihobe, 2007).

<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>April 13th, 1403</td>
<td>The river overflowed and much of Bilbao was swept away</td>
</tr>
<tr>
<td>April 16th, 1418</td>
<td>The floods washed San Antón bridge away</td>
</tr>
<tr>
<td>April 29th, 1428</td>
<td>----</td>
</tr>
<tr>
<td>September 14th, 1453</td>
<td>Extensive damage</td>
</tr>
<tr>
<td>September 22nd, 1592</td>
<td>----</td>
</tr>
<tr>
<td>September 8th, 1651</td>
<td>----</td>
</tr>
<tr>
<td>1709</td>
<td>The floods washed San Francisco bridge away</td>
</tr>
<tr>
<td>November 1st, 1737</td>
<td>----</td>
</tr>
<tr>
<td>1801</td>
<td>The first floors of the buildings were flooded</td>
</tr>
<tr>
<td>1858</td>
<td>The areas of La Ribera, el Arsenal, Bidebarrieta, etc. were flooded</td>
</tr>
<tr>
<td>April 11th, 1874</td>
<td>The Arenal bridge suffered substantial damage</td>
</tr>
<tr>
<td>December 28th, 1908</td>
<td>The areas of Sendeja, Campo del Volantín y la Peña were flooded</td>
</tr>
<tr>
<td>May 14th, 1913</td>
<td>Water levels reached 2 metres at La Peña</td>
</tr>
<tr>
<td>September 26th, 1953</td>
<td>The stream Elguera caused material damage</td>
</tr>
<tr>
<td>October 15th, 1953</td>
<td>Water levels reached more than 1 metre</td>
</tr>
<tr>
<td>June 12th, 1975</td>
<td>Water levels reached 1.5 metres above rail station’s platforms</td>
</tr>
<tr>
<td>May 21st, 1977</td>
<td>The floods damaged the industry and agriculture</td>
</tr>
<tr>
<td>June 13th, 1977</td>
<td>Water levels reached 4 metres at the Arsenal area, roadblocks</td>
</tr>
<tr>
<td>August 8th, 1983</td>
<td>Affected neighbourhoods</td>
</tr>
<tr>
<td>August 26-27th, 1983</td>
<td>Severe damage</td>
</tr>
<tr>
<td>April 7th, 1988</td>
<td>Some areas overflowed, with at Peña</td>
</tr>
</tbody>
</table>

Table 8.3: Historical list of floods in Bilbao. Source: Ayuntamiento de Bilbao, 2008b.

PEMU have also conducted a hydro-meteorological basin analysis to determine flow volumes and peak flow rates for the floods of August 1983, the most devastating ones, as well as to estimate return periods. According to collected data from hydro-meteorological basin analysis, the peak discharge of the August 1983 floods was 3059 m$^3$/s for the river Nervión in Bolueta, and 1401 m$^3$/s for the river Cadagua in Castrejana. The return period of
the floods have been estimated taking the values of the flow obtained from the “Estudio de inundabilidad en poblaciones en el ámbito de cuencas intracomunitarias de la C.A.P.V. – Documento Básico: Estudio Hidrológico”, as well as from the values of rainfall recorded these days.

In 2007, the Environment and Spatial Planning Department of the Basque Country applied a methodology previously developed by the British Government under the United Kingdom Climate Impacts Programme (UKCIP) to:

1) determine the impacts of climate change in Bilbao,

2) identify the cost-efficient tools and means necessary to adapt to climate change, and

3) mitigate the impact of climate change on the most vulnerable sectors of the Basque economy:
   • Agriculture
   • Coastal zones, marine fisheries and fishery sector
   • Mountain areas and soil resources
   • Energy
   • Human health.

The average annual damage costs of flooding of the Ria de Bilbao in the baseline climate scenario, without the impact of climate change, range between EUR 224.64m and EUR 275.09m (in 2005 prices) (Ihobe, 2007). Damage to residential buildings account for the majority of costs. As the magnitude of the flood increases, the amount of damage to non-residential properties increases, and damage to such buildings constitutes a larger and more important proportion of the total damages. Other impacts include injuries and deaths, and the cost of emergency services.

Predicted damage costs for 2080, in the reference scenario – which reflects the expected figures for the baseline scenario combined with the expected socio-economic changes estimated up to 2080 – range between EUR 229.25m and EUR 218.27m (in 2005 prices) (Ihobe, 2007). The difference between these results and damages in the current scenario is due to the increase in units that are exposed to flooding (population growth and therefore residential and non-residential buildings increase) (Ihobe, 2007).

In the climate change scenario the expected average annual damage for the climate change scenario (in 2005 prices) rises to between EUR 358.46m and EUR 439.77m with a 25% increase in flooding. The cost variance attributable to climate change, which is the difference between the climate scenario and reference scenario costs ranged between EUR 129.21 and 158.51m (+56%).

8.3.2.1.1 Heatwaves

Studies on urban thermal comfort have shown that because of Bilbao’s characteristically warm temperatures its population is scarcely affected by heat stress. However stronger temperature increases and heatwaves are predicted to have an effect on human health. Impacts are thought to include an increase of sickness and deaths, due particularly to an increase in episodes of acute respiratory problems and allergies (Basque Government, 2008).

Average temperatures in Spain are expected to increase by as much as 5°C to 7°C in summer and 3°C to 4°C in winter (Basque Government, 2008). Extreme maximum temperatures in the Basque area are expected to increase by between 1°C and 1.5°C by the coast, and by 3.5°C in the rest of the Basque country (Basque Government, 2008). Extreme minimum temperatures on the coast are expected to increase between 1°C and 1.5°C, in the
area of the Atlantic watershed area are expected to increase between 2°C and 2.5°C and an increase between 2.5°C and 3°C is expected in the southern part of the Basque country (Basque Government, 2008).

Temperature increases result in more evapotranspiration; 130mm are expected by the end of the century for the coastal area of the Basque region, temperature rise also lead to an increased risk of forest fires (Basque Government, 2008).

Bilbao’s close location to the sea means it has been industrialising very rapidly since the 1800s. This has led to environmental degradation in the city. Bilbao has very high PM$_{10}$ levels, with up to 70% of these levels related to the city’s traffic and industrial activities (Gonzalez-Aparicio et al., 2012). Air quality is also expected to decline with any climate-related temperature increase, which may lead to increases of tropospheric ozone levels, particularly during summer months (Basque Government, 2008).

In terms of SO$_2$, PM$_{10}$, NO$_2$ and CO$_2$ in 2003 there were 263 days with acceptable and good air quality and 2 days with poor quality (Ayuntamiento de Bilbao, 2008a). In 2007, 267 days could account for having admissible or good air quality and 55 days had bad quality and 43 days had very bad air quality (Ayuntamiento de Bilbao, 2008a).

GHG emissions in the Basque countries increased by 21.9% between 1990 and 2006, from 20.94 Mt CO$_2$e to 25.52 Mt CO$_2$e (Basque Government, 2008).

8.3.2.1.2 Drought

Between August 1988 and November 1990 the Basque region experienced one of the most significant droughts (Ministerio de Medio Ambiente, 2007). The restrictions implemented during this drought affected more than 1,200,000 inhabitants and an important part of the industrial sector in Bilbao and Victoria (Ministerio de Medio Ambiente, 2007). During the drought the municipality undertook a set of actions which achieved a saving of 27hm$^3$ of water, which equates to approximately 8% of the total consumption during the 14 months of water restrictions (Ministerio de Medio Ambiente, 2007).

8.3.3 Adaptation costs

8.3.3.1 Sustainability

Bilbao has implemented Local Agenda 21 (LA21), a plan developed at the 1992 United Nations Conference on Environment and Development in Rio. LA21 consists of a commitment by governments to work towards a transition to local sustainability (Ayuntamiento de Bilbao, 2013). In 1994, Bilbao also signed the European Union’s “Aalborg Charter”. The Aalborg Charter is a programme inspired by Local Agenda 21 and brings together ideas of good governance, environmental protection, sustainability and society (Sustainable cities, 2013).

From 1999 to 2000, under LA21, Bilbao initiated a starting diagnosis with proposals of indicators related to the important issues addressed in the “Modelo de la Calidad Ambiental en la Gestion Municipal 1999-2000” (Ayuntamiento de Bilbao, 2013). In 2003, Udalsarea 21 – the Basque Network of Municipalities for Sustainability – was created and Bilbao’s municipality participated in the project, in an attempt to enhance the achievement of local sustainability and promote the LA21 (Aberásturi, 2007; Ayuntamiento de Bilbao, 2013).

In 2004 there was a review of the LA21 Sustainability Diagnosis and in 2005 Local Action Plan 2005-2008 was launched (Ayuntamiento de Bilbao, 2013). The 2005-2008 Action Plan was aimed at reducing water consumption, moving towards sustainable transport, reducing pollution and improving environmental quality, introducing sustainability criteria in planning and land management (Ayuntamiento de Bilbao, 2013). The Second Sustainability Action Plan 2009 to 2013, aims to review previous commitments to local sustainability and show Bilbao’s commitment to local sustainability (Ayuntamiento de Bilbao, 2013). Ecoeuskadi
2020 or the “Estrategia Vasca de Desarrollo Sostenible” (the Basque Sustainable Development Strategy 2020), is the future plan for the Basque country to keep to their commitments for sustainability (Gobierno Vasco 2011).

From 2002-2006; 2007-2010 and 2011-2014, the Basque region implemented the “I Programa Marco Ambiental de la CAPV”; the “II Programa Marco Ambiental” and the “III Programa Marco Ambiental”. The objective of the Programa Marco Ambiental is to help change the inertia of behaviour by public or private organizations and citizens that impact negatively on the environment, and focus on a positive trend of improving the welfare and the quality of life of citizens, promoting a transition to a more eco-efficient industry and a sustainable economic model (Euskadi, 2014).

As part of the “Plan Vasco de Lucha contra el Cambio Climatico” – an extensive plan to combat climate change – the Basque authorities have approved the implementation of an Environmental Inspection & Control Plan. This Plan is aimed at protecting the Basque environment by enforcing environmental regulations to ensure sustainable development (Basque Government, 2008).

In order to raise awareness on the issue of sustainable development, the Basque government has implemented School Agenda 21. With School Agenda 21 environmental awareness is to be included in school curricula.

**8.3.3.2 Flooding and water management**

In 2001 a study commissioned by the Consorcio de Aguas Bilbao-Bizkaia (the metropolitan water company) proposed the construction of two draining tunnels 3.5 km away from the bed of the Ria de Bilbao (Uriona, 2009). The cost of such a project was estimated at EUR 220m, however the project failed to be implemented (Uriona, 2009). The Ministry of Agriculture, Food and Environment has invested EUR 11m for the reconstruction and reinforcement of the piers of the Nervion River in Bilbao.

Bilbao Ria 2000, the project connecting all levels of government to sponsor city investment, has completed a project for the construction of a new water sanitation system which reduces environmental contamination of the city (UN, 2013). The project cost a total of EUR 1bn (UN, 2013). The Basque Government has also put in place legally binding building restrictions in areas at risk of flooding. If a zone is at a 10 year risk of flooding, then building is not permitted (Uriona, 2013).

In flood-prone areas restrictions on land use are addressed to avoid major damage. Specifically, the PEMU recommends the following limitations:

- Future residential buildings’ ground floor must be at a level not affected by 100 years-flood or hazardous damage from 500 years-flood.
- Non-residential buildings must be at a level high enough to avoid water to reach 0.5 metres above the floor of the building.

**8.3.3.3 Air pollution control**

In 1968, SO$_2$ levels in the city reached 2,000 µg/m$^3$ (Gonzalez-Aparicio et al., 2012). In response to these high levels the 38/1972 Act and the 833/1975 decree on Atmospheric Environment Protection were instigated and the Department of Environment (DoE) of the Basque country and the Basque Air Quality Surveillance and Control Network (AQS N) were created (Gonzalez-Aparicio et al., 2012).

Focus on improving air quality since the 1970s led to a 95% reduction of Bilbao’s SO$_2$ emissions to around 15 µg/m$^3$ in 2012 (AQS N 2011, cited by Gonzalez-Aparicio et al., 2012). However such improvements have not occurred with levels of particulate matter (PM). Registered levels of PM$_{10}$ in Bilbao in 2003 exceeded the legal limit fixed by the 1999/30/EC
Directive (50 µg/m³) more than 35 times per year (AQSN 2011, cited by Gonzalez-Aparicio et al., 2012)

In reaction to the emission recorded in 2003, the Air quality Action Plan was developed in 2006 and updated in 2009 showing an improving compliance with pollutant thresholds (Labein 2006, and Labein 2009, cited by Gonzalez-Aparicio et al., 2012).

After participating in the Covenant of Mayors in 2012, Bilbao signed the Sustainable Energy Action Plan (SEAP). In SEAP Bilbao engages to prevent 251,428 tonnes of CO₂e from being released (CASCADE, 2012). This corresponds to a 30.8% reduction compared to the 2005 baseline (CASCADE, 2012). This is to be achieved through “energy efficiency, sustainable transportation, renewable energy, generation and management of waste, water and environment” (CASCADE, 2012). In order to reach these objectives EUR 809m is to be invested from 2011 to 2020 (CASCADE, 2012).

8.3.3.4 Energy efficiency

The Basque government set up the Basque Country Energy Strategy 2001-2010 (3E 2010 Strategy) through the Basque Energy Board (EVE), 3E 2010 is an attempt to make the Basque region less oil-dependent whilst developing greater assurances of supply (Basque Government, 2008).

As part of their individual energy efficiency and renewable projects, the municipality of Bilbao together with San Sebastian, Durango and Beizama, aims to reduce energy consumption by 2 million Kwh/year and CO₂ by 1,500 tonnes (Ihobe, 2009). For example, the municipal sports centre’s facilities in Bilbao will be renewed by introducing photovoltaic and thermal solar energy systems and a co-generation system (Ihobe, 2009).
8.4 Bogota

8.4.1 Bogota’s economy

Bogota is a city located 2640m above sea level, in a savannah of the high plateau of the eastern Andean mountains. The city is framed by a mountain system mainly in the east and is crossed by important rivers such as the Tunjuelo, Fucha and Juan Amarillo —located in the southern area of the city— which flow into the Bogota River on the city’s western edge.

The GDP of the metropolitan area of Bogota in 2012 was USD 140.9bn (EUR 108.7bn) (Brookings Institution, 2012b), in comparison to national GDP of USD 369.6bn (EUR 277.3bn) (World Bank, 2014) (thus the city produced 38% of the national GDP in 2012), with GDP per capita in the city of USD 15,891 (EUR 12,255) (Brookings Institution, 2012b). The metropolitan area has a population of 8,868,395 and an employment rate of 51% in 2012, a 2.2% growth from the previous year (Brookings Institution, 2012a).

Bogota’s largest industry sector is in the business and finance sector, at 35.3% of the metro output share (see Figure 8.3). Other major areas include local and non-market with an output of 19.2% and trade and tourism with an output of 15.7% (Brookings Institution, 2012b).

8.4.2 Climate impact costs

Bogota’s economy faces a range of climate change risks including: risks to building stock, infrastructure, transport and business disruption, energy costs, and health costs. These risks are related particularly to the following climate-related impacts: inland flooding, landslides and wildfires (Campos et al., 2011). Figure 8.4 shows the number and percentages of disasters in Bogota compared to other main cities in Colombia divided into separate disaster categories. While detailed figures are not available for Bogota, Figure 8.5 shows the economic losses for individual extreme weather events such as floods and storms across Colombia (EM-DAT, 2013). Floods and storms have led to significant economic costs between 1970 and 2012.
8.4.2.1 Inland flooding

Floods are particularly common in the Tunjuelo River Basin (Southeast). The surrounding region includes 35 per cent of Bogota’s population (Pacific Disaster Center 2006). Overall, 18 per cent of the urban area of Bogota is occupied by people living in informal settlements, which amounts to about 1.4 million people. According to the Pacific Disaster Center (2006), a substantial number of informal settlements are in high risk zones of flooding and landslides which make them extremely vulnerable. The Tunjuelito River Flood in 2002 led to 2,109 people losing their homes in Bogota. Economic cost assessments have not been undertaken for the 2002 river flood.

Yamin et al. (2013) have modelled flood risks in Bogota using a case study of the area surrounding the Quebrada Limas River and estimated the maximum loss due to flooding for a period of up to 100 years (see Figure 8.6). They included losses due to number of people, buildings and direct economic losses of buildings, contents and profits (Yamin et al., 2013). The costs are estimated to increase every year and most significantly in the first 20 years.
Flooding events in other parts of Colombia can give a sense of the risks faced by Bogota. For example, the February 2009 flood of the Mira River in Nariño Department south of Bogotá led to thousands of homes destroyed and 30,000 people affected in municipality of
Tumaco in the Southwest of the country (Catarius and Espach, 2009). In May 2008, heavy rains led to a runoff that flooded Magdalena and Cauca Rivers which caused 27 out of the 32 Departments in Colombia being affected. The river reached its highest level in 40 years. In the course of this flood the estimates ranged from 1.2 million to 1.7 million people being affected by the flood. A 2007 flood affected 1.4 million Colombians, due to the flood 270,000 homes and businesses got destroyed and most of the country was affected.

Over 15.5 million Colombians have been affected by floods, landslides, and torrential rains during the past 30 years (Adaptation Fund, 2012). 38,000 people have died as a consequence of these events. The National Planning Department (DNP) estimates events related to climate between 1970 and 2000 have caused COP 4.2 trillion (EUR 1.7bn) in damages, which is equal to about 2.66 per cent of Colombia’s GDP. The country has registered 28,000 disaster events between 1970 and 2011, 60 per cent of these after the 1990s (Campos et al., 2011).

Between 1970 and 2011, housing losses due to major disasters were approximately COP 3.8 trillion (EUR 1.5bn), while intermediate and small disasters caused losses up to COP 9.5 trillion (EUR 3.7bn). Landslides are particularly common during heavy rains (Pacific Disaster Center, 2006). Overall, 910 of the total 48,000 hectares of the city are built on landslide-prone zones. The districts Ciudad Bolivar (Southeast), San Cristobal (Southeast), Bosa (Southwest) and Usme (Southeast) are particularly vulnerable to this threat. Rapid urbanization has led to informal settlements being built on highly unstable landslide zones which poses a threat to the local population.

Landslides in 2001 and 2003 near La Carbonera and El Espino in Northeast Bogota led to 150 to 200 hectares of land affected (Pacific Disaster Center, 2006). The landslides hit Altos de la Estancia, a settlement located in Ciudad de Bolivar (UN Habitat, 2012). This part of Bogota began a process of detachment from the main mountain body in 1998. An area of 110 hectares was lost and 4,000 housing units and surrounding infrastructure were affected.

Climate change presents an additional indirect cost for the rural livelihoods in the region around Bogota. With predicted increases in temperature, the quantity of crops that are essential for the region’s food security are predicted to decline (Eitzinger et al., 2014). This could result in farmers migrating to higher grounds. The highlands are also the source of water supplies for many families and farms located on the hillsides and grasslands downstream. Farmers who are migrating uphill in search for more land are likely to cut down more of the forest in search of land. The subsequent deforestation and change of land-use in the highlands is damaging to ecosystems, the sustainability of small-holder agriculture and rural livelihood.

### 8.4.2.2 Heatwaves

Despite the fact that the majority of fires in Colombia are triggered by humans as a result of agricultural practices, grazing and hunting, Bogota’s vegetation remains vulnerable during dry seasons. The Páramo (moor) which secures natural filtering of water for the city is especially vulnerable during these weather conditions.

Authorities reported wildfires affecting 28,000 people in the south of Bogota in January 2005 and destroying 350 hectares of forest (Hamer, 2010; El Espectador, 2010). In Manila, an area west of Bogota, 37 municipalities were affected by a fire which reached the outskirts of Bogota.

### 8.4.2.3 Storms

The storms in 1994 hit the southeast of Bogota and pulled material from the quarry in the El Zuque district (UNDP, 2007). This affected the waterway of the Quebrada Chiguaza which caused a subsequent landslide in which six people died, one person went missing, 60 homes destroyed and in total 822 people were affected.
8.4.3 Adaptation costs

8.4.3.1 Current infrastructure and resilience

Bogota has implemented a number of policy measures with respect to disaster risk management (Zeiderman, 2012). Since the mid-1980s, the local and national authorities have been promoting more effective coordination among different actors involved. Furthermore, national policy is placing more emphasis on moving away from responding to emergencies to planning policies protecting the city from future events.

Bogota has developed a ‘District Emergency Prevention and Relief System’ (Sistema Distrital para la Prevención y Atención de Emergencias, SDPAE) (World Bank, 2011). Like its national equivalent, the SNPAD, the SDPAE is a multi-sector and inter-agency network of public and private entities. This system is coordinated by the Directorate of Emergency Prevention and Relief (Dirección para la Prevención y Atención de Emergencias, DPAE). The main objective of the SDPAE is to achieve integrated risk management to prevent natural disasters.

Through the adoption of the ‘Emergency Prevention and Attention Plan’ (PDPAE) by the city of Bogota, a ten-year risk management policy has been formulated (World Bank, 2011; Lampis, 2013). This ‘Master Plan’ is a pioneer in the country; it notably includes risk management policy for the period 2005-2015 and names responsible sectors institutions and agencies as well as strategic areas. The stakeholder involved with flood control and water management is the Bogota Water and Sewerage Company (Empresa de Acueducto y Alcantarillado de Bogota - EAAB). The Low-income Population Housing Agency (Caja de Vivienda Popular –CVP) is responsible for resettling families who live in high-risk areas.

A number of international agencies have also been involved with risk management in Bogota. Both the United Nations and the World Bank have provided substantial technical and financial assistance to Colombia through the GFDRR (Campos et al., 2011).

8.4.3.2 Poverty reduction and settlements

Law 388 in 1997, also referred to as ‘Ley de Desarrollo Territorial’ (Territorial Development Law), determines improvements of neighbourhoods and housing as one of the key areas of land use planning in the city (UNDP, 2007). In 1998, a programme aimed at improving illegal settlements was adopted named the Low-income Population Housing Agency (Caja de Vivienda Popular, CVP). This agency develops programmes which address the challenges arising from more than 175,000 inhabitants arriving in Bogota each year. The major goal of the programme is to change the legalisation in these areas to improve living conditions.

Following this programme, the Land Use Plan (Plan de Ordenamiento Territorial, POT) has been adopted in 2000 for a period of ten years under the Enrique Peñalosa’s Administration (UNDP, 2007). This programme included low-cost housing projects for low-income households, comprehensive slum upgrading programmes and resettlement for people located in high-risk areas. This programme aimed at moving households to safe, suitable houses in other parts of the city, thus strengthening their social and economic inclusion. In addition, steps were also taken to monitor the occupation of land that is unsuitable for urbanization, in order to limit the number of resettled people.

The Relocation of Families of “Altos de la Estancia” in Bogota programme focuses on the relocation of families out of high risk zones to improve living conditions (Tovar, 2005). The area at risk between 1999 and 2000 included an area of 70 hectares and 3,000 families, including kindergartens, schools, parks and public facilities. A total of 3,033 families were subscribed to the programme. Of these a total of 1,800 families or approximately 6,000 people have been resettled using about COP 20bn (EUR 6.6m). The strategy was promoted by the SDPAE and financed through the district which invested COP 50bn (EUR 15m) since
the beginning until the year 2005. Table 8.4 shows the distribution of funds financing this project until 2005. The majority of funds were carried by CVP.

<table>
<thead>
<tr>
<th>Association</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Year 4</th>
<th>Year 5</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fondo de Prevencion y Atencion de Emergencias de Bogota-Fopae2</td>
<td>COP 1.2bn</td>
<td>COP 1.4bn</td>
<td>COP 1.6bn</td>
<td>COP 820m</td>
<td></td>
<td>COP 5bn</td>
</tr>
<tr>
<td>Caja de la Vivienda Popular</td>
<td></td>
<td></td>
<td>COP 4.6bn</td>
<td>COP 3.5bn</td>
<td>COP 3.5bn</td>
<td>COP 11.6bn</td>
</tr>
<tr>
<td>Fondo de Desarrollo Local de Ciduad³</td>
<td></td>
<td></td>
<td>COP 1.5bn</td>
<td>COP 1.4bn</td>
<td></td>
<td>COP 2.9bn</td>
</tr>
<tr>
<td>Total Budget</td>
<td>COP 1.2bn</td>
<td>COP 1.4bn</td>
<td>COP 7.7bn</td>
<td>COP 5.7bn</td>
<td>COP 3.5bn</td>
<td>COP 19.6bn (EUR 6.2m)</td>
</tr>
</tbody>
</table>

Table 8.4: Origin of the funds and percentages of funds each sponsor gives. Source: Tovar, 2005.

In the El Zuque district a programme was implemented for the relocation of families which were diagnosed to live in high non-mitigable risk areas. This followed storms that affected the El Zuque district in the southeast of Bogota (UNDP, 2007). The DPAE included 8,245 families located in high risk areas. The exposure to risk has been reduced for an estimated 17,000 people by this programme.

The project is part of the improvement of “Barrios” coordinated through the CVP (UNDP, 2007). Overall, 500 barrios and 1,860,000 people benefited from this programme which was implemented across 12 different localities in Bogota. The estimated budget for this programme was around COP 258bn (EUR 83.7m). The following Table 8.5 shows the budget

<table>
<thead>
<tr>
<th>Policy measure</th>
<th>Funding (billion COP)</th>
<th>Funding (million EUR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Institutional Strengthening</td>
<td>COP 3.9</td>
<td>EUR 1.4</td>
</tr>
<tr>
<td>Territorial works</td>
<td>COP 1.9</td>
<td>EUR 0.67</td>
</tr>
<tr>
<td>Zoning</td>
<td>COP 69.4</td>
<td>EUR 24.6</td>
</tr>
<tr>
<td>Water Management</td>
<td>COP 3.8</td>
<td>EUR 1.3</td>
</tr>
<tr>
<td>Environment and risk prevention</td>
<td>COP 130.4</td>
<td>EUR 46.2</td>
</tr>
<tr>
<td>Mobility</td>
<td>COP 19.5</td>
<td>EUR 6.9</td>
</tr>
<tr>
<td>Community facilities</td>
<td>COP 20.6</td>
<td>EUR 7.3</td>
</tr>
<tr>
<td>Housing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Social</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Participatory planning</td>
<td>COP 1.4</td>
<td>EUR 0.50</td>
</tr>
<tr>
<td>Strengthening the organisation of the community</td>
<td>COP 1.5</td>
<td>EUR 0.53</td>
</tr>
<tr>
<td>Coexistence and safety</td>
<td>COP 3.1</td>
<td>EUR 1.1</td>
</tr>
<tr>
<td>Productivity and employment</td>
<td>COP 2.6</td>
<td>EUR 0.92</td>
</tr>
<tr>
<td>Total</td>
<td>COP 258.1</td>
<td>EUR 91.4</td>
</tr>
</tbody>
</table>


² Fund for Prevention and Attention of Emergencies (FOPAE)
³ Fund of Local Development of Cities
The Nueva Esperanza neighbourhood in Rafael Uribe Uribe, in the southeast of Bogota, is a watershed of the Hoya del Gueaura creek near the Entres Nubes District Ecological park (Parque Ecológico Distrital Entre Nubes, PEDEN), one of Bogota’s natural reserves (World Bank, 2011). The DPAE declared the area a “high-risk zone”. A resettlement programme was financed under the World Bank. A census and appraisal of the two largest estates were undertaken, and the areas valued at COP 4.3bn (EUR 1.7m). The total cost of the resettlement programme is around COP 32.4bn (EUR 12.8m) including a range of resettlement measures (see Table 8.6).

<table>
<thead>
<tr>
<th>Program</th>
<th>Institution</th>
<th>Costs (COP) in Millions</th>
<th>Costs (EUR) in Millions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resettling households</td>
<td>CVP</td>
<td>COP 28,550.5</td>
<td>EUR 11.2</td>
</tr>
<tr>
<td>Improving habitats</td>
<td>District Health Secretary Hospital Rafael Uribe Uribe</td>
<td>COP 323.6</td>
<td>EUR 0.13</td>
</tr>
<tr>
<td>Identifying at-risk households</td>
<td>FOPAE</td>
<td>COP 437.8</td>
<td>EUR 0.17</td>
</tr>
<tr>
<td>Recovering degraded land environmentally</td>
<td>District Department of Environment</td>
<td>COP 1,123</td>
<td>EUR 0.44</td>
</tr>
<tr>
<td>Recovering degraded land environmentally</td>
<td>Local Development Fund Rafael Uribe Uribe</td>
<td>COP 330.7</td>
<td>EUR 0.17</td>
</tr>
<tr>
<td>Improving resettled households’ productive activities</td>
<td>CVP Secretariat of Economic Development IPES</td>
<td>COP 1,598.3</td>
<td>EUR 0.62</td>
</tr>
<tr>
<td>Total cost</td>
<td></td>
<td>COP 32,433.4</td>
<td>EUR 12.8</td>
</tr>
</tbody>
</table>


8.4.3.3 **Inland flood management**

Creating an urban drainage system which makes Bogota a more climate change resilient city remains a major challenge (Rodríguez et al., 2008; Hazen and Sawyer, 2013). Across the city, 96 per cent of the waste water system (around 5,400 km of pipes, including primary and secondary networks) has already been constructed. In addition, 93 per cent of storm drainage systems (around 2000 km of pipes) have been constructed. The Saltire wastewater treatment plant (WWTP), operated by the Water and Sanitation Utility (EAAB) (Empresa de Acueducto y Alcantarillado de Bogota) and owned by the District Government, reduces pollution in the waste water and improves the water quality in the middle basin of the Bogota River.

Despite progress, Bogota’s urban drainage system still lacks the capacity to address current and future risks of flood (Rodríguez et al., 2008). The waste water from domestic and industrial sources and combined sewer overflows lead into the rivers Saltire, Fucha and Tunjuelo and other open channels across the city. Even during dry weather, the wastewater treatment system has around 25 per cent of the capacity needed. In addition, limited capacity and a large number of poor connections between the storm drainage system and the waste water system have created a major challenge to the city during pluvial floods.
8.4.3.4 Water management

In terms of water management, Bogota receives around 70 per cent of its drinking water from the Páramo, which is a high-elevated wetland ecosystem (Postel, 2005). The vegetation absorbs the precipitation and snowmelt and cleans the water. Therefore, there is little need for reservoir storage or further more expensive treatment. The water delivered to the local water plants requires only minor treatment. However, due to agricultural pressures and rapidly decreasing vegetation, the purity and the reliability of drinking water is threatened. Despite the fact that 95 per cent of Bogota’s households had potable water and 87 per cent have sewage services in 2005, challenges remain and Bogota plans to increase water security through watershed protection and efficiency measures (Postel, 2005).
8.5 Hyderabad

8.5.1 Hyderabad’s economy

Hyderabad is a city situated on the Deccan plateau at an altitude of around 540m. It is a hilly urban area on the banks of the Musi river, 90km downstream from its source. The GDP for Hyderabad in 2012 was USD 31.8bn (EUR 24.1bn), with GDP per capita at USD 4,065 (EUR 3,078) (Brookings Institution, 2012b). This compares to India’s national GDP of USD 1.842 trillion (EUR 1.42 trillion) in 2012 (World Bank, 2014), translating to Hyderabad contributing 1.72% of the national GDP. The key industries which shape the socioeconomic profile of the city are the IT and chemical/pharmaceutical industries (Kit, 2014).

The area of Hyderabad was redefined in 2007, resulting in population growth between censuses of 87% between 2001 and 2011, from 3,637,483 to 6,809,970 (India Online Pages, 2014). The 2012 employment rate was 44% (Brookings Institution, 2012b). The social composition comprises 1.7 million slum dwellers (22% of the population) (India Online Pages, 2014). In 2001, the population living below the poverty line was 429,189, which as a percentage of the population then was 14.1% (GHMC, 2005).

8.5.2 Climate impact costs

8.5.2.1 Inland flooding

As the Musi river flows through Hyderabad the city has historically been susceptible to river flooding. However, since the creation of two large dams in the 1920s, the city is now less vulnerable to river flooding.

With heavy rainfall occurring throughout the monsoon, and particularly high levels in September, Hyderabad is susceptible to pluvial flooding (Lüdeke et al., 2010). This is especially the case with the effect of climate change increasing the frequency of extreme precipitation events. The maximum level of rainfall on record in a 24 hour period occurred on 24th August 2000, with 240.5mm of precipitation (Government of Andhra Pradesh, 2010). During this time, the water level in the Musi river did not increase considerably suggesting that the resulting floods were due to pluvial flooding rather than from the river (Geological Survey of India, 2013).

The city faces various challenges that exacerbate flooding in Hyderabad. These include inadequate drainage capacity, illegal encroachment of natural water courses, diversion of water courses to allow for building, dumping of rubbish and building materials leading to silting of drains, and an increase of impervious surfaces leading to higher run off (GHMC, 2005).

Case studies of previous floods include the severe floods on the 28th September 1908, 23rd-24th August 2000 and 8th-10th August 2008. Table 8.7 shows the damage costs and numbers of people affected from these floods, estimated by the India Meteorological Department (Apte, 2009) and the A.P. State Disaster Management Plan, August 2010.

In the 2008 flood, the maximum intensity of rainfall was reported at 40mm per hour – substantially higher than Hyderabad’s drain capacity at around 12mm per hour (Apte, 2009). In the 2000 flood, 90 residential areas were flooded, in some cases under 3m to 4.5m of water, and parts of roads were washed away (Zameer et al., 2013).
28/09/1908  23-24/08/2000  8-10/08/2008

<table>
<thead>
<tr>
<th>Type of flooding</th>
<th>Pluvial and river</th>
<th>Pluvial</th>
<th>Pluvial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfall</td>
<td>430mm</td>
<td>240.5mm</td>
<td>237mm</td>
</tr>
<tr>
<td>Property Loss/Worth</td>
<td>80,000 houses</td>
<td>35,693 houses</td>
<td>INR 495.2m</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(EUR 32.7m)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(EUR 7.8m)</td>
</tr>
<tr>
<td>Loss of life</td>
<td>15,000</td>
<td>26</td>
<td>0</td>
</tr>
<tr>
<td>Population Affected</td>
<td>600,000</td>
<td>200,000</td>
<td>150,000</td>
</tr>
</tbody>
</table>

Table 8.7: Severe flooding events in Hyderabad. Source: Apte, 2009 using data from the India Meteorology Department.

8.5.2.2 Heatwaves

While other areas of Andhra Pradesh State experience higher extreme temperatures (such as a high of 51°C in Kothagudem in 2002), temperatures in Hyderabad have not been reported to be as high. However, fatalities due to heatwaves in Hyderabad have been reported (The Times of India, 2003).

A heatwave in 2013 reportedly resulted in 84 deaths in Andhra Pradesh State (Deccan Chronicle, 2013). The State Government announced in 2013 that it would pay INR 50,000 (EUR 700) to families below the poverty line if family members died due to sunstroke.

In 2003, heatwaves claimed over 3,000 lives in Andhra Pradesh State (Government of Andhra Pradesh, 2010).

8.5.2.3 Air pollution

Air pollution in Hyderabad is already a major challenge for the city. During the year 2011, Hyderabad reported a yearly average PM$_{10}$ level of 74µg/m$^3$ (Central Pollution Control Board, 2013). This is lower than previous years and part of a downward trend, with levels of 85, 81 and 79µg/m$^3$ in years 2008, 2009 and 2010 respectively. However, it remains higher than the Indian national ambient air quality standards for average annual PM$_{10}$ levels of 60µg/m$^3$ (Central Pollution Control Board, 2009), and substantially higher than World Health Organisation standard of 20µg/m$^3$.

8.5.3 Adaptation costs

8.5.3.1 Current infrastructure and resilience

In 1908, Hyderabad suffered a major flood from the Musi river. Consequently, two dams were constructed to reduce the risk of river flooding in the future: the Osman Sagar dam constructed in 1920 and the Himayat Sagar dam in 1927 (Kit et al., 2011).

In contrast, more recent flooding events such as the August 2000 flood have resulted mainly from heavy rainfall combined with poor urban planning (Geological Survey of India, 2013). The August 2000 flood completely washed away 77 slums, indicating that slums are particularly vulnerable areas in the city (Kit et al., 2011). Another important observation is that while many movable and immovable properties were lost or damaged due to torrential rainfall, the water level in the Musi had not risen significantly, and districts near Hyderabad were in fact experiencing drought-like conditions. Had there been better urban planning, the surface runoff could not only have been diverted more effectively, but would also have benefited the adjacent states which were dry at the time (Geological Survey of India, 2013).

The Greater Hyderabad Municipal Corporation (GHMC) recognises that construction and maintenance of storm water drains, under the responsibility of the GHMC and urban local bodies, have historically been a low priority, without a strategic plan (GHMC, 2005). Primary and secondary drains carry storm water into the river Musi or the lakes located in the city. In
total there are 140km of these drains leading to the Musi. In addition, roadside tertiary drains discharge into the primary drains. Their total length in 2005 was approximately 800km, covering around 30% of roads, and a drainage capacity of 12mm per hour. The GHMC has stated that their aim is to have drains covering 130% of the length of roads. However there are many problems with these drains, for instance they are being used to discharge sullage and septic tank overflows and because many of them are open, they often get clogged up with rubbish and silt.

8.5.3.2 Future adaptation costs

Hyderabad has no specific climate change adaptation plan. The University of Hyderabad has raised the profile of climate change and its impact on water resources at the national level (Reachout Hyderabad, 2010). Adaptation measures in Hyderabad are aimed at current climate impacts and development challenges, such as those underpinning the strategy in the GHMC City Development Plan published in 2005.

8.5.3.3 Poverty reduction and slums

Poverty reduction is a key objective in the GHMC City Development Plan, with a strategy to eradicate slums in Hyderabad by 2021. Under the plan, the relocation of slums currently in hazardous and vulnerable areas is being supported by INR 550m (EUR 9m) over seven years (GHMC, 2005).

8.5.3.4 Flooding and water management

Storm water drainage and flooding prevention have received substantial attention from the Hyderabad authorities. A number of strategies have been outlined that aim to improve the current drainage system, increase construction of additional drains, and divert drains in problem areas.

The Drainage Rehabilitation Program aims to improve and strengthen the connections between secondary and tertiary drains to primary drains, as well as prioritising maintenance such as controlling weed growth, limiting dumping of waste and controlling the growth of encroachments, with urban local bodies desilting drains before the onset of the monsoon season. The Improvement Works and Construction of Tertiary Drains strategy aims to increase the drain coverage to 130% of road length, and to convert all unlined drains to drains lined with brickwork and masonry.

The strategies for Conservation of Water Bodies and Protection of Environmental Resources include initiatives to restore water bodies to their original condition, protect water bodies and open spaces from further encroachments.

The Green Hyderabad Environment Program aims to protect around 30 of the 169 lakes in the metropolitan area, while Rehabilitation of Ecosystems plans to deepen and construct side walls for both drains and tanks, which would limit the risk of flooding, and desilting of drains and tank beds would remove toxic and hazardous materials, as well as increasing capacity of tanks. Monitoring and Quality Control have been planned to be undertaken by the urban local boards by testing of water quality parameters within their respective jurisdictions and taking corrective measures for any cases of results worse than permissible standards (GHMC, 2005).

The 2005 GHMC City Development Plan included cost allocations for some of the city's outlined projects. The seven year plan included expenditure of INR 20,640m (around EUR 350m) on upgrades of storm water drains. This included INR 320m (EUR 5m) on capacity building, INR 7,020m (EUR 120m) on primary drains rehabilitation and INR 7,700m (EUR 130m) on the construction of secondary and tertiary drains.
8.6 New York City

8.6.1 New York City’s economy

New York City is the largest municipal region by population in the United States, with one of the highest wealth levels in the world. The metropolitan area of New York has a population of 19,128,439 (Brookings Institution, 2012b), with a growth rate of 1-2% between 2010 and 2012 (New York City Planning Department, 2012).

The GDP for New York City in 2012 was USD 1.21 trillion (EUR 0.91 trillion) (Brookings Institution, 2012b), representing 7.4% of the United States national GDP, recorded at USD 16.2 trillion (EUR 12.3 trillion) (World Bank, 2014). This equated to GDP per capita in the city of USD 63,238 (EUR 47,890). In the same year, the employment rate was 45% (NYC-CEO, 2014). Poverty rates in the city have been growing in recent years; with those living under the CEO poverty threshold\(^4\) growing from 19.0% of the population in 2008 to 21.3% in 2011 (NYC-CEO, 2014).

According to the Brookings Institution, the largest market sector in New York is business and finance, representing 40.3% of the city’s GDP (Brookings Institution, 2012b) (see Figure 8.7). This is followed by the local/non-market sectors (37.2%) and trade and tourism (12.3%). In terms of trade, chemical products (including pharmaceuticals), financial services, business services, tourism, and royalties account for 70% of the city’s total exports (Istrate and Marchio, 2012). The city is also an important centre for mass media, journalism, publishing and the creative industries (Currid, 2006).

![Figure 8.7: Share of New York City’s metropolitan area GDP by sector. Source: Brookings Institution, 2012b.](image)

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\(^4\) The CEO poverty threshold takes into account spending on basic necessities—food, clothing, shelter and utilities (NYC-CEO, 2013). It is a threshold specific to New York City, where a national U.S. threshold developed for the Federal Supplemental Poverty Measure is adjusted to the varying housing costs. It differs from the official poverty threshold which is based on the cost of a minimum diet and which is uniform across the United States. The official poverty rate shows growth from 16.8% in 2008 to 19.3% in 2011.
8.6.2 Climate impact costs

8.6.2.1 Flooding

One of the highest climate-related risks to New York City is sea flooding resulting from a storm surge. Overall, the damage costs of Hurricane Sandy, which struck the city in 2012, were estimated at around USD 19bn (EUR 14bn) (City of New York, 2013). Sandy resulted in 43 deaths, 6,500 patients evacuated from hospitals and nursing homes, 88,700 buildings flooded (of which around half were outside the 100-year floodplain), and 1.1 million children unable to attend school for a week.

Almost 2 million people were without power for at least four or five days, and in some cases power was down for several weeks in areas with overhead power lines (City of New York, 2013). Around 11 million travellers were affected, with subway lines being fully or partially restored a week after the hurricane. However, some elements of the system remained closed for much longer, with repairs expected to take months or years for certain parts of the system.

As evidenced by Hurricane Sandy, a large number of buildings, transportation networks, tunnels and underground infrastructure are at risk from a storm surge (City of New York, 2013). Ferries and marine transport are also at risk. Major risks also exist for utility services. Most steam generation assets and their distribution systems are located in floodplains. Similarly the electricity system is at a high risk from flooding, as most of the critical infrastructure is located in the floodplains.

A moderate risk exists for the natural gas system, as city gates could lose their monitoring and control systems and low-pressure distribution pipes could experience water infiltration (City of New York, 2013). Asset damage and power disruption could also lead to releases of untreated and partially treated sewage into waterways. Solid waste would be affected, with disruptions to rubbish collection resulting from flooding of transportation networks, and excess debris produced as a result of property damage. Liquid fuel terminals and refineries are highly susceptible to flooding, due to their location in floodplains.

Healthcare facilities are currently at a moderate risk, but with projections for the changing climate, their risk will increase significantly by the 2050s (City of New York, 2013). A similar pattern can be expected for the effect on telecommunications facilities. Similarly, food supply could be affected, with direct damage possible to Hunts Point and retailers in the floodplain, and the indirect effects of disruptions to the supporting systems such as the utilities, liquid fuels and transportation systems, with power outages affecting the whole supply chain.

An increase in precipitation due to climate change would increase turbidity, pathogen and contaminant levels which require treatment and challenge the disinfection process, as well as increasing the risk of localised flooding, due to rainfall exceeding the capacity of sewer systems (City of New York, 2013).

8.6.2.2 Storms

New York City faces the threat of strong winds, especially in relation to coastal storms. Buildings are at moderate risk from strong winds; building codes are calibrated to anticipated wind speeds but in-place stock and equipment may be vulnerable (City of New York, 2013). The electric system is also at moderate risk, due to damage to overhead power lines and the risk to street trees and forestry which would also impact on the power lines, as well as transportation. Increased likelihood of power outages could disrupt operations of supply infrastructure of liquid fuels, which is served by above-ground lines.

Strong winds can cause damage to the current transportation infrastructure, with moderate risk to most modes of transportation, including aviation (City of New York, 2013). The only transportation infrastructures at a low risk from winds are tunnels and subways.
The main impacts are falling trees, broken overhead utility lines, property damage and power outages (City of New York, 2013). At high enough speeds, winds can also cause building damage. Precautionary measures include the closure of bridges, causing transportation problems, with commuters unable to get to work. Parks were also closed prior to Sandy hitting New York, with facilities closed for three days, and volunteers helping with the clean-up afterwards.

**8.6.2.3 Heatwaves**

Heatwaves kill more Americans each year than all other natural disasters combined (City of New York, 2013). Heatwaves are more severe in New York City than in neighbouring counties due to the Urban Heat Island effect, affecting energy use, comfort and quality of life. They strain the city’s power grid and cause deaths due to heatstroke and exacerbate chronic health conditions. A heatwave in July 2006 resulted in 40 deaths from heat stroke (New York City Department of Health and Mental Hygiene, 2006). This was the most deaths from heat stroke since 1952, when 61 deaths occurred. In addition, the death rate from other natural causes in 2006 was estimated to have increased by 8%, or about 100 more deaths, during the heatwave lasting from July 27th to August 5th. A more severe heatwave or one paired with a major power outage could cause even more deaths (City of New York, 2013).

The city authorities predict that increased healthcare demands caused by heatwaves could be absorbed by current levels of healthcare operations (City of New York, 2013). However, power outages could lead to evacuation of hospitals and medical centres, as HVAC systems are required for operation and many are not connected to backup power.

Increased heatwaves are expected to impact on living conditions in high-rise buildings and lead to more power failures, with electricity infrastructure becoming a major risk category by the 2020s (City of New York, 2013). Power outages could lead to telecommunication outages, while extreme heat could also shorten the lifespan of electronic equipment if spaces are not sufficiently air-conditioned or insulated.

Movable infrastructures such as bridges and switches are likely to be impacted by heatwaves, leading to transport disruption (City of New York, 2013). The safety and comfort of commuters on the subway would be affected, and a reduced electrical supply would also affect the reliability of transport, including the disruption of the supply of liquid fuels.

An indirect possible impact on wastewater caused by power outages is the reduced treatment levels and sewage bypass, which is a problem during heatwaves (City of New York, 2013).

Heatwaves can also exacerbate air pollution levels. Each year PM$_{2.5}$ pollution is estimated to cause more than 3,000 deaths, 2,000 hospital admissions for lung and heart conditions and approximately 6,000 emergency department visits for asthma (City of New York, 2011).

**8.6.2.4 Drought**

Several droughts have occurred in the last 50 years, with the most intense lasting from 1963-1965, which resulted in significantly reduced water use by residents and business, through both mandatory and voluntary restrictions (City of New York, 2013). Since then, water demand has dropped, thus reducing the risk to New York from drought. The city currently has a three step warning system in place, as detailed in the Drought Management and Contingency Plan, with detailed guidelines established to identify when a Watch, Warning or Emergency should be declared (City of New York, 2012).

**8.6.2.5 Coastal erosion**

The predicted increase of coastal erosion combined with sea level rise is expected to lead to increased impacts of storms (City of New York, 2013). In one estimate, the damage costs of a similar storm to Hurricane Sandy could be almost five times higher by the 2050s, even if
it is assumed that no further development happens in the floodplain. The waves and retreating waters caused by Hurricane Sandy caused New York’s beaches to lose up to 2.3 million cubic metres of sand citywide.

### 8.6.2.6 Coldwaves and snow

Snowfall results in costs of snow ploughing operations, transport disruptions and accidents, as well as closure of schools (City of New York, 2013). Freezing temperatures can cause frostbite and hypothermia, especially in the more vulnerable population, such as the elderly. The city has also issued warnings about using stoves and ovens to heat homes, which can result in fires and carbon monoxide exposure (NYC Severe Weather, 2014).

Past events include a blizzard in December 2010, when more than 510mm of snow fell in the city, causing major travel disruptions as airports and rail shut down across the city and Long Island (New York City Office of Emergency Management, 2013). Drivers who got stuck in the snow abandoned their vehicles, creating further difficulties for the snow ploughs to clear accumulating snow.

A snowstorm in February 2006 caused snowfall of 680mm over a period of 16 hours (New York City Office of Emergency Management, 2013). The city deployed 2,500 workers to cover 12 hour shifts removing snow, airport and rail services were cancelled, the subway experienced extensive delays and New York City’s Bus service was running at 50% capacity.

In February 2003 almost 600mm of snowfall covered the city (New York City Office of Emergency Management, 2013). 42 lives were claimed nationwide, with two attributed to the metropolitan area of New York City- one due to carbon monoxide poisoning while a man was warming up his car, and the other due to a collapsing roof from the weight of the snow. The estimated cost to the city for this event is quoted as USD 20m (EUR 18.6m).

### 8.6.3 Adaptation costs

New York City has an adaptation plan, PlaNYC, originally launched in 2007, but updated in 2011, encompassing many goals for achieving a greener city by increasing resilience of communities, natural systems and infrastructure to climate risks (City of New York, 2011). In terms of climate change mitigation, the city aims to reduce GHG emissions by more than 30%, to be achieved by an ongoing planning process.

In 2013, a resilience plan was published as part of PlaNYC, including a breakdown of 10-year capital and study cost preliminary estimates (City of New York, 2013). The following sections outline the major conclusions of the plan (see Table 8.8). A full breakdown by initiative can be found in the report. Overall, if NYC implements all the resilience measures in the plan, the total cost is estimated to be EUR 10-12bn (1.14-1.35% of the city’s GDP).

<table>
<thead>
<tr>
<th>Resilience measure</th>
<th>Specific measures</th>
<th>Costs (EUR million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water and waste water</td>
<td>Protect wastewater treatment facilities from storm surge</td>
<td>3,445-4,020</td>
</tr>
<tr>
<td></td>
<td>Improve and expand drainage infrastructure</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Promote redundancy and flexibility to ensure constant supply of high-quality water</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coastal protection</td>
<td>Increasing coastal edge elevations</td>
<td>2,660-3,060</td>
</tr>
<tr>
<td></td>
<td>Minimising upland wave zones</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Protection against storm surge</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Improve coastal design and governance</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Category</td>
<td>Objective</td>
<td>Total</td>
</tr>
<tr>
<td>-------------------</td>
<td>---------------------------------------------------------------------------</td>
<td>----------------</td>
</tr>
<tr>
<td>Buildings</td>
<td>Strengthen new and substantially rebuilt structures to meet the highest resiliency standards moving forward</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Retrofit as many buildings as possible so that they will be significantly more resilient than they are today</td>
<td>2,290-2,490</td>
</tr>
<tr>
<td>Healthcare</td>
<td>Ensure critical providers’ operability through redundancy and the prevention of physical damage</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reduce barriers to care during and after emergencies</td>
<td>620-710</td>
</tr>
<tr>
<td>Transportation</td>
<td>Protect assets to maintain system operations</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Prepare the transportation system to restore service after extreme climate events</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Implement new and expanded services to increase system flexibility and redundancy</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>607-767</td>
</tr>
<tr>
<td>Parks</td>
<td>Adapt parks and expand green infrastructure to shield adjacent communities from the impacts of extreme weather events</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Retrofit or harden park facilities to withstand the impacts of climate change</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Protect wetlands, other natural areas, and the urban forest</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Develop tools for comprehensive climate adaptation planning and design</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>508-840</td>
</tr>
<tr>
<td>Economic recovery</td>
<td>Support community and economic recovery in impacted areas</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>235-290</td>
</tr>
<tr>
<td>Utilities</td>
<td>Redesign the regulatory framework to support resiliency</td>
<td>Subject to rate case decision</td>
</tr>
<tr>
<td></td>
<td>Harden existing infrastructure to withstand climate events</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reconfigure utility networks to be redundant and resilient</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reduce energy demand</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Diversify customer options in case of utility outage</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>Subject to rate case decision</td>
</tr>
<tr>
<td>Telecommunications</td>
<td>Increase accountability to promote resiliency</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Enable rapid recovery after extreme weather events</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Harden facilities to reduce weather-related impacts</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Create redundancy to reduce risk of outages</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>Subject to rate case decision</td>
</tr>
<tr>
<td>Food supply</td>
<td>Identify and harden critical food distribution assets</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Improve the resiliency of consumer access</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Protect solid waste facilities and disposal networks</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>15-38</td>
</tr>
<tr>
<td>Liquid fuels</td>
<td>Seek to harden the liquid fuels supply infrastructure</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Enhance the ability of the supply chain to respond to disruptions</td>
<td></td>
</tr>
<tr>
<td>Category</td>
<td>Description</td>
<td>Total</td>
</tr>
<tr>
<td>-----------------------------------------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>--------</td>
</tr>
<tr>
<td>Improve the city’s ability to fuel first responders and private critical fleets</td>
<td></td>
<td>15-30</td>
</tr>
<tr>
<td>Community preparedness</td>
<td>Improve the ability of communities to prepare for and respond to disasters</td>
<td>2.3-15</td>
</tr>
<tr>
<td>Environmental protection and remediation</td>
<td>Protect sites with hazardous substances and encourage brownfield redevelopment</td>
<td>0.76-9</td>
</tr>
<tr>
<td>Insurance</td>
<td>Target affordability solutions to low-income policyholders</td>
<td>&lt;2</td>
</tr>
<tr>
<td></td>
<td>Define resiliency standards for existing buildings</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Incorporate resiliency standards in insurance underwriting</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Expand pricing options for policyholders</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Improve awareness and education about insurance</td>
<td></td>
</tr>
<tr>
<td>GRAND TOTAL</td>
<td></td>
<td>10,398-12,271</td>
</tr>
</tbody>
</table>

Table 8.8: A stronger, more resilient New York: breakdown of resilience measures. Source: City of New York, 2013.

### 8.6.3.1 Sea flooding protection

PlaNYC outlines the need for vulnerable neighbourhoods to be protected by various coastal defences, with costs being allocated for offshore breakwaters and wetlands, which will weaken waves approaching the coastline, and for maintenance of beaches to shield inland communities (City of New York, 2013). Other strategies include putting in place both permanent and temporary floodwalls, as well as reinforcing bulkheads and tide gates to protect against storm surge.

Coastal initiatives aimed at increasing coastal edge elevations have been projected to cost USD 295-450m (EUR 220-340), with a large proportion of this sum going towards raising bulkheads in low-lying neighbourhoods (USD 80-100m; EUR 60-75m) and completion of emergency beach nourishment on the Rockaway Peninsula (USD 100-125m; EUR 75-95m) (City of New York, 2013).

Minimising upland wave zones has been allocated USD 670-875m (EUR 507-662m), with the main initiatives being the study of and installation of breakwaters adjacent to and south of Great Kills Harbor (USD 200-250m; EUR 150-190) and the study and installation of wetlands for wave attenuation in Howard Beach and to study further flood protection improvements within Jamaica Bay (USD 250-300m; EUR 190-230m) (City of New York, 2013).

The majority of coastal protection spending will focus on protecting against storm surge, with an estimated cost of USD 2,250-2,515m (EUR 1,700-1,900m) (City of New York, 2013). The initiative with the highest cost is the study and installation of local storm surge barriers at Newtown Creek, with a cost of USD 950-1,000m (EUR 720-760m). Other main initiatives in this part of the spending include completion of existing studies on Staten Island and implementation of coastal protection projects (USD 400-450m, EUR 300-340m) and installing integrated flood protection systems in Manhattan, including the Lower East Side (USD 300-350m; EUR 230-270m).

Other initiatives, aimed to improve coastal design and governance, have been allocated funding of around USD 35-80m (EUR 26-60m) (City of New York, 2013).
8.6.3.2 Buildings and neighbourhoods

By 2030, New York City expects to have almost one million more inhabitants than in 2005 (City of New York, 2013). Consequently, one of the city’s main strategies is to create sufficient housing to meet this increase in population. Strengthening new and sustainably rebuilt structures to meet the highest resiliency standards will cost the city an estimated USD 1,130-1,245m (EUR 855-945m), mainly consisting of the cost of rebuilding and repairing housing units destroyed and substantially damaged by Hurricane Sandy (USD 950-1,000m; EUR 720-760m).

Retrofitting as many buildings as possible to substantially increase their resilience is projected to cost USD 1,895-2,040m (EUR 1,435-1,545m), with USD 700-750m (EUR 530-570m) allocated towards retrofitting public housing units damaged by Sandy to increase future resiliency and USD 1,150-1,200m (EUR 870-910m) allocated to encouraging existing buildings in the 100-year floodplain to adopt flood resiliency measures through an incentive programme and targeted requirements (City of New York, 2013).

8.6.3.3 Transport

The maintenance and improvement of a reliable transportation system with expanded and sustainable transportation choices is essential for New York to enhance the city’s quality of life, and to provide opportunity for economic growth (City of New York, 2013).

The protection of assets to maintain system operations will cost around USD 655-780m (EUR 495-590m), with the highest spend contributed to the reconstruction and resurfacing of key streets damaged by Sandy (USD 450-500m; EUR 340-380m) (City of New York, 2013).

Preparing the transportation system to restore service after extreme climate events will cost around USD 30-75m (EUR 22-57m), with the highest proportion of that spending allocated to construction of new ferry landings to support private ferry services (USD 20-40m; EUR 15-30m) (City of New York, 2013).

Implementing new and expanded services to increase system flexibility and redundancy will cost an estimated USD 120-160m (EUR 90-120m), with the highest cost being the expansion of the city’s Select bus service network (USD 80-100m; EUR 60-75m) (City of New York, 2013).

8.6.3.4 Economic recovery and business resilience

Supporting community and economic recovery in impacted areas will cost around USD 310-385m (EUR 235-290m), with the largest initiative being the launch of business recovery and resiliency programs, at a cost of USD 150-175m (EUR 110-135m) (City of New York, 2013).

8.6.3.5 Utilities

A number of initiatives have been outlined to redesign the regulatory framework to support resiliency, to harden the existing infrastructure to withstand climate events, to reconfigure utility networks to be redundant and resilient, to reduce energy demand and to diversify customer option in case of utility outage. However, costs are yet to be allocated, subject to the 2013 rate case decision (City of New York, 2013).

8.6.3.6 Liquid fuels

Initiatives have also been put in place aimed at improving the liquid fuels supply infrastructure and enhancing the ability of the supply chain to respond to disruptions (City of New York, 2013). A cost of USD 20-40m (EUR 15-30m) has been estimated to improve the city’s ability to fuel first responders and private critical fleets by making municipal fuelling stations more resilient and enhancing mobile fuelling capability to support both city government and critical fleets.
8.6.3.7 **Healthcare**

Initiatives to ensure critical providers’ operability through redundancy and the prevention of physical damage are projected to cost USD 820-930m (EUR 620-705m) with USD 700-750m (EUR 530-570m) allocated for the retrofitting of existing hospitals in the 500-year floodplain (City of New York, 2013). Another USD 1-10m (EUR 0.76-7.6m) has been allocated to schemes for reducing barriers to care during and after emergencies.

8.6.3.8 **Community preparedness**

Around USD 3-20m (EUR 2.3-15m) will be used for improving the ability of communities to prepare for and respond to disasters (City of New York, 2013).

8.6.3.9 **Telecommunications**

Telecommunications initiatives are in place to increase accountability to promote resiliency, to enable rapid recovery after extreme weather events, to harden facilities to reduce weather-related impacts and to create redundancy to reduce risk of outages (City of New York, 2013).

8.6.3.10 **Parks**

Adaptation of parks and expansion of green infrastructure to shield adjacent communities from the impacts of extreme weather events will cost USD 370-680m (EUR 280-515m), with USD 250-500m (EUR 190-380m) of that budget dedicated to the restoration of the city beaches (City of New York, 2013).

Retrofitting and hardening of park facilities to withstand the impacts of climate change will cost USD 270-350m (EUR 205-265m), mainly by relocating or increasing the resiliency of playgrounds and athletic fields, at a cost of USD 125-150m (EUR 95-115m) (City of New York, 2013).

Other costs for improving of parks are USD 30-60m (EUR 23-45m) allocated for protection of wetlands, other natural areas and the urban forest, and USD 1-20m (EUR 0.76-15m) to develop tools for comprehensive climate adaptation planning and design (City of New York, 2013).

8.6.3.11 **Environmental protection and remediation**

USD 1-12m (EUR 0.76-9m) has been estimated to be the cost of the protection of sites with hazardous substances and the encouragement of brownfield redevelopment (City of New York, 2013).

8.6.3.12 **Water and waste water**

Protection of wastewater treatment facilities from storm surge will cost around USD 1,025-1,160m (EUR 775-880m) (City of New York, 2013). Improvement and expansion of the drainage infrastructure is estimated at a cost of USD 1,675-1,850m (EUR 1,270-1,400m). Promoting redundancy and flexibility to ensure constant supply of high-quality water has been estimated at USD 1,850-2,300m (EUR 1,400-1,740m).

8.6.3.13 **Food supply**

Schemes to identify and harden critical food distribution assets, to improve the resiliency of consumer access and to protect solid waste facilities and disposal networks have been allocated an overall estimated cost of USD 20-50m (EUR 15-38m) (City of New York, 2013). This follows major disruptions of the food logistics network during and following the flooding from Hurricane Sandy.

8.6.3.14 **Air quality**

Air pollution in the city still remains a significant concern. However, by enlisting the help and funding of private and public partners, New York has set out to “achieve the cleanest air
quality of any big U.S. city” (City of New York, 2011, p.15). Over half of the city’s PM$_{2.5}$ levels originate from outside the city, and the Congressional delegation is continuously supporting enforcement of federal laws. However, the city is also dealing with pollution from local sources, having successfully sought a state law to reduce the sulphur content in Number 2 heating oil by 99%, enacting a local law which requires the use of 2% biodiesel in heating oil and creating the renewed low sulfur Number 4 oil classification. Current investments include millions of dollars spent on boiler conversions in schools using oils Number 4 and 6 in their boilers, to switch use to cleaner fuels. By 2011 this had already been completed at 13 schools and plans are in place to phase out Number 6 heating oil use at more than 200 school buildings by 2015.

The initiatives outlined by the city include plans to understand the scope of the challenge, reducing transportation emissions, (examples including facilitating the adoption of electric vehicles, reducing illegal idling and retrofitting ferries), reducing emissions from buildings (by promoting the use of cleaner-burning heating fuels, as in the example of boiler conversions in schools) and updating of codes and standards (City of New York, 2011).

8.6.4 Cost benefit analysis

The PlaNYC resiliency report states that while Sandy caused around USD 19bn (EUR 14bn) in losses, a storm of the same magnitude could cause an estimated USD 90bn (EUR 68bn) (in current value) in losses by the 2050s, a cost almost five times higher, due to the effects of climate change on sea level rise (City of New York, 2013).

If the first phase of coastal protection measures as well as power and building protections are taken into account, the projected losses for the 2050s are reduced by up to 25% (around USD 22bn; EUR 17bn), which would result from the USD 10-12bn (EUR 7.5-9bn) investment in adaptation measures (City of New York, 2013). The analysis assumes the city as it is today. If all of the other measures are also taken into consideration this would result in a larger reduction in damage costs, and other investments by State-led transportation authorities and others could reduce future costs even further.

This cost benefit analysis only quantifies value of losses avoided from any future coastal storms. However, the measures that are going to be implemented will also protect NYC from damage due to other extreme events such as heavy downpours and heatwaves which are also predicted to increase in likelihood with climate change (City of New York, 2013).
8.7 Rio de Janeiro

8.7.1 Rio de Janeiro’s economy

Rio de Janeiro is located on Brazil’s Atlantic coast. The core of the city is on flat land around the Western shore of Guanabara Bay. The South Zone (Zona Sul) is built around beaches and separated from the north by the densely forested Tijuca mountain range, with peaks reaching 1,000m above sea level. The more recently urbanised Western Zone is located on beaches and surrounding coastal lagoons. Much of the flat land of the city is built around former coastal marshes, lagoons and estuaries.

In 2012, the metropolitan area of Rio had a population of 11,968,886 with a high growth of 25% between 1990 and 2012. The employment rate was 46% in 2012, a 2.2% change from the previous year. Overall, 14% of the population lives in informal settlements.

In 2012, Rio’s metropolitan GDP was USD 194.9bn (EUR 150.3bn) (Brookings Institution 2012b). This represents 8.7% of Brazil’s GDP of USD 2.252 trillion (EUR 1.737 trillion) (World Bank, 2014). GDP per capita in the city is USD 16,282 (EUR 12,557) (Brookings Institution, 2012b).

Rio’s largest sector is the local and non-market sector, representing 30% of the economy (Brookings Institution, 2012b). Other key sectors include business and finance (28%), trade and tourism (15%) and commodities (9%) (see Figure 8.8).

![Figure 8.8: Share of Rio’s metro output by industry. Source: Brookings Institution, 2012b.](image)

8.7.2 Climate impact costs

8.7.2.1 Flooding and landslides

Pluvial flooding and landslides are currently the main climate-related threats in Rio de Janeiro (De Sherbinin and Hogan, 2011). Climate change is expected to lead to a change in the pattern of precipitation and sudden rainfalls which could lead to a higher frequency of
both flooding and landslides. Informal settlements are particularly at risk, as housing is often built on steep hillsides using unsafe building practices, inadequate drainage infrastructure and unregulated development. Vegetation which serves as a natural flood protection is often destroyed by these hillside settlements. Natural flood protections are also under strain because of Rio de Janeiro’s high population density. Rio de Janeiro’s average population density is 4,640 persons per sq. km and 8,000 to 12,000 people per sq. km in smaller administrative units across the municipality of Rio de Janeiro.

In January 2011 flooding and landslides killed 450 people in the state of Rio de Janeiro (De Sherbinin and Hogan, 2011). Another source estimates that the January 2011 floods in Rio killed 900 people and led to estimated costs of BRL 2.2bn (EUR 925m) (Salim, 2012). Across the Southeast of Brazil - which includes both Rio de Janeiro and São Paulo - 8,000 people were killed, over 100,000 people were displaced and key infrastructure was destroyed (Jha et al., 2011).

Approximately 200 people died during April 2010 flooding and landslides and several thousands were displaced. The total cost of this event amounted to losses of up to BRL 21.9bn (EUR 9.97bn) (De Sherbinin and Hogan, 2011). In Rio, 67 people died and hundreds of homes were destroyed (Government of Brazil, 2012). Heavy rains in June 2010 led to 107 people being killed and damages amounting to costs of up to BRL 986.5m (EUR 449.7m) (Swiss Re, 2011).

The February 1988 rainfalls and subsequent floods killed 58 people (Government of Brazil, 2012). The landslide in January 1967 killed about 100 people and injured 300. The landslides in January 1966 killed 70 people and injured 500.

8.7.2.2 Heatwaves

High temperatures have been recorded to impact on energy and health in Rio. According to local press reports, temperatures in December 2012 rose up to 43.1°C which caused a number of power cuts and left crucial infrastructure such as the airport without power and air-conditioning (Tavener, 2012).

The WHO estimated that urban outdoor air pollution including motor transport, small-scale manufacturers and other industries which use biomass and coal for cooking and heating and the coal-fired power plants are the largest contributor to air pollution in Rio. Residential wood and coal burning and high traffic volumes also contribute to air pollution (Onursal and Gautam, 1997).

8.7.2.3 Storms and sea-level rise

Storm events combined with predicted sea-level rise are likely to exacerbate coastal erosion, tidal flooding and contribute to drainage problems in low-lying areas of the city (De Sherbinin and Hogan, 2011). During the April 2010 storm, 265 people were killed and 74,500 people were displaced across the state of Rio de Janeiro. The economic costs were BRL 328.8m (EUR 149.9m. In February 1996 a storm hit the South and West Zones of Rio de Janeiro killing 59 people and leaving 1500 people homeless (Beser de Deus et al., 2013). The damage was mostly centred in Jacarepagua, a neighbourhhood in the city of Rio de Janeiro.

8.7.2.4 Drought

Predicted decreases in precipitation rates in winter and spring may cause more droughts and increase vulnerability to water scarcity (De Sherbinin et al., 2007). Rio sources the majority of its water from the Paraiba River basin in Minas Gerais, which if affected, could lead to threats to water security in the city. A large proportion of Brazil’s electricity is generated by hydroelectric plants. In 2001, a drought led to severe shortages in electricity across the country. Consumers had to cut electricity consumption by 20-25 percent.
8.7.3 Adaptation costs

8.7.3.1 Flood and landslide management

Central and local government have invested in improving basic infrastructure and social conditions in informal settlements which are typically the areas most vulnerable to flooding and landslide risks (De Sherbinin et al., 2007; De Sherbinin and Hogan, 2011). However, little physical flood protection infrastructure has been established.

The 1996 heavy rainfall led to a new institute being established called the Institute of Geotechnics (IG) which prepared long-term emergency plans to protect the city against landslides (Jha et al., 2011). The group, comprising technical experts, civil engineers and geologists, established a number of earth-retaining structures. In addition to this initiative the agency was responsible for surveying and mapping geological and geotechnical features in the Rio de Janeiro municipal area. The risk-reduction programme was approved by the mayor and started to be implemented in 2010. The budget increased more than tenfold in 2010 after the approval. As a consequence, 117 siren stations were installed, with 58 being equipped with automatic gauges or pluviometers (Government of Brazil, 2012). The rain gauges transfer data to the Municipal Operations Centre every 15 minutes which allows the city to monitor the critical amount of rainfall.

The Operations Centre Rio de Janeiro (CO-Rio) is a city wide system integrating data from 30 agencies as a response to nation-wide flash floods in 2010 in Brazil. The project costs Rio about BRL26.1m (EUR 10.8m). The centre enables real-time communication and can significantly reduce the impact of crisis situations by minimizing disruptions to public services and activities in the city (Government of Brazil, 2012). The operations centre brings together 30 bodies of the city administration including civil defence, traffic, conservation, municipal guard as well as key utility and service concession holders such as the metro and Rio Niteroi bridge which can be directly affected when severe weather events occur.

Other services include computer networks, protection against electrical break-downs, access to high-speed internet, and full back up telecommunications systems. The centre operates 24 hours a day, 7 days a week with 400 professional staff members. Since 2010, rainfall events are now recorded more consistently.

8.7.3.2 Air quality

The environmental authorities in Rio de Janeiro have been installing air quality control stations in places where competitions will take place for the 2016 Olympic Games. This is being undertaken to reduce the effects of air pollution on athletes. A total of 16 new air quality monitoring stations have been installed in Rio de Janeiro at a cost of BRL 26m (EUR 10.8m).

8.7.3.3 City level adaptation Policy

The City of Rio de Janeiro released its climate change policy in January 2011 (Law No. 5.248) which includes both adaptation and mitigation measures (Prefeitura do Rio de Janeiro, 2010). It creates the legal framework that allows municipalities to create climate change strategies and develop individual targets (World Bank, 2013). The Municipal Environment Office (Secretaria Municipal de Meio Ambiente, Cidade Nova - SMAC) coordinated the climate change policy of Rio de Janeiro. It has strong ties to different areas of the municipal administration as well as strong partnerships with academic institutions (Prefeitura do Rio de Janeiro, 2010). SMAC developed a vulnerability map for the metropolitan region of Rio de Janeiro which identifies the physical and socio-economic vulnerabilities the environment of the region faces.

The Climate Change and Sustainable Development Management Office (Gerência de Mudanças Climáticas e Desenvolvimento Sustentável - GMCDS) of SMAC is coordinating
the implementation of the GHG Emissions Monitoring System and the development of The Municipality Plan of Adaptation and Resilience to Climate Change.

The Municipality Plan of Adaptation and Resilience to Climate Change is being planned for mid-2015. It aims to cover the diagnosis of the city considering the biophysical, economic and social, environmental and health, urban infrastructure and institutional framework issues, the update of the vulnerability map and the identification of strategies for mitigation and adaptation.

Upgrading of informal settlements is a key measure for reducing the future costs of floods (De Sherbinin et al., 2007). Rio de Janeiro invested more than BRL 1.3bn (EUR 454.5m) into its ‘Programa Favela Bairro’ - a project to improve basic infrastructure, health and education for half of a million of its poorest residents. In June 2013, the government of Brazil announced that it will invest BRL 2.5bn (EUR 909m) into Rio de Janeiro’s informal settlements to provide water and sewage facilities for the poor.

8.7.3.4 National level adaptation policy

At the national level, the Brazilian Government instituted the Inter-Ministerial Committee on Climate Change (CIMGC) in 2007 to guide and prepare the ‘National Plan on Climate Change’. (Ministerio do Meio Ambiente, 2013). The ‘National Plan for Climate Change’ is planned to be finished in 2015 and aims to present measures of actions to promote adaptation in the country, evaluating cost effectiveness, synergies, conflicts and co-benefits of the measures considered. The Ministry of Environment is responsible for the coordination and preparation of this plan. Sectorial plans are already available for transportation, energy, biodiversity, natural disasters, coastal zones, cities, food and agricultural security, industry, health and water. The Inter-Ministerial Working Group Adaptation under the CIMGC has the main responsibility for the area of climate change adaptation.

The Ministry of Science and Technology has established the National System for Prevention and Early Warning of Natural Disasters, costing around BRL 507m (EUR 227m). The Ministry aims to make the System operational by the end of 2014.

The infrastructural programme under President Dilma Rousseff which is known as the Programa de Aceleracão do Crescimento 2 (PAC 2) made a commitment to invest into improving social and urban programmes, energy and logistics. It is the second infrastructural programme after PAC which was introduced by former President Lula da Silva. The Government of Brazil has committed to spend BRL 959bn (EUR 436.2m) between 2011 and 2014.

There are six key areas to this programme: Minha Case, Minha Vida (My House, My Life), Cidade Melhor (Better City), Comunidade Cidada (Citizen Community), Water e Luz para Todos (Water and Light for All, Energy, and Transport). The programme Cidade Melhor (Better City) commits to protect the city from extreme weather events and is committed to improving sanitation, providing risk-area housing safety, and paving roads in needy communities.

Table 8.9 lists the financial investments planned by the Brazilian government to improve infrastructure, housing and logistics under PAC 2 (Loudiyi, 2010). The ‘Better City’ programme has planned investments of BRL 57.1bn (EUR 25.5bn).
<table>
<thead>
<tr>
<th>PAC 2 Initiatives</th>
<th>2011-2014</th>
<th>Post-2014</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Better city</td>
<td>57.1 (25.5)</td>
<td>-</td>
<td>57.1 (25.5)</td>
</tr>
<tr>
<td>Bringing citizenship to the community</td>
<td>23.0 (10.3)</td>
<td>-</td>
<td>23.0 (10.3)</td>
</tr>
<tr>
<td>Housing</td>
<td>278.2 (124.4)</td>
<td>-</td>
<td>278.2 (124.4)</td>
</tr>
<tr>
<td>Water and Light for All</td>
<td>30.6 (7.4)</td>
<td>-</td>
<td>30.6 (13.7)</td>
</tr>
<tr>
<td>Transportation</td>
<td>104.5 (46.7)</td>
<td>4.5 (2)</td>
<td>109.0 (48.7)</td>
</tr>
<tr>
<td>Energy</td>
<td>465.5 (208.1)</td>
<td>627.1 (280.4)</td>
<td>1,092.6 (488.3)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>958.9 (428.7)</td>
<td>631.6 (282.4)</td>
<td>1,590.5 (711.1)</td>
</tr>
</tbody>
</table>


Drainage systems have the ability to reduce the effect of floods as they can transport water after collecting it (Swiss Re, 2011). Assuming that they are operational in 2014, the planned drainage systems have the potential to reduce expected loss in 2030 by BRL 1bn (EUR 447.1m). The planned drainage projects built under PAC 2 cost around BRL 10.4bn (EUR 4.65bn) and are predicted to lower potential expected economic losses in 2030 by nearly BRL 1.1bn (EUR 491.8m).

Over the period of 2011-2014, BRL 1.3bn (EUR 559.6m) of PAC 2’s Cidade Melhor (Better City) programme was allocated to hillside stabilisation projects to reduce the risk from landslides in the mountainous areas (Swiss Re, 2011). Slope stabilisation is predicted to reduce the annual expected loss due to flash floods by 10 per cent and reduce the annual expected costs by BRL 154.5m (EUR 70.5m) in 2030.

Building codes include the implementation of waterproof building materials and can reduce the annual expected costs of flooding by 20 per cent (Swiss Re, 2011). In 2030, the averted loss could amount to BRL 1.4bn (EUR 626m). In the period between 2013 and 2030, Brazil would be able to avert estimated costs of BRL 8.8bn (EUR 3.9bn) in present values with the implementation of these building codes. Enforcement of building codes requiring sealing of doors and windows on the ground floor could reduce the annual expected loss by more than BRL 1.3bn (EUR 581.3m) in 2030.

Table 8.10 shows the expenses of upgrading the ground floor of all houses at flood risk (Swiss Re, 2011). On average, sealing costs around five per cent of the capital value of the ground floor. The capital value is calculated through the capital stock per house in 2010 and by assuming that about 50 per cent are located on the ground floor. Through multiplying these costs with the number of houses that are at flood risk Swiss Re estimate that around BRL 5.5bn (EUR 2.5bn) would be needed to upgrade all houses at flood risk. Splitting the costs equally over 20 years, the present value amounts to BRL 2.3bn (EUR 1bn).

<table>
<thead>
<tr>
<th>Adaptation measure</th>
<th>BRL</th>
<th>EUR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital stock per house</td>
<td>66,465</td>
<td>22,772</td>
</tr>
<tr>
<td>Capital stock ground floor per house (50% of total)</td>
<td>33,233</td>
<td>13,386</td>
</tr>
<tr>
<td>Cost upgrade floor per house (5% of capital stock ground floor)</td>
<td>1,662</td>
<td>669.5</td>
</tr>
<tr>
<td>Houses at flood risk total Brazil (3 persons per house, on average)</td>
<td>5,553,320</td>
<td>2,236,880</td>
</tr>
<tr>
<td>Costs for building upgrade in all houses at risk</td>
<td>5,342,230,000</td>
<td>2,151,850,000</td>
</tr>
</tbody>
</table>

Table 8.11 shows that building codes which enforce sealing of the ground floor are currently estimated to avert losses of up to BRL 1.4bn (EUR 626m) by 2030 (Swiss Re, 2011). Drainage projects are likely to reduce the damage costs by almost BRL 1bn (EUR 447m) and measures to tackle hillside stabilisation by over BRL 165m (EUR 73.8m). Additional stabilisation for hillsides which is a measure of the PAC 2 and costs around BRL 1.4bn (EUR 626m) could avert losses by BRL 158m (EUR 70.6m) annually.

<table>
<thead>
<tr>
<th>Adaptation measures</th>
<th>Costs</th>
<th>Averted loss in 2030</th>
<th>PV cost*</th>
<th>PV averted loss*</th>
<th>Cost-averted loss ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drainage projects</td>
<td>USD 5.9bn</td>
<td>USD587m</td>
<td>USD5.1bn</td>
<td>USD3.4bn</td>
<td>1.51</td>
</tr>
<tr>
<td></td>
<td>BRL12.6bn</td>
<td>BRL1.3bn</td>
<td>BRL10.9bn</td>
<td>BRL7.3bn</td>
<td></td>
</tr>
<tr>
<td></td>
<td>EUR 4.5bn</td>
<td>EUR 444.6m</td>
<td>EUR 3.9bn</td>
<td>EUR 2.6bn</td>
<td></td>
</tr>
<tr>
<td>Hillside stabilisation</td>
<td>USD800m</td>
<td>USD94m</td>
<td>USD693m</td>
<td>USD539m</td>
<td>1.29</td>
</tr>
<tr>
<td></td>
<td>BRL1.7bn</td>
<td>BRL200m</td>
<td>BRL1.5bn</td>
<td>BRL1.1bn</td>
<td></td>
</tr>
<tr>
<td></td>
<td>EUR 606m</td>
<td>EUR 71.2m</td>
<td>EUR 525m</td>
<td>EUR 408m</td>
<td></td>
</tr>
<tr>
<td>Building codes</td>
<td>USD3.1bn</td>
<td>USD772m</td>
<td>USD1.8bn</td>
<td>USD5049m</td>
<td>0.32</td>
</tr>
<tr>
<td></td>
<td>BRL6.6bn</td>
<td>BRL1.6bn</td>
<td>BRL3.8bn</td>
<td>BRL10.8bn</td>
<td></td>
</tr>
<tr>
<td></td>
<td>EUR 2.3bn</td>
<td>EUR 585m</td>
<td>EUR 1.3bn</td>
<td>EUR 3.8bn</td>
<td></td>
</tr>
<tr>
<td>Urban planning</td>
<td>N/A</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Early warning system</td>
<td>USD288m</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>BRL486m</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>EUR 173m</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Field work and training</td>
<td>USD0.21m</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>BRL0.4m</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>EUR 0.16m</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 8.11: Summary of adaptation measures, their costs and loss aversion potential. Source: Swiss Re, 2011.
9 Conclusions

9.1 Climate threats in cities

The results of this Review show that a range of climate-related threats, including both extreme weather events and slow onset events, have potentially substantial costs for cities (though not all threats, extreme weather events, and “loss and damage” are faced by all cities). The main extreme weather events identified were: sea and tidal flooding, inland flooding (fluvial and pluvial), storms (strong winds), heatwaves, drought, air pollution, coldwaves and snow. Further extreme threats included landslides and wildfires. In addition, “slow onset events” were identified that are associated with mean temperature changes as opposed to extreme events. However, almost no research has been undertaken to quantify the costs of slow onset events.

9.2 Climate losses

The climate-related events for which costs were sourced for the RAMSES case study cities between 1900 and 2013 ranged between EUR 1.1m (London heatwave in 2003) and EUR 14bn (flooding from New York City’s Hurricane Sandy in 2012). In terms of city wealth, the costs of events ranged from 0.0002% to 3% of municipal GDP. The costs of different extreme weather events in the case study cities follow a similar pattern to total European level costs estimated by the EEA. Examining the events with the highest losses across the case study cities, costs were highest for flooding followed by storms, with heatwaves and drought having much lower market costs.

At the European level, according to the European Environment Agency (EEA), flooding led to the highest weather-related costs between 1998 and 2009 in Europe. Flooding damages totalled EUR 52.2bn, followed closely by storm damages of EUR 44.3bn. Heatwaves, coldwaves, forest fires and drought caused substantially lower market costs, between EUR 4.9bn and 10bn. In contrast, heatwaves and coldwaves were responsible for many more excess fatalities, and the health costs of these extreme events are most likely to be substantial. Between 1998 and 2009, 77,551 recorded excess deaths were attributed to heatwaves and coldwaves – the vast majority of these being due to the heatwave in the hot summer of 2003.

At the city level, the climate-related events for which costs were sourced for the RAMSES case study cities between 1900 and 2013 ranged between EUR 1.1m (London heatwave in 2003) and EUR 14bn (flooding from New York City’s Hurricane Sandy in 2012). In terms of city wealth, the costs of events ranged from 0.0002% to 3% of municipal Gross Domestic Product (GDP). The costs of different extreme weather events in the case study cities follow a similar pattern to total European level costs estimated by the EEA. Examining the events with the highest losses across the case study cities, costs were highest for flooding followed by storms, with heatwaves and drought having much lower market costs (see Figure 9.1).

Heatwaves and drought were perceived by city official stakeholders to represent substantially higher future costs under climate change compared to actual historical costs of these impacts (see Figure 9.2). The difference between historical costs from high impact events and perceived future costs from climate change by city officials should be researched further, particularly in terms of policy decision making.
Almost no published evidence exists for the costs of adaptation for the case study cities. One exception is New York City where, following Hurricane Sandy, the authorities commissioned an adaptation plan to build resilience to a similar future hurricane. The estimated adaptation costs ranged from EUR 3.45bn – 4.02bn for upgrading the water and waste water systems to improvements in healthcare, transport and parks resilience each requiring over EUR 500m.

While evidence was lacking for adaptation costs in the case study cities, the Review was able to identify the major sectors of the economy for each of the cities to determine where adaptation measures may be needed in the future (see Figure 9.3). In London and New York City, the business and financial services sectors are particularly valuable, and Hurricane Sandy highlighted the vulnerability of these sectors in New York City when financial trading was suspended for three days. In Antwerp, the seaport – one of the largest in Europe – is a major component of the city’s and region’s economy, particularly in the trade and transportation sectors. While in Bilbao, the contribution of the industrial and manufacturing sector is higher than in the other case study cities.

While not all these sectors will have the same levels of vulnerability to climate-related impacts, this review nonetheless highlights those sectors where the city authorities should be particularly interested in assessing the risks.
9.4 Evidence for costs: gap analysis

One of the main objectives of this Review was to assess the gaps in historical data on the costs of climate-related events. The evidence for historical costs of extreme events in cities is incomplete and often estimated using different assumptions (e.g. different sectors, different cost accounting, market or non-market effects, and inclusion or exclusion of network and indirect effects). Furthermore, evidence for the costs of slow onset events was not available. This makes a rigorous comparison of costs across types of climate-related event and across sectors highly challenging. For Antwerp and Bogota, no historical costs were recorded in the literature or were known to exist by the city authorities and local stakeholders (see Table 9.1). The most comprehensive data reviewed were for London. However, even for London, a range of gaps were found in terms of specific impacts (e.g. slow onset events) and specific sectors (e.g. a comprehensive cost assessment of health costs due to heatwaves).

Where quantitative estimates have been produced, the climate risks most frequently examined are associated with either market costs or health costs. Almost no studies have been conducted on other non-market and indirect costs at the city level, where uncertainties are even higher than for market impacts. One of the reasons for this lack of research is the deficit in urban metrics that can be used for cost assessments. Unlike national governments, there is no standard accounting methodology at the municipal level for indicators such as wealth, economic growth, carbon emissions and employment. Outside Europe, many cities collect no standardised data at all.

While there is a paucity of data on historical costs of extreme events, there is almost no published evidence for the costs of adaptation measures sector by sector for the case study cities. One exception is New York City where, following Hurricane Sandy, the authorities commissioned an adaptation plan, and this plan focuses on one threat in particular – sea flooding.
The number of studies on market and non-market costs in cities is low. One of the reasons for this lack of research is the deficit in urban metrics that can be used for cost assessments. Unlike national governments, there is no standard accounting methodology at the municipal level for indicators such as wealth, economic growth, carbon emissions and employment. Outside Europe, many cities collect no standardised data at all. This is both a challenge for the RAMSES project, and also an opportunity to identify areas where data may exist. Nonetheless, it is important to recognise the current limitations in developing rigorous and comprehensive cost assessments of climate impacts and adaptation measures at the city level.

Furthermore, it should be noted that some of the threats where evidence is scarce and that are consequently not included in detail in this Review could nevertheless have substantial costs to cities in the future. As a consequence, the research team recommends that research is targeted on some of these other areas beyond the scope of the RAMSES project.

Overall, the majority of impact and cost assessments undertaken have been at the national or the international scale. The city-scale comparisons that do exist tend to be more qualitative, highlighting areas of primary and secondary vulnerability, local priorities, and high-level ranges of possible adaptation responses. Most have been undertaken in OECD countries. The complexity of down-scaling climate predictions that are meaningful to the local level, determining the spatial and temporal boundaries of direct and indirect impacts, determining the relevant market and non-market valuations, and managing uncertainty demonstrates why qualitative studies are more commonly undertaken. However, qualitative frameworks can be valuable for their opportunity to engage with stakeholders, discern institutional responsibilities, and reveal external (non-bounded) interdependencies.
Where quantitative estimates have been produced, the climate risks most frequently examined are associated with either market costs or health costs. Almost no studies have been conducted on non-market and indirect costs at the city level, where uncertainties are even higher than for market impacts. Even for market costs, the number of studies on cities is low. One of the reasons for this lack of research is the deficit in urban metrics that can be used for cost assessments. Unlike national governments, there is no standard accounting methodology at the municipal level for indicators such as wealth, economic growth, carbon emissions and employment. Outside Europe, many cities collect no standardised data at all. This is both a challenge for the RAMSES project, and also an opportunity to identify areas where data may exist. Nonetheless, it is important to recognise the current limitations in developing rigorous and comprehensive cost assessments of climate impacts and adaptation measures at the city level.

9.5 Lessons for RAMSES

The results of the Review have implications for the ongoing RAMSES project. The large gaps in historical data for climate-related events in case study cities suggest that standardised and transferable tools for cost assessments cannot be developed solely through extrapolation from bottom-up historical data. It will also require top-down methodologies.

In terms of the costs of adaptation measures, very few cities have attempted comprehensive cost-benefit analyses. This is partly due to the complexity of urban systems (both in the large number of sectors and the potential cascading effects within and across sectors) as well as the uncertainty of climate impact levels and frequency. The very high degree of uncertainty that this creates overall suggests that any cost assessment framework will need to consider thresholds and option spaces for policy makers rather than simply deterministic projections based on bottom up accounting methods.

Finally, stakeholder engagement and analysis in this Review suggest that the expectations of city officials with regard to the costs of different types of climate-related impacts do not necessarily match the actual costs incurred by historical events. Whatever the reasons for this mismatch, it will be important that RAMSES continues to engage with stakeholders proactively to ensure that the ongoing research is not only policy-relevant, but also provides decision makers with a stronger evidence base than currently exists.
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List of Abbreviations

ACT - Adapting to Climate Change in Time
ADAPTO - Adaptation Action Planning Toolkit
APAT – Territory and Environmental Protection Agency (Agenzia Protezione Ambiente e Territorio)
BLUE AP - Bologna Adaptation Plan for a Resilient City
BUA - Business As Usual
CIPE - Committee for Economic Planning (Comitato Interministeriale per la Programmazione Economica)
CMCC - Euro-Mediterranean Centre for Climate Change (Centro Euro-Mediterraneo per il Cambiamento Climatico)
CNR – National Council of Research (Consiglio Nazionale delle Ricerche)
COM - Covenant Of Mayors (Patto dei Sindaci)
CRED - Centre for Research on the Epidemiology of Disasters
EEA - European Environment Agency
EU - European Union
GRABS - Green and Blue Space
ISPRA – Environmental Protection Institute (Istituto per la Protezione Ambientale)
ISTAT – National Institute of Statistics (Istituto Nazionale di Statistica)
MATTM - Italian Ministry for the Environment, Land and Sea (Ministero dell'Ambiente e della Tutela del Territorio e del Mare)
MEF - Ministries of Economy and Finance (Ministro dell'Economia e delle Finanze)
MeSP - Metropolitan Strategic Plan (Piano Metropolitano Strategico)
MIPAAF - Ministry of Agriculture, Food and Forestry Policies (Ministero delle Politiche Agricole e Forestali)
MIUR - Ministry of University and Research (Ministero dell'Istruzione, dell'Università e della Ricerca)
MOP - Municipal Operative Plan (Piano Operativo Comunale)
MS - Member States
MuSP - Municipal Structural Plan (Piano Strutturale Comunale)
NAS - National Adaptation Strategy
NCCCC - National Conference on Climate Change (Conferenza Nazionale sui Cambiamenti Climatici)
OECD - Organisation for Economic Co-operation and Development
PTCP - Territorial Coordination Plan of the Province (Piano Territoriale di Coordinamento Provinciale)
PUC - Urban Master Plan (Piano Urbanistico Comunale)
SEAP - Sustainable Energy Action Plan (Piano d’Azione per l’Energia Sostenibile)
UHI - Urban Heat Island
UNFCCC - United Nation Framework Convention on Climate Change
UBRs - Urban Building Regulations (Regolamento Edilizio Urbano)
VSL - Value of Statistical Life
WTP - Willingness To Pay
1 Executive Summary

Climate change is a significant challenge for European and national policy agendas, and debates about impacts, costs assessment and enacted strategies by (trans)national and local policies are still in an early phase. However, most Members States of the European Union have adopted National Adaptation Plans through an approach that involves national, regional and local levels, as well as selected stakeholders. A particular focus is also devoted to urban strategies, as Europe is becoming more “urbanised” in terms of population density, spatial planning, human settlements, transport networks and economic flows. The necessity to provide methodologies able to assess costs and benefits of adaptation is urgent. In this way, likely and actual damage impacts and related costs have to be assessed on the basis of specific literature and on innovative evaluation methods, both qualitative and quantitative, involving economic and social aspects of urban life, policies and politics. Furthermore, urban policies are required that are able to ensure good standards of quality of life within the cities, also through climate change adaptation. Adaptation is also intimately related to the concept of vulnerability, because generally a system that is more vulnerable to climate change impacts require more adaptive capacities. However, it is still difficult to translate this relation into costs for adaptation.

The objective of the Annex is thus twofold:

a) to present an overview about how climate change adaptation issues and costs are developed in the current policy agenda in Italy, both at national and urban scale;

b) to point out significant aspects of urban vulnerability, that policy makers and scholars have to consider in future strategies of adaptation to climate change impacts, particularly in the case of extreme rainfall.

The Italian state-of-art will be described through an overview of the climate change adaptation policies since its earlier steps during the 1990s. Section 2 will analyse and discuss preliminary experiences of costs assessments in relation to flood and heat waves, although they do not present a specific urban target. Some strategies of climate change adaptation will also be presented for some Italian cities and metropolitan areas, summarised in the Table “Italian Cities” at the end of this report. Sections 3, 4 and 5 will discuss two
severe floods, occurred in 1970 and 2011 in the Italian city of Genoa. They will be described looking at the damages and related costs assessments as well as on changing vulnerability factors contributing to an increased risk. In this way, a comparison with the RAMSES case studies is carried out in terms of vulnerability aspects (Section 6). In Section 7, adaptation and mitigation strategies, implemented by Genoa to increase the coping capacities with climate change effects, are described as suggestions for those RAMSES case studies with similar vulnerability aspects. Finally, Section 8 will present the experience of the BLUE AP adaptation plan of the Italian city of Bologna as an example of an advanced stage of adaptation plan in an Italian city. The paper proposes five conclusive remarks, also in the way of suggesting main recommendations for the future activities of WP5 and the RAMSES project in general:

1) only recently climate change adaptation has been added to the Italian policy agenda, and related costs assessments have just emerged within the political debate. Thus, updated results about the assessment of adaptation costs in Italy are lacking, but studies of the National Conference on Climate Change (NCCC) since 2007 represent a seminal contribution to provide preliminary results about climate change impacts, such as floods and heat waves. Costs and benefits analysis of climate change adaptation would further allow to understand priority areas of intervention with very constrained budgets, and to indicate the size and the scale of the main challenges in Italy;

2) some Italian cities and metropolitan areas have adopted climate change adaptation plans, even though preliminary and comprehensive adaptation costs are still not definitively integrated within these plans. The Table “Italian Cities”, annexed at the end of the report, reviews some of the existing experiences of adaptation plans in Italian cities. It reveals that strategies mainly aim to cope with floods and heat waves’ risks, particularly focusing on river management and land use policies. These strategies are also integrated in ordinary urban planning tools as well as civil protection activities and grassroots networks;

3) the Mediterranean area is a hotspot in terms of climate change. Settlements are at risk of severe consequences in the near future due to the effects of climate change, including the interruption of main urban functions. Genoa represents an emblematic case study for Mediterranean cities, as it is a crucial hub for road, railway and maritime infrastructure networks in Southern Europe and in the Mediterranean basin. It has been taken as example due to huge potential losses related to climate change impacts such as extreme rainfalls. The high monetary losses value – without considering intangible losses – as experienced in 1970 and the 2011, has shown that the inaction option, or Business As Usual (BUA) scenario, is unsuccessful. In fact, inaction could determine heavy damages, deeply undermining the expected outcomes of sustainable development;

4) damages occurred in 1970 and 2011 events have been high due to some vulnerability conditions characterizing the urban context of Genoa. Urbanization and related issues (such as urban sprawl, land take and soil sealing, abandonment of rural areas) contributed to exacerbate the effects of extreme events damages, by greatly modifying geomorphological conditions in face of inland flooding threat. These factors should be analysed also in the main RAMSES case studies, in order to define specific adaptation measures and, consequently, to address the main related costs. In detail, the review carried out on losses resulting from 1970 and 2011 events in Genoa reports the sectors in which specific adaptation measures are required. In detail, a part from improving ecosystem services (e.g. water absorption capacity of the soil to reduce run off), it is important to develop adaptation strategies even for infrastructures, with a focus on transport and services (gas and water pipelines). Despite the fact that they have been seriously damaged and that they have caused indirect impacts in other sectors (e.g. industries, commerce, etc.) Genoa has not yet adopted an adaptation plan. However, for
the future, the city can take advantage to a considerable set of data collected by other initiatives and research projects, recently developed in terms of both mitigation and adaptation measures;

5) in the Italian context, climate change adaptation has still not been included in a comprehensive framework/plan and does still not have a defined cost assessment. However, a successful experience of an adaptation plan in an Italian urban area is the BLUE AP of Bologna. BLUE AP identifies the targeted areas on the basis of spatial, social and planning characteristics. The aim is to obtain homogeneous development strategies which are inspired by sustainability goals. For the prevention of river floods and heat waves and the conservation of biodiversity, main strategies aim at enhancing river infrastructures, creating green spaces within urban environment, and ensuring a more sustainable management of water resources.

2 Overview on adaptation measures and costs related to climate change in Italy

The European Union (EU) releases about 11% of global carbon emissions, relevantly contributing to global warming (Reckien et al., 2013) and exacerbating the climate change impacts. Climate change adaptation represents thus a significant challenge on the EU Member States (MS) agenda. MS formulate their adaptation policies according to EU requirements into Framework Directives and funding systems. Several countries have already created their National Adaptation Strategies (NAS) (Biesbroek et al., 2010) to outline projected climate change impacts and regional and/or sectorial vulnerabilities, and to suggest possible adaptation measures (Juhola and Westerhoff, 2011; Westerhoff et al., 2011). Within the EU, the Southern Mediterranean is characterised by widespread natural stresses affecting natural environment and social systems. This region is and will continue to be one of the most vulnerable to climate change (Giorgi and Lionello, 2008), according to projections for both temperatures and precipitation regimes. Climate change impacts are mainly related to extreme temperature rise, increased frequency of extreme weather events (heat waves, droughts and severe rainfalls), and reduced annual precipitation. The Southern Mediterranean will be negatively affected by climate change impacts over the next decades, combining biophysical factors with anthropogenic stresses and relatively low adaptive capacity.

2.1 Climate change risks in Italy

Italy is dramatically increasing its vulnerability and exposure to risks, due to its fragile environments and altered *equilibria* among social and ecological systems. Just to provide an example, the report by Legambiente (2014) in collaboration with the Italian Civil Protection Department states that 6,633 Italian Municipalities (82% of 8,871 Municipalities) present areas subject to hydrogeological risks. However, the report does not distinguish the size (high, medium of low) of the risk in such areas. Potential climate change impacts and vulnerability include:

- stress conditions on water resources, leading to a reduction in water availability and quality, especially in summer in Southern regions and islands;
- alterations of hydro-geological regimes and increasing landslides, flash mud/debris flows, rock falls and flash floods risk; the most exposed areas to flood include the Po River valley, Alps and Apennines;
- soil erosion, degradation and desertification risk in Southern Italy and soil critical conditions in specific areas of Northern Italy (Salvati and Zitti, 2009);
- forest fires and droughts risk along the Alps and in Southern Italy;
• risk of biodiversity and natural ecosystems loss in Alpine areas (Bosello et al., 2007) and of wetlands loss, marine and coastal biodiversity and ecosystems (Bianchi and Morri, 2000; Bianchi, 2007);
• risk of coastal flooding and erosion due to the increasing occurrence of extreme events and sea level rise (Bosello and De Cian, 2013);
• reduction of crop production (see also Moonen et al., 2002);
• impacts on health of most vulnerable individuals: heat-related mortality and morbidity; cardio-respiratory diseases from air pollution; injuries, deaths and illnesses due to disasters; allergies, occurrence of vector-, water- and food-borne diseases (see consequences of 2003 heat waves in Italy, in Conti et al., 2005 and Alberini and Chiabai, 2007a; 2007b);
• losses in economic sectors, such as: energy sector, due to a potential reduction of hydropower production; winter and summer tourism sector, due to worsening conditions in snow cover, water availability, floods and fires; fishery sector, due to the likely decline in productivity; transport sector, due to pressures on urban and rural infrastructures, transport networks and settlements (Medri et al., 2013).

The Italian most vulnerable areas to climate change are:
• the Alps and mountain ecosystems (glacier and snow cover loss);
• coastal zones (erosion, flooding and susceptibility to alterations of marine ecosystems);
• arid areas (threat of desertification);
• areas subject to hydro-geological risks (the Po plain as well as the Alpine and Apennine regions) (Carraro and Sgobbi, 2008; CEPS and ZEW, 2010; Medri et al., 2013).

Furthermore, socio-economic inequalities across Italian regions and geographical patterns occur, potentially leading to different degrees of climate change vulnerability (Gambarelli and Goria, 2004; CEPS and ZEW, 2010) and of its related costs both in terms of impacts and of adaptation. See for example the north–south, urban-rural, and coastal areas-inland gradient indicated for vulnerability to land degradation (Salvati and Zitti, 2007; 2009).

2.2 Policy response to climate change in Italy

Climate change adaptation will thus be a crucial task in Italy along the next years. In the past decades, climate change adaptation policies did not have high political priority at the national scale, compared to other MS. Only recent attempts of creating NAS have been emerged based on the EU climate change policies framework (Westerhoff, 2010). However, these attempts often showed lack of coordination, and delays in implementation and investments due to uneven administrative capacity and differentiated approaches across regions (OECD, 2013). Additionally, the lack of coordination among research projects to assess climate change impacts on small areas has resulted in fragmented outputs (Westerhoff and Juhola, 2010). Climate change policies began with the international agreements about emissions reduction and mitigation of greenhouses gas (GHG). Italy’s first explicit climate change policy has been developed under the ratification of the United Nation Framework Convention on Climate Change (UNFCCC) in January 1994. The same year, the Inter-ministerial Committee for Economic Planning (CIPE) approved the National Programme for the stabilization of Carbon Dioxide emissions at the levels of 1990 by the year 2000. Under the coordination of the Italian Ministry for the Environment, Land and Sea (MATTM), CIPE created a framework for a programme to achieve GHG’s emissions reduction targets. In 1998, guidelines for national policies and measures about the GHG’s emissions reduction outlined methods and deadlines for achieving the targets set by the National Programme (Westerhoff, 2010; Medri et al., 2013).
In 2000, the “Research Programme on Sustainable Development and Climate Change” was approved, jointly funded by MATTM and the Ministries of Economy and Finance (MEF), University and Research (MIUR), and Agriculture, Food and Forestry Policies (MIPAAF). This programme aimed at filling gaps of knowledge about climate variability and related impacts, baseline data and vulnerability of several socio-economic and environmental sectors. It also included the creation of the Euro-Mediterranean Centre for Climate Change (CMCC), founded in 2005, aiming to develop climate simulations and models for the Mediterranean basin (Westerhoff and Juhola, 2010). In 2007, preliminary activities to the NAS started in the framework of the National Conference on Climate Change (NCCC), organised by the Italian Agency for Environmental and Territorial Protection; countrywide climate change vulnerabilities were analysed to identify priorities and to investigate the role of stakeholders and technical bodies in adaptation. (Westerhoff, 2010; Westerhoff and Juhola, 2010).

After the Conference, two documents were produced:

- the “Manifesto per il clima: Un New Deal per l’adattamento sostenibile e la sicurezza ambientale”, that asked MATTM to develop a National Adaptation Strategy by 2008, to be implemented by 2011;
- the “Prime 13 azioni per l’adattamento sostenibile”, that prioritised intervention areas for adaptation policies by MATTM and other ministries (Westerhoff, 2010; Juhola and Westerhoff, 2011).

Climate change adaptation has also been included in sectorial strategic documents related to biodiversity, agriculture and forestry as well as human health. In 2012 MATTM outlined a preliminary NAS in the meeting Stato delle conoscenze riguardo ai cambiamenti climatici in Italia. CMCC has been in charge for the document (MATTM, 2013). A ”Tavolo Tecnico” has been constituted under the lead of CMCC and involving research institutes and universities to collect scientific information about climate change, while a Tavolo Istituzionale involved Ministries and other institutions (such as Civil Protection, Regions, Public Administration, and so on) in preparing the ongoing NAS design for public consultation in September 2013 (MATTM, 2013). Stakeholders and citizens have been involved in preparing the NAS through an ex-ante survey on the perception of adaptation and public consultations on the document. The document is based on national strategies of other MS and European Environment Agency (EEA) reports, including the White Book of EC “L’adattamento ai cambiamenti climatici: verso un quadro d’azione europeo” (2009), “Guiding principles for adaptation to climate change in Europe” (2010) and “Adaptation in Europe” (2013) (MATTM, 2013). Currently under discussion, it is however to be expected that the NAS will be approved soon.

### 2.3 Climate change costs assessments in Italy

Currently, climate change adaptation frameworks in Italy are still fragmentary and represent works in progress. Gaps have to be filled in terms of knowledge, methods and scenarios for a climate change adaptation costs assessment. Seminal attempts have been provided by CMCC’s reports presented during the preparatory meetings for the NCCC on 2007 (see Carraro et al., 2007; Carraro, 2008; Carraro and Sgobbi, 2008). These studies attempted to frame the climate change analysis in terms of vulnerability and risks, policy recommendations, measures, strategies and costs related to impacts, inaction and adaptation. However, a small number of studies assessed climate change adaptation costs at the national scale. In terms of floods and landslides risks, Carraro and Sgobbi (2008) cited an APAT (2006) report, for which the total costs of reducing these risks are estimated to be EUR 42m (of which only 1.15 million was budgeted in 2006). Regarding the tourism sector in mountain areas, Bigano and Bosello (2007) and Bosello et al. (2007) estimated the adaptation costs to snow cover loss to allow the survival of the tourism sector and a relevant part of the local economy in the Alpine arch. They considered the production of artificial snow as the most common strategy to cope.
2.4 Coastal erosion and sea level rise

In terms of coastal erosion, the assessment of climate change adaptation costs for Italy is very limited, and few researches have been implemented for coastal areas. In depth analysis of adaptation costs in urban areas are also lacking. Therefore this paragraph does not target urban environments; rather, it aims at providing an overview of climate change adaptation costs for coastal areas in Italy. Nunes and Chiabai (2007) analyse the case of the MOSE dykes in the Venice Lagoon, while Carraro and Sgobbi (2008) estimate the costs of inaction in terms of land lost to sea level rise and the optimal investment in infrastructure for coastal protection in Italy, as presented in Table 1.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>A2*</th>
<th>B2*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea Level Rise</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Year</td>
<td>2020</td>
<td>2030</td>
</tr>
<tr>
<td>Cost of protection (&quot;optimal investment&quot;)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% GDP</td>
<td>0.0003</td>
<td>0.0006</td>
</tr>
<tr>
<td>Value (USD million)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>450.1</td>
<td>1537.1</td>
<td>1773.4</td>
</tr>
</tbody>
</table>

Table 1: Cost of protection (USD million) from sea level rise in Italy. *A2 and B2 scenarios according to IPCC (adapted from Carraro and Sgobbi, 2008, p. 13)

A seminal analysis of adaptation costs on coastal areas has been provided by Gambarelli and Goria (2003; 2004), assessing adaptation costs for coastal floods on the Fondi Plain (near the city of Latina, Latium region), sited in an important agricultural area of Central/Southern Italy. This plain is characterised by some common features – both geomorphic and socio-economic - with other vulnerable areas along the Italian coasts. Besides, the general framework of this cost-benefit analysis can also be adapted to different contexts, addressing impacts other than sea level rise. The assessment of costs by different adaptation options is based on a scenario of expected sea levels at various future temporal steps. Data on sea levels are geo-referenced and overlapped on land use maps by using GIS tools, while some political and economic stakeholders have been interviewed in order to better understand the local specificities of the area. The case study is simplified, as:

- mitigation costs are not accounted for. The authors assumed that, even if mitigation measures will have been undertaken in the next years, they are not capable to change the foreseen effects on sea level rise before the chosen time horizon of 2100;
- if adaptation measures are implemented, the residual damage is set equal to zero. This is coherent with the assumption that protecting coasts with suitable defensive works completely avoids land losing its economic value (Gambarelli and Goria, 2004).

Thus, adaptation is justified, according to a cost efficiency approach, if the following condition is fulfilled:

\[ \text{ADAPTATION COSTS} < \text{EXPECTED DAMAGES WITHOUT ADAPTATION}. \]

The expected damages without adaptation correspond to the value of land which is at risk of being permanently flooded. Gambarelli and Goria (2004) assume that all the land which is foreseen to reach an altitude below 0 within the considered time horizon will be lost forever, without appropriate defences. Initially, the threatened areas have been calculated for the selected time horizons (2002, 2050, 2100), corresponding to different sea levels. The selected land uses are agricultural land, forest and residential areas. Then, as Table 2 shows, the analysis consists of five further steps:
Estimation of agricultural areas at risk along three years through the determination of:
- the soil nature: peaty/non-peaty areas above sea level;
- the type of cultivation (reclaimed and non-reclaimed land), thanks to the analysis of an aerial picture of the area under investigation;
- areas occupied by greenhouses, according to the property rights (private land, state-owned, municipal, etc.).

Table 2: Five operations for assessing adaptation costs to flood risk in the Fondi Plain (adapted from Gambarelli and Goria, 2003; 2004)

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimation of agricultural areas at risk along three years through the determination of:</td>
<td>Attribution of economic value to the risk areas according to land use and ownership, referring to the market value when possible. The value per hectare (or per square meter, in the case of households) was retrieved by interviews to local stakeholders.</td>
<td>Calculation of the income flow generated in areas at risk, by the ratio of total income produced in the Fondi plain to the area below sea level in the three considered years.</td>
<td>Choice of two different discount rates (3% and 1%) to perform a sensitivity analysis.</td>
<td>Hypothesis of two scenarios (Low and High).</td>
</tr>
</tbody>
</table>

Through a mathematic equation that considered the value of the area currently above sea level and the area that will fall below sea level in periods 2002-2050 and 2050-2100, a measure of the damage impacts of sea level rise in the Fondi plain has been provided. The value of the whole area prone to flood risk over the period 2002-2100 varies in the range of EUR 131-268m, depending on the scenario (low or high), the discount rate (3% or 1%) and the lower or upper limit of the range (Table 3).

Hypothesis 1: no adaptation and consequent inland loss

As Table 3 shows, the present value of the area at risk of permanent flooding within the time horizon 2002-2100 varies in the range of EUR 130-270m, depending on the considered scenario (low, high), the discount rate (3%, 1%) and the upper and lower limits assigned to some variables.

<table>
<thead>
<tr>
<th>Discount rate</th>
<th>Low scenario</th>
<th>High scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>3%</td>
<td>130.86</td>
<td>186.52</td>
</tr>
<tr>
<td>1%</td>
<td>145.78</td>
<td>202.73</td>
</tr>
</tbody>
</table>

Table 3: Value (in EUR million) of the whole area at risk in the Fondi plain (adapted from Gambarelli and Goria, 2003; 2004)

Hypothesis 2: land protection by strengthening of the present system for land reclamation

In this case, the following actions are required:
- increasing the power of some of 11 water scooping pumps;
- increasing the carrying capacity of canals and elevation of banks (356 km);
- extending the irrigation system;
• improving the sewage system in the Fondi city.

Thus, the estimated total adaptation costs are around EUR 250–300m.

**Hypothesis 3: land protection by reconstruction of the pre-existing dune as a first barrier to sea-level rise**

In this case the following actions are required:

• rebuilding of 12 km of dunes and its waterproofing (EUR 12–15m);
• values of houses to be demolished (EUR 30–50m);
• elevation of banks in the lakes behind the dune (not quantified);
• closing of 2 existing canals with direct discharge into the sea and building of new scooping machines for the streaming out of water (Gambarelli and Goria, 2004).

These results are partial due to the lack of a technical feasibility study of the adaptation options. The results show that, due to an already developed and well working drainage system, the incremental costs linked to the expected sea level rise are much lower compared to the potential damage implied by the strategy of the inaction option. The estimated potential damage ranges between EUR 130–270m, while an amount of EUR 50–100m is considered sufficient by the interviewed experts to accommodate the existing drainage system to the projected sea levels. The results indicate that in other plains, with different characteristics related to the functionality of the drainage system and/or the land use of threatened areas, the economic analysis could suggest the inefficiency of this kind of protection measures. Additionally, the results concerning the second adaptation option do not allow to draw any conclusions about its economic efficiency, due to the limited available information (Gambarelli and Goria, 2004).

### 2.5 Heat waves

In terms of heat waves in Italy, the survey of Alberini and Chiabai (2007a; 2007b) asked residents aged 30–75 of five cities (Venice, Milan, Genoa, Rome and Bari) to report their Willingness To Pay (WTP) for reducing the mortality risk due to cardiovascular and respiratory causes, using a survey-based approach of contingent valuation. According to Section 2.3.1 of the main document of this Deliverable, WTP is a subjective method, that can vary by circumstances related to, for example, time, income, social or cultural norms. Consequently, its unit values need to be ‘normalised’ to demographic or socio-economic factors to allow their application to global models. These results, thus, can just be considered a broad estimation of the benefits of policies of adaptation costs’ assessment related to heat waves.

This would allow the calculation of VSL (Value of Statistical Life), the rate at which people trade off income for a risk reduction. In these terms,

\[
VSL = \frac{\partial WTP}{\partial R}
\]

where WTP is the Willingness To Pay for a change in the risk of dying, and R is the risk of dying. VSL can equivalently be described as the total WTP (\(\partial WTP\)) by a group of N people (\(\partial R\)) experiencing a uniform reduction of 1/N in their risk of dying. For example, considering a group of 10,000 individuals, and assuming that each WTP is EUR 30 to reduce own risk of dying by 1 in 10,000, the VSL implied by this WTP is EUR 30/0.0001, or EUR 300.000 (Alberini & Chiabai 2007a, p. 241). Absent any changes in the precipitation patterns, Italians would be willing to pay about EUR 325–370 per household per year to avoid a 1°C increase in July temperatures. Combining these results with the additional deaths recorded in Rome in summer 2003, and assuming that the value of the disamenity entirely reflects the additional deaths due to the heat wave, a VSL of EUR 3.345m is obtained (Alberini & Chiabai 2007a) (Table 4).
An overview of adaptation plans in some Italian cities

Currently, adaptation is a crucial task for Italy, also given the very recent floods on agricultural and residential areas and infrastructural networks of Apulia, Sardinia and Emilia-Romagna regions, and in the capital city of Rome, and snow storms and avalanches impacting on infrastructures, tourism activities, human deaths and biodiversity loss on the Alps. MATTM should address main goals of adaptation strategies adopted at the national scale. However, these strategies explicitly require an approach that enables local actors to enact own initiatives according to NAS (see also Medri et al., 2013). At the local level some experiences of Metropolitan areas, Provinces and Municipalities are addressing climate change adaptation through the implementation of action plans and incentive programs, as in most of the urban areas of Europe (Reckien et al., 2013). Others are also developing guidelines for local adaptation of urban systems (Medri et al., 2013). Cities are in fact crucial actors in the climate change adaptation discourse, due to the worldwide increasing demographic trends of cities and the consequently rise of climate change vulnerability in urban areas (see Hallegatte and Corfee-Morlot, 2011).

At the end of this report, the table “Italian Cities” shows programmes and plans implemented by Italian metropolitan areas and cities. It does not aim to be fully comprehensive or to review all the adaptation strategies at the urban level in Italy, rather than highlighting some significant experiences. The table describes adaptation strategies that mainly aim to cope with flood and heat waves risks in urban areas. In terms of plans and strategies, Northern Italy (considering also the regions of Emilia Romagna and Marche in Central Italy) seems to be generally in a more advanced stage than Central and Southern Italy. River management (e.g. in the Venice-Padova metropolitan area and the Provinces of Turin and Reggio Emilia) result as decisive in addressing effective adaptation strategies. In fact, most of these strategies regard the greening of river stripes, the restoration of fluvial landscapes and the maintenance of green urban spaces as prevention of heat waves’ effects and a more rational use of water and land resources. Furthermore, a rational and more efficient use of energy in private and public buildings will serve to prevent resource consumption for urban functions (e.g., Faenza or Modena - Bologna metropolitan areas). Some of these strategies are also integrated in the ordinary urban planning tools such as civil protection activities, and in the case of heat waves this allows to activate warning systems and solidarity networks (e.g., Ancona and Alba) among institutions, hospitals and associations to take care of the most vulnerable people. The adoption of adaptation strategies in Italian urban areas will also hopefully allow to have a better defined framework of adaptation costs in urban areas.

In the last decade Italy is doing some appreciable steps to adapt the everyday life of its inhabitants to climate change. In this way, OECD (2013) suggests that the Italian NAS should strictly focus on the development of a robust and integrated evidence base about climate change impacts, to identify, assess and monetise the key climate risks and

<table>
<thead>
<tr>
<th>Size of the risk reduction</th>
<th>30-49 years old (healthy)</th>
<th>60-69 years old (healthy)</th>
<th>60-69 years old (at risk)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Based on median WTP</td>
<td>Based on median WTP</td>
<td>Based on median WTP</td>
</tr>
<tr>
<td>1 in 10,000 a year</td>
<td>2.28</td>
<td>1.16</td>
<td>1.63</td>
</tr>
<tr>
<td>5 in 10,000 a year</td>
<td>0.83</td>
<td>0.42</td>
<td>0.59</td>
</tr>
</tbody>
</table>

Table 4: VSL (in EUR million) per range of ages. VSL is median/mean WTP, divided by the risk reduction. Calculations assume average income per household member in Italy, male, married, no children, no college degree (adapted from Alberini and Chiabai, 2007a; 2007b).
opportunities. Additionally, a detailed costs and benefits analysis of adaptation can allow to understand priority areas for action within very constrained budgets, and to indicate the size and the scale of the main challenges. Furthermore, an effective adaptation strategy should address long-term climate change impacts in all government policy and programs. The involvement of relevant stakeholders in developing the strategy is crucial. These include ministries, regional governments, local authorities, scientific institutions, the private sector and the civil society. Their participation would ensure effective policy harmonisation and coherence in view of Italy’s complex governance model. Finally, the NAS should also include a structured review process to assess progress towards implementation and effectiveness in mainstreaming adaptation into government policies, based on an agreed set of monitoring indicators.

3 Genoa: key facts and relevance for the RAMSES project in terms of damages and adaptation costs

In Italy, earthquakes represent the most disruptive natural disaster events for number of victims and economic losses. Nevertheless, in terms of “affected people” the EM-DAT global disaster database shows the absolute supremacy of floods (see Figure 2). In detail, in Italy, referring to the 1900-2013 period, the event that has involved the largest number of people has been the 1970 flood that seriously affected the city of Genoa, located in North-Western Italy.

<table>
<thead>
<tr>
<th>Disaster</th>
<th>Date</th>
<th>No Total Affected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flood</td>
<td>7-Oct-1970</td>
<td>1,301,650</td>
</tr>
<tr>
<td>Flood</td>
<td>3-Nov-1966</td>
<td>1,300,000</td>
</tr>
<tr>
<td>Earthquake</td>
<td>23-Nov-1980</td>
<td>407,700</td>
</tr>
<tr>
<td>Earthquake</td>
<td>6-May-1976</td>
<td>218,222</td>
</tr>
<tr>
<td>Flood</td>
<td>14-Nov-1951</td>
<td>170,000</td>
</tr>
<tr>
<td>Earthquake</td>
<td>28-Dec-1908</td>
<td>150,000</td>
</tr>
<tr>
<td>Earthquake</td>
<td>6-Apr-2009</td>
<td>56,000</td>
</tr>
<tr>
<td>Earthquake</td>
<td>15-Jan-1968</td>
<td>55,463</td>
</tr>
<tr>
<td>Flood</td>
<td>14-Oct-2000</td>
<td>43,000</td>
</tr>
<tr>
<td>Earthquake</td>
<td>26-Sep-1977</td>
<td>38,100</td>
</tr>
</tbody>
</table>

*Figure 2: Top 10 natural disasters in Italy for the period 1900 to 2013 sorted by numbers of total affected people (EM-DAT, 2013)*

The city of Genoa - currently home to around 582,320 people (ISTAT, 2013) - represents a case study of national relevance in terms of geo-hydrological risk (Brandolini, 2012). Starting from 1822 up to now, Genoa has experienced, more than 38 major flood events all referred to its main river Bisagno, (Faccini et al., 2012). The last one occurred on 4 November 2011, at only one year from another occurred severe event. This put on evidence how climate change can play an important role in exacerbating damages and how important it is to implement mitigation and adaptation measures. The 4 November 2011 event represents, from the meteorological and hydrological perspective, a paradigm of flash floods in the Mediterranean environment (Silvestro et al., 2012). Due to its geographical position within the Mediterranean basin (see Figure 3), the city of Genoa is significantly susceptible to climate change. The occurrence of high intensity and/or heavy rainfall events is favoured by peculiar meteorological and orographic conditions, such as the proximity of the Apennines’ main watershed to the Ligurian Sea (Brandolini, 2012).
Such a configuration has been recognised as the main cause for the genesis of Genoa cyclones (Trigo, 2002), a phenomena known also as “Genoa Low” or Ligurian Depression, that involves not only the city but the entire regions of Liguria and Northern Toscana. In detail, the “Genoa Low” consists of a low pressure area, consequence of a thermal contrast between the perturbations from the Atlantic Ocean and the warm seawater of the Ligurian Gulf. Such a contrast often leads to severe precipitations and, in some cases, to extreme rainfalls, in some cases identified as “water bombs”. The formation of “water bombs” has a very short time for emergency warnings, and this aspect makes them particularly relevant in terms of impacts and potential damages as also Figure 4 highlights. This phenomenon is favoured by the increase of days characterised by a higher sea temperature, that is one of the expected effects of climate change.

From a climate change perspective the province of Genoa shows a modest increase in temperatures and negligible annual trends for rainfalls but significant anomalies and growth of extreme events. What transforms heavy rainfalls in severe flood events is the complex morphological configuration of the territory and the intervention of anthropogenic processes happened over the past century. The municipal territory consists of ten main catchments characterised by very steep slopes and a small fluvial-coastal plain. The most extensive catchments are those of the Polcevera (138 km$^2$ of which 37 km$^2$ in the municipal district) and Bisagno rivers (93 km$^2$, 53 km$^2$ in the municipal district); the remaining basins have areas under 30 km$^2$ (Brandolini, 2012). This aspect gains prominence due to the fact that specific hydrologic analysis have highlighted that heavy long duration rainfalls cause major consequences in the big catchments in contrary to intense rainfalls that will more likely compromise little catchments. This review describes two major flood events in Genoa in 1970 and 2011. As shown in Figure 5, the first was an extreme event in terms of a day accumulated rainfall and involved mainly the Polcevera and Bisagno catchments whereas the second, due to the concentration of rainfall in a narrow span of time, caused major disruption to the Fereggiano brook - that is the last tributary of Bisagno river - and, as a consequence, to the Bisagno river itself. Other minor rivers flooded during the latter event.
As a consequence of both the rainfall regime and the morphological features specific to this area - including the 35-45% average slope of hills, as reported by Faccini et al. (2012) - shallow landslides have been triggered, such as debris flows and soil slips that are very common in the Ligurian territory (Brandolini et al., 2012; Cevasco et al., 2010), provoking in turn other monetary damages.

The following review of damages takes into account what occurred to the Bisagno catchment in both the extreme events (see the morphology of Bisagno river Valley in Figure 6). In detail, apart from morphological conditions, other factors have contributed to the occurrence of great damages and represented factors of vulnerability toward more likely flash floods events. These factors are more related to urban shape, city features and land use and can be observed also in other urban contexts. Urbanization and high density population make Genoa one of the major hydrological risk areas in Italy. A recent mapping activity carried out by the Civil Protection of the Environment Department of the Liguria Region shows that 16% of the municipality of Genoa is exposed to flood risk (Il Secolo XIX, 2013).

As a consequence, the city of Genoa gains relevance within the RAMSES project as “test field” to outline the factors of vulnerability that should be taken into account in order to assess climate impacts and costs of damages, according to the overall objective of the project. The 2011 Genoa event has been considered relevant also at global scale, as shown in Figure 7 (Munich RE, 2012).
For the sake of completeness, it is worth mentioning that, as a consequence of expected higher temperatures, Genoa is also exposed to heat waves (Conti et al., 2007). Urban setting and urban texture (e.g. compactness of building stock) play a crucial role in terms of vulnerability even in face of heat waves.

4 Damage and impact costs of 1970 and 2011 flash flooding events in Genoa

In the last century the municipal area of Genoa has been affected by recurring flood events, often originating from the Bisagno river and some of its tributaries (see Figure 8). The Fereggiano brook is the last tributary of the Bisagno river. Both the streams flow under a cover in their last sections – for, respectively, 1.5 km and 0.6 km (Silvestro et al., 2012) following works realised in the late 1930s.

According to a broad classification of flood damages, losses can be distinguished in direct and indirect losses and in turn, in monetary (or tangible/market) and non-monetary (intangible) losses (Figure 9).

Figure 7: Major 2011 disasters events (Munich RE, 2012)

Figure 8: The Bisagno river, the Fereggiano brook and the Sturla torrent with evidence of the canalised and covered sections (in red) (adapted from Colombini, 2012)
<table>
<thead>
<tr>
<th>Direct loss</th>
<th>Indirect loss (loss as a consequence of flood water)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monetary (tangible)</td>
<td>e.g. Disruption to transport, loss of added value in commerce and business interruption, legal costs associated with lawsuits</td>
</tr>
<tr>
<td>Non-monetary (intangible)</td>
<td>e.g. Stress and anxiety, disruption to living, loss of community, loss of cultural and environmental sites, ecosystems resource loss</td>
</tr>
</tbody>
</table>

![Figure 9: Classification of types of loss from floods (modified from EMA, 2002)](image)

For the latter detailed data is scarce, but, as an example, the heritage of many libraries has been seriously damaged in the 2011 event, as shown in Figure 10.

![Figure 10: Non-monetary damages to cultural heritage occurred in 2011 flood (MIBAC, 2013)](image)

Referring to physical damages, no database exists in order to have the same source to compare the 1970 and the 2011 Genoa flood events. Nevertheless, the reported typology of losses and the related monetary value are useful to give an idea about to what extent a future flood event can provoke losses in the absence of implementing an effective adaptation policy. The data referred to the damages of the two events are different according to the source, even in terms of casualties. For example, for the 1970 event, the EM-DAT global disaster database, reports, in terms of direct damages due to the flooding of Bisagno river, 37 victims whereas the Provincia di Genova (2001) reports only 10 casualties. Another reliable source for the 1970 event is the database of the AVI project, carried out by the Italian Research Center (CNR, 2000). It provides a census of Italian areas historically hit by floods and landslides in the period 1918-1990, and collects data on over 10000 landslides and 5000 floods occurred in Italy. Data reported by the AVI project are more qualitative (e.g. typology and use of damaged building) than quantitative. A more detail source for economic estimation of damages is provided by the Chamber of Commerce of Genoa, as reported by Bianchi (1970). Referring to the 2011 Genoa flood, the EM-DAT database does not report a monetary estimation for damages, probably because of the incompleteness of data. Hence, data have been researched in local sources and, in detail, within the Municipal and Regional decrees published in the aftermath of the event.

### 4.1 The 1970 Genoa flood

From 7 to 10 October 1970, Genoa was affected by exceptional levels of precipitation, with rainfall intensity peaks of 453.4 mm/d at the Ponte Carrega rain gauge (Regione Liguria, 1980), and a peak flow of the Bisagno river of 950 m$^3$/s. was recorded at the river mouth.

The Bisagno river, together with Polcevera and Leiro torrents, flooded in several points, coming back in their bed only on 9 October. In detail, the moving flow rate, by exceeding the 500 m$^3$/s$^{-1}$ - value used for the design and construction of the canalization and coverage
of the river’s final stretch in the Thirties of the last century -, increased the pressure on the Bisagno stream coverage, and provoked a hydraulic regurgitation that caused the flooding of many streets in proximity of the cover. The flooding involved about 3.5 km$^2$ of the city (Brandolini, 2012). Over 1,301,650 people were affected by the flood and many infrastructures, as roads, gas, electricity and telephone lines, were severely damaged. Commercial and industrial activities were suspended (Gatti, 2012) due to power failure and fires, and heavy damages to agricultural terraces, typical of rural Ligurian landscape, occurred. The event provoked losses in over 20 municipalities with casualties in the municipalities of Voltri and Mele, collapses of bridges (one in Busalla and 3 in Campoligure), damages to sewage systems and embankments, interruption of roads and railways, destruction of over 18 km of phone communication wires. Furthermore, some buildings were threatened by landslides triggered by the heavy rainfall. The cost of damages, extended to the neighbourhood of Genoa, had been as follows in the Table 5 (Gatti, 2012):

<table>
<thead>
<tr>
<th>Damages</th>
<th>Costs(^1)(EUR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Railways infrastructures</td>
<td>5.17m</td>
</tr>
<tr>
<td>Highways</td>
<td>8.62m</td>
</tr>
<tr>
<td>Roads (ANAS)</td>
<td>28.4m</td>
</tr>
<tr>
<td>Gas and water pipelines</td>
<td>1.12m</td>
</tr>
<tr>
<td>Municipality of Genoa</td>
<td>60.3m of which</td>
</tr>
<tr>
<td>a) Public estate</td>
<td>3.45m</td>
</tr>
<tr>
<td>b) Natural history Museum</td>
<td>3.88m</td>
</tr>
<tr>
<td>c) Sewage systems</td>
<td>5.60m</td>
</tr>
<tr>
<td>d) Cemeteries</td>
<td>1.29m</td>
</tr>
<tr>
<td>e) Markets</td>
<td>862,000</td>
</tr>
<tr>
<td>f) Technological plants</td>
<td>862,000</td>
</tr>
<tr>
<td>g) Enterprises</td>
<td>8.62m</td>
</tr>
<tr>
<td>h) Public transport</td>
<td>6.03m</td>
</tr>
<tr>
<td>Small and medium industrial enterprises</td>
<td>215m</td>
</tr>
</tbody>
</table>

Table 5: Economical loss data for 1970 event as reported by the Genoa Commerce Chamber (Gatti, 2012)

Referring exclusively to the city of Genoa, as reported by the Province of Genoa (2011), the damage costs estimated by the Municipal Office were higher than the data from the Chamber of Commerce. They amounted to app. EUR 86m of which about 30% related to public works only. Private people declared damages for more than EUR 8m, whereas building stock damage amounted to about EUR 13m, of which only EUR 5m related to the buildings located in the city centre.

4.2 The 2011 Genoa flood

The heavy rainfall that affected Genoa between the 4 and 6 November 2011 belongs to an extra tropical macrostorm that brought heavy snowfall to the Central and Eastern US during the last day of October 2011. This system, coming across the Atlantic Ocean, regained strength by combining with the remnants of the tropical storm Rina that hit the Yucatan region and Cuba from 23 to 28 October 2011 (Silvestro et al., 2012). The potential water content increased. The Mediterranean temperature was 1.0 - 1.5°C higher than in the last 20 years. The contact between perturbation and the warm sea surface produced the above mentioned effect in terms of intense and spatially concentrated precipitation. In detail, the rainfall phenomenon affected the Liguria Region from the 3 to 9 of November with a peak in the city of Genoa on 4 November 2011. This rainfall was responsible for the flooding of different rivers: the Fereggiano brook, the Bisagno river and the Sturla torrent. Within 3 hours, 220 mm of rainfall were measured at the Ponte Carrega rain gauge. This matched the

\(^1\) The costs, originally expressed in Italian “Lire”, have been upgraded to the year 2011 and converted in Euros (http://rivaluta.istat.it/Rivaluta/).
200 years peak flow in terms of period of return (PR) of the event (ISPRA, 2011). The peak flow corresponding to the 200 years PR is 1300 m$^3$ that much exceeds the 500 m$^3$ value that the Bisagno river was able to drain after its canalization. Part of the physical damages occurred during this event can be estimated through the intervention declared by the Municipality of Genoa as “extreme urgency” intervention, as reported in the final report of the Special Council Commission nominated for investigating the flood event (Grillo, 2011) and as summarized in the Table 6 below.

<table>
<thead>
<tr>
<th>Maximum Urgency Interventions (typology)</th>
<th>Calls for intervention</th>
<th>Activated intervention (number)</th>
<th>Costs (EUR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road, walls, scarps</td>
<td>133</td>
<td>80</td>
<td>13.8m</td>
</tr>
<tr>
<td>Schools</td>
<td>31</td>
<td>3</td>
<td>679,000</td>
</tr>
<tr>
<td>Public building stock, including offices</td>
<td>32</td>
<td>2</td>
<td>381,000</td>
</tr>
<tr>
<td>Sport structures</td>
<td>42</td>
<td>2</td>
<td>101,000</td>
</tr>
<tr>
<td>AMIU$^2$ (Municipal society in charge for urban waste collection)</td>
<td></td>
<td></td>
<td>3.24m</td>
</tr>
<tr>
<td>ASTER (Municipal society for territorial services)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mediterranea Acque$^4$ (private society devoted to manage the water service)</td>
<td></td>
<td></td>
<td>557,000</td>
</tr>
<tr>
<td>Gas network</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td>18.7m</td>
</tr>
</tbody>
</table>

Table 6: Maximum urgency intervention established by Genoa Municipality after the 2011 flood (Grillo, 2011)

Maximum urgency works included physical reconstruction and functional restoration activities. They have been funded both by Municipal and National Funds, even by charging a specific excise tax on the national petrol price. Referring to National Funds, Legambiente (2012) reports about a total of EUR 66.9m allocated for covering maximum urgency works emerged after the events happened in Liguria in October and November 2011 (including damages occurred in the “Cinque Terre” area that has a high landscape value being a UNESCO world heritage site). Referring to the same emergency (Cinque Terre and Genoa), other channels of funding have been activated and, in detail, 18 million euros came from the European Social Fund and EUR 30m from the ERDF, devoted to restore activities for damaged enterprises (Legambiente, 2012). A more detailed analysis on the 2011 occurred damages in the private sector is provided by the Genoa Chamber of Commerce (Table 7).

<table>
<thead>
<tr>
<th>Sectors</th>
<th>Number of damaged enterprises</th>
<th>Damages (EUR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commerce</td>
<td>746</td>
<td>53.3m</td>
</tr>
<tr>
<td>Services</td>
<td>153</td>
<td>22.2m</td>
</tr>
<tr>
<td>Artisans</td>
<td>318</td>
<td>11.5m</td>
</tr>
<tr>
<td>Industries</td>
<td>60</td>
<td>7.53m</td>
</tr>
<tr>
<td>Tourism</td>
<td>37</td>
<td>3.18m</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1314</td>
<td>97.7m</td>
</tr>
</tbody>
</table>

Table 7: Damages to enterprises according to different activities (Chamber of Commerce, 2011)

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2 The costs, originally expressed in Italian “Lire”, have been upgraded to the year 2011 and converted in Euros (http://rivaluta.istat.it/Rivaluta/).
3 AMIU and ASTER, in the immediate aftermath of the disaster, arranged for cleaning streets and buildings from debris and mud through pump for the aspiration of water and other mechanical devices.
4 Mediterranea Acque, in the aftermath of the disaster, operated for ensuring the presence of clean water in water tanks.
The snapshot of damages affecting enterprises, classified according to the different activities, shows that the major damage concerns goods for commerce, real estate for tourism and services whereas major losses are related to equipment for the industrial and artisan sector.

5 Vulnerability factors for the occurrence of damages in 1970 and 2011 flash floods

The size and typology of damages occurred in Genoa in the two above described events find their origin in the peculiar exposition and vulnerability factors of the city. As stated by Brandolini (2012), the main land use change due to the development of harbour, industrial, and residential areas has strongly impacted on geomorphological processes. The Bisagno Valley has been the object of a radical transformation during the last 150 years. In the mid of the 19th century, the Bisagno Valley was rich of small cultivated lots and the landscape was characterised by terraces of olive trees. Starting from 1926, Genoa developed important urban services, like the prison, the stadium, the slaughterhouses, the kennel, the fruit market, public houses and different municipal housings. In order to complete the inclusion of some neighbourhoods, the final segments of the Bisagno river and the Fereggiano brook were canalised in their final parts at the end of Thirties (see Figure 11).

![Figure 11: The coverage of Bisagno river at Brignole railway station](image)

The evolution of urbanization over one century, as reported by Tizzoni (2011) (see Figure 12), shows a significant increase of urban areas (from 3 to 11%) and crops (including...
special crops) at the expense of woodland, forests and vineyard cultivated terraces, useful for absorbing water and reducing the runoff. In terms of urban areas, an in-depth analysis has been carried out by some authors (Rosso, 2012; Faccini, 2012). Figure 13 shows the progressive development of buildings over time.

![Figure 13: Urbanization in Genoa over the centuries (Rosso, 2012). Last image on the right refers to 1997 (Faccini, 2012)](image)

Such data shows that the development of the city did not take into account extreme events, recently even more frequent and concentrated due to the effects of climate change. According to the River Basin Plan of the Bisagno river (2001), the event occurred on 4 November 2011 was characterised by a Period of Return of 200 years (PR=200) that is correctly taken into account by the Basin River Plan (see Figure 14). The Plan itself includes interventions to be realised in order to face these peak conditions. According to hydraulic estimations, the flood could have presumably been avoided if such interventions had been realised.

![Figure 14: Qualitative estimation of rainfall height in respect to time (Garotta, 2012)](image)
In 2011 Genoa had already experienced the 1970 flood and other disruptive events (see two pictures in Figure 15, comparing the Brignole Station as flooded after 1970 and 2011 events). Which measures were taken in the 30 years between the two events in to avoid a disaster replication?

This question introduces another aspect of vulnerability that can be indicated as “institutional vulnerability”. According to the definition provided by the European research project ENSURE (2011), institutional vulnerability represents “the exposure and vulnerability of individuals, communities or organizations to the uncontrollable adverse consequences of another organisation’s critical shortcomings”.

Based on the reconstruction of facts made by Tizzoni (2011), in the period 1970 - 2001, the work of flow diverting on the Fereggiano brook - as designed in two different lots in the middle of Eighties - was not concluded. In detail, the works on the second lot were suspended due to legal anomalies internal to commitment procedures. The realised part of the works (first lot) resulted to be non-compliant with safety conditions. In the meantime other disruptive events occurred in Genoa. For example, other 2 people lost their lives and heavy damages have been produced following a 1992 flood event.

From an institutional vulnerability perspective, the behaviour of the public administration that did not guarantee the transparency of the bid, as well as the behaviour of the company in charge of realizing the works, generated other forms of vulnerability (economic, social, physical, etc.).

Another facet of institutional vulnerability is represented by the behaviour of politicians and policy makers during the emergency. Broadly speaking, decisions taken during emergency can play a determinant role in respect to the consequences of a disruptive event. According to Italian law, the City Mayor is in charge of competencies in disaster prevention and emergency plan development, as well as response action coordination in disaster situations. In the aftermath of the 2011 disaster, a great debate took place due to the behaviour of the City Mayor. The Mayor was accused of negligent behaviour for not giving warnings to the close schools and streets next to the flooded Fereggiano brook where the victims lost their life. Furthermore, the Mayor was prosecuted for not having promptly implemented the civil protection actions established for these circumstances. Also, the Assessor for Civil Protection, some civil protection organizations and some municipal managers were prosecuted for the same reason (Il Corriere, 2013). Although the Liguria Region had communicated a “2 level Alert”\(^5\) (from 6 a.m. of 4 until the 6 November) due to weather conditions, the population appeared to be unaware and unprepared to face the event.

The choices of approving the Bisagno river canalisation project in the 1930s has generated other forms of vulnerability and, for this reason, represent per se another form of

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\(^5\) “Alert 2” means high risk for the safety of people and properties due to spread flooding in the area surrounding watercourses and also likely landslide of the slopes.
institutional vulnerability. The restriction of the river section compliant with respect to a PR=50 years flow, that means a low flow expectation, is in fact one of the determinant factors of the following disasters. It is worth noting that the River Basin Plan, carried out by the Province of Genoa in 2001, took this critical aspect into account by applying different typologies of measures for mitigating flood risk.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Imperia</td>
<td>125</td>
<td>67</td>
<td>24,077</td>
<td>11,541</td>
<td>17,492</td>
<td>5,820</td>
</tr>
<tr>
<td>Savona</td>
<td>140</td>
<td>69</td>
<td>26,092</td>
<td>12,936</td>
<td>20,447</td>
<td>5,391</td>
</tr>
<tr>
<td>Genova</td>
<td>86</td>
<td>64</td>
<td>41,282</td>
<td>20,404</td>
<td>23,666</td>
<td>45,230</td>
</tr>
<tr>
<td>La Spezia</td>
<td>120</td>
<td>32</td>
<td>30,397</td>
<td>14,149</td>
<td>17,169</td>
<td>6,148</td>
</tr>
<tr>
<td>Total</td>
<td>471</td>
<td>232</td>
<td>121,858</td>
<td>59,032</td>
<td>78,764</td>
<td>21,888</td>
</tr>
</tbody>
</table>

*Table 8: Areas exposed to hydrogeological risk in Liguria (ANCE – CRESME (2012) - elaboration on ISTAT data and Dipartimento Protezione Civile

Hydrological analysis carried out after the disaster (Garotta, 2012) have also shown that, if river basin plan measures had been put into practice, the occurred floods could have been avoided and damages would have been less huge. The geo-hydrological critical condition of the Bisagno catchment was defined by the Italian Civil Protection Agency as a “national emergency” in 2001. In fact, the Bisagno river flows through the most urbanised part of Genoa, with around 100,000 inhabitants in an area with a high concentration of economic and industrial activities (Brandolini, 2012). Broadly speaking, a more recent survey (see Table 8) has highlighted that nearly the totality of municipalities of the Province of Genoa (64 of 67) are affected by a high level of hydrogeological risk.

6 Vulnerability factors in Genoa with significance for RAMSES case studies

The previous section has highlighted the major factors of vulnerability of the city of Genoa with regard to floods which can be expected to occur more frequently due to the effects of climate change. These factors are:

1) The high level of urbanization that, in turn, can be distinguished, according to Lombardini and Giusso (2013) as follows:
   a) *urban sprawl*, that describes the urban expansion characterised by a low density, especially in peripheral areas;
   b) *land take*, or previously rural areas transformed in urbanised areas by urban and infrastructure development;
   c) the progressive *abandonment of rural areas*.

Referring to point a), it is worth noting that, leaving aside the centre of the city and the related surrounding circular area, Genoa is characterised by a low-density and land-consuming urban expansion. As a consequence, urban sprawl in Genoa has become considerably high. In detail, the recent report on the Environmental State of Urban context (ISPRA, 2013) analyses the high scattering indicator 6 of the administrative boundaries of Genoa (e.g., 80% vs. 44% of Milan). The trend of Genoa is similar to other European (Kasanko et al., 2006) and specifically Southern Mediterranean cities (such as Marseille, Barcelona, Athens, Rome, Naples, Istanbul) (Catalàn et al., 2008), particularly of medium/large size, that are losing their traditional compactness as maintained throughout the centuries. Urban sprawl affects rural and semirural areas through an expansion characterised by low density and invasive transport infrastructures and

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6 The scattering indicator aims to represent the level of urban sprawl, and is expressed as the ratio between the non continuous urbanised area and the total urbanised area.
facilities. Thus, these areas become *de facto* peripheral settlements of the city. Urban sprawl significantly influences the climate change dynamics. In fact, dispersed settlements with a low density of buildings require more energy compared with the compact ones in terms of housing services (e.g. air conditioning), of transports for commuting and of services (waste and water facilities, public lightening) (see also Grimmond, 2007). Broadly speaking, the way according to which the population is spread out, land use, soil sealing, land take and soil consumption greatly influence the response of ecosystem services in face of climate change.

Referring to point b), the Liguria Region is the 5th Italian Region in terms of land take (ISTAT, 2012). It should be accounted that probably the soil consumption has been limited over time due to morphological barriers typical of Genoa. On the one side, land take can contribute to a major exposure of human settlements and goods to flood risk. On the other side, the drainage capacity of soils may be radically altered, specifically through the reduction of the useful surface for water absorption and the increase of the runoff quota, including the restriction of run-off section through canalisation works. Not surprisingly, the land take concept is close to the soil sealing one.

Concerning point c), in the Liguria region, traditional agricultural practices on the terraced slopes surrounding the metropolitan area of Genoa have been abandoned (Brandolini, 2012), causing a "grass" area shift from 10% to 21% (see also Figure 12). The abandonment of terraced areas impacts on the geomorphological system: the lack of maintenance of a man-altered landscape implies erosion processes, and causes land degradation. This leads to an increase of the geomorphological hazard with wide problems of instability in the fragile Liguria soils. For example, according to Legambiente (2014), 99% of Municipalities in Liguria present areas exposed to hydrogeological risk. This problem is dramatically relevant also due to a direct interface between the hinterland and the urbanised coastline (Brancucci and Paliaga, 2006).

2) The lack of a widespread monitoring network on the Fereggiano brook. Its risk has been underestimated, probably due to its limited size. An efficient early warning system for the Fereggiano does not exist, even though the exposure of the neighbourhoods nearby has been sufficiently recognised along the past decades. An effective flood-oriented monitoring system, as integrated meteo-hydrological systems for real-time flood forecasting, could represent a cheap solution for enacting measures of risk reduction, especially compared to other, e.g. structural measures.

3) Decision-makers management in the immediate pre-event and during the emergency itself (institutional vulnerability). As described before, several pitfalls have been emerged in the preparedness and the emergency management of the disaster, particularly in the case of the 2011 event, even due to the questionable choices of the Mayor and the Municipality in managing the decisional process.

4) Mistakes during urban development phases, such as the reduction of river flow sections since the 1930s and the following planning mistakes since the 1960s. These latter allowed the city to expand along its sloppy water channel, altering the drainage regime and the water flows.

Factors 1 and 4 had contributed crucially to the impacts of 1970 and 2011 events, while factors 2 and 3 have been significant especially in the 2011 event.

The in-depth description of flood experiences in Genoa as well as the analysis of climate change vulnerability, helps to clarify some significant aspects of vulnerability that also present in some of the RAMSES case studies. For this reason, the vulnerability factors of Genoa are compared with those of the case study cities.

Table 9 reports the vulnerability factors as described in the previous paragraphs, compared with the RAMSES case study cities. It emerges that Genoa shows several similarities to the
other RAMSES case studies in terms of vulnerability: urban sprawl can be defined as the leitmotif among the vulnerability factors of a city, being present in all the selected cities of RAMSES. This is also true for soil sealing, which is strictly connected to the dispersion of urban settlements. The condition is similar for the layout of urban settlements that can cause the Urban Heat Island (UHI). All cities are in fact affected by increasing temperatures due to climate change, of which effects on human health are exacerbated particularly in compact urban areas. Criticisms are also related to the lack of monitoring systems. On the one side, cities such as London, Antwerp or New York have a well-developed system of monitoring risks (for example in river management and sea level rise monitoring) that can be considered as preliminary activities for addressing adaptation strategies and measures. On the other side, cities such as Rio or Hyderabad do not have or are in the early phases of discussion and implementation\(^7\). On the other hand, the abandonment of rural areas, being a dramatically increasing problem in mountain or marginalised rural areas of Southern Europe (see for example Arnaez et al., 2011, for Spain), seems to be an exclusive problem of Genoa. This might be caused by the traditional landscape of terraced areas, that also represents a significant (cultural) mark of Liguria and Genoa. In other cities, such as Rio de Janeiro or Bogotá, rural areas nearby the city are not abandoned, but have been occupied for the growth of informal settlements, strongly increasing the exposure to landslides and debris-flow risks for those fragile and slope soils. In this way, urban governance and policies of Genoa and the RAMSES case cities can be compared in terms of extreme event experiences and current adaptation strategies, measures and planning. This comparison contributes to show differences about the involvement of different actors within the decision making process of climate change adaptation and vulnerability issues.

The next paragraph will describe the adaptation and mitigation measures to climate change scheduled for Genoa and adopted by policy makers - highlighting also the economic aspects associated to them - that can constitute a suggestion for decision makers of the other RAMSES case cities.

\(^7\) See for example the proposal of mitigation and adaptation initiatives in Hyderabad with the project “Sustainable Hyderabad” (2008-2013).
<table>
<thead>
<tr>
<th>Vulnerability factors (as identified for Genoa):</th>
<th>London</th>
<th>Rio de Janeiro</th>
<th>Antwerp</th>
<th>Bogotá</th>
<th>New York</th>
<th>Bilbao</th>
<th>Hyderabad</th>
<th>Skopje</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban sprawl</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Land take and soil sealing</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Abandonment of rural areas (leading to soil erosion and slopes instability)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Compact layout of urban settlements (vulnerability to UHI)</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Lack of monitoring systems</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Lack of mitigation plan</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

Table 9: Climate change vulnerability factors of Genoa compared to RAMSES case studies.
7 Adaptation and mitigation measures and related costs in face of climate change

Costs for damages resulting from the 1970 event have been estimated to more than EUR 160m. The total costs of the event, however, including consequent relief efforts spanning the period 1970-1980, amounted to a total of nearly EUR 500m (CNG, 2010). Such direct costs show that inaction is an unacceptable option in the face of climate change threats. Economic simulations coupled with climate scenarios show that the benefits of adaptation can be noteworthy (see Figure 16). The implementation of adaptation measures can make a significant difference in terms of costs compared with scenarios in which no action is undertaken. Anyway, it is worth specifying that the variables at stake often have non-linear relationships with each other.

![Figure 16: Economic costs with and without adaptation showing the reduction of costs following the implementation of adaptation measures (Feyen and Watkiss, 2011)](image)

The municipality of Genoa and other administrations acting at a “supra local” scale, e.g. its related multi-scale and multi-level institutions such as the Province, the Liguria Region or the River Basin Authorities, have focused their attention on the improvement of some ecosystem services in order to adapt to climate change. In detail, such ecosystems services can be summarised as follows:

a) flood management;

b) surface water management (runoff);

c) soil erosion reduction.

The Genoa municipality has undertaken a lot of measures specifically devoted to climate change. The most popular one is the adhesion to the Covenants of Majors campaign in 2009, a European voluntary initiative aimed at achieving a 20% reduction in GHG emissions.

The Sustainable Energy Action Plan (SEAP), approved by the European Commission in 2010, is the tool through which the municipality aims at meeting the objectives of the campaign. Measures are mitigation-tailored. Among the actions included in the plan for the reduction of GHG emissions, there is a specific action devoted to “Green and urban spaces” consisting of increasing the quantitative and qualitative value of green spaces, in order to consider them not merely as residual spaces for urbanisation, but as an integrated part of the everyday networks and relations of the city.
Such an initiative is also connected to a specific Green Spaces Plan and to the vision included in the proposal of the new Master Plan, or Municipal Urban Plan, named Piano Urbanistico Comunale (PUC) that, conversely to the SEAP, is a mandatory tool on city level.

In detail, the PUC of Genoa (see Figure 17) presents the vision of the city in which two conceptual lines, the “green” and the “blue”, are drawn within the administrative boundaries. The green line encloses the built up area, including a non-homogenous urban texture within which empty spaces have to be requalified; the blue line represents the relationship between the built up area and the sea. The Table 10 highlights which are the current main adaptation measures to climate change in Genoa, deriving from several sources and initiatives. Particularly worthy to note is the fact that the new Master Plan hardly promotes measures against the urban sprawl phenomenon, especially in the area included between the green and the blue line. This would be needed in order to preserve the environmental, ecologic and landscape value of the territory surrounding the city.

<table>
<thead>
<tr>
<th>Action/output</th>
<th>Effects</th>
<th>Tool/initiative</th>
<th>Implementing body/actor</th>
<th>Economic and financial aspects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planting of about 5000 trees for a total of more than 47000 linear meters</td>
<td>Improvement of infiltration soil capacity and increase shade surface against high temperatures</td>
<td>PUC SEAP</td>
<td>Municipality</td>
<td>Not available</td>
</tr>
<tr>
<td>Promoting an integrated model for Planning</td>
<td>Improve the coordination and the relationship among different plans</td>
<td>Genoa Smart City</td>
<td>Genoa Smart City association founded by the Municipality and having about 70 partners (organizations, companies, universities, etc.)</td>
<td>Non quantifiable</td>
</tr>
<tr>
<td>1) ADAPTO (Adaptation Action Planning Toolkit) 2) Adaptation Action Plan (AAP) to climate change</td>
<td>1) ADAPTO is an evaluation tool for vulnerability and risk toward climate change 2) Realization of prototypes of Blue and Green Infrastructures</td>
<td>GRABS (GReen And Blue Space adaptation for urban areas and eco town project)</td>
<td>Province of Genoa</td>
<td>INTERREG IV C programme and ERDF funds</td>
</tr>
</tbody>
</table>
Requalification of the final section of Bisagno river. The first lot, up to the central police station has been finished. The second lot goes from the central Police station to the Brignole railway station (see Figure 15).

<table>
<thead>
<tr>
<th>The first lot has brought the flow rate capacity from 500 to 700 m/s. The conclusion of the second lot will bring the flow rate to 850 m/s</th>
<th>River Basin Plan</th>
<th>Special commissioner for Liguria Region</th>
<th>€ 35,730,000,00 II Lot, II functional (ISPRA, 2014)</th>
</tr>
</thead>
</table>

Realization of a special channel for deviating exceeding water (Bisagno “scolimatore” channel)

<table>
<thead>
<tr>
<th>The channel (approved project) will allow diversion of 370 m³/s of water from Bisagno and alleviates Fereggiano and other little rivers in case of heavy rainfall.</th>
<th>River Basin Plan</th>
<th>Liguria region, Province of Genoa, and Genoa municipality</th>
<th>€ 265,000,000,00 (Comune di Genoa, 2014)</th>
</tr>
</thead>
</table>

Table 10: Main adaptation measures to climate change in climate conditions and its consequences (own elaboration).

Consistently with objectives and actions defined in the SEAP, the Genoa municipality has launched the initiative “Genoa Smart City” in 2010 for an efficient and sustainable city model (MATTM, 2012). Referring to climate change, the main aim consists of going beyond the climate and energy objectives established by European Commission by investing on innovation on smart grid, renewable sources of energy, ICT, residential buildings, energy efficiency, electric mobility, and overall, on a model of integrated planning and management in order to take into account climate change criticalities and challenges.

Clearly “planning-oriented” have been the results produced by the GRABS cooperation project (2008-2011). 13 partners from 8 EU Member States participated in the project, among them the Province of Genoa. The project, co-financed by the INTERREG IVC programme and, in Italy, also by the ERDF fund, grounded on the assumption that spatial planning and urban design can provide rapid and effective solutions for adaptation to climate change and can lead to a reduction of local communities’ vulnerability. In the project the provincial scale is recognised as the best for the integration of different sectorial planning purposes in terms of adaptation measures definition. Demonstrative action for testing the indicators resulting from research activities have been carried out in the Polcevera and Scrivia valleys (near Genoa) as pilot projects to be replicated in other areas of the provincial territory characterised by a high level of urbanization.

A very interesting aspect of GRABS was the capacity of developing an inclusive process through the involvement of politicians, managers and communities for the realisation of local projects. An output of the project has been the ADAPTO tool that is structured on the basis of a set of environmental indicators, in order to analyse the vulnerability conditions of a territory, and also its capacity to cope with stress conditions and changes. By this perspective it aims to quantify also the resilience of a territorial system. The ADAPTO tool has been integrated in the update of the Territorial Coordination Plan of the Province (PTCP) as reported by Celenza (2011) (see Figure 18). The GRABS indicator matrix for assessing vulnerability of the entire territory of the Province has been taken into account.

---

8 The Province of Genoa is a Public Authority acting at an intermediate level between municipalities and Liguria Region, and incorporates the territory of 67 municipalities.

9 The PTCP is a general spatial planning tool approved in 2002 and actually under the decennial revision set by law.
within the Strategic Environmental Assessment procedure that is mandatory for plans and programmes according to the 2001/42/CE Directive.

Figure 18: Methodological framework developed within GRABS project for implementing Adaptation Action Plan (Celenza, 2011)

With respect to floods, also structural measures aimed at adapting to (more frequent) high value flows can be evaluated as adaptation measures. Referring to the case at stake, works for improving the hydraulic functionality of the final covered section of the Bisagno river and the Fereggiano brook and the realization of a channel devoted to reduce the river flow rate at the peak are in progress (see Figure 19). It is worth noting that some of the quoted tools/initiatives (River Basin Plan, PUC, GRABS project), represent a considerable tank in terms of information for the implementation of a future comprehensive Adaptation Action Plan for Genoa. Undoubtedly, flood and water management should represent one of the “relevant planning areas” to deal with.

Figure 19: Sketch of the layout of scolmatore channel for deviating exceeding flow rate (Tizzoni, 2011)

For better investigating the estimation of adaptation costs, mainly referred to hydro-meteorological risks, a specific questionnaire was developed by the authors and sent to the Genoa Municipal Administration. It included a table with a list of likely adaptation measures (e.g. the realization of artificial basins for irrigation, interventions of rural agricultural terraces, reforestation for reducing soil erosion, modification of building municipal regulations, realization of tank for collecting water and so on) for which the Administration was asked to point out costs and likely benefits. Other questions referred to economic resources allocated for adaptation measures, implementation of Blue and Green Infrastructures after the GRABS project at urban scale, sectors involved in adaptation policies, etc. Unfortunately, the Municipality of Genoa (in detail, the Public works and Civil
Protection Sector) has never replied to the questionnaire, probably due to the major emergencies occurred in the period in which the questionnaire has been sent (weather emergency of January 2014).

8 A focus on the BLUE AP project, the adopted adaptation plan of Bologna

As shown in the last paragraph, although Genoa is developing several adaptation strategies, an adaptation plan is still missing. For this reason, a focus on an Italian city that is currently implementing its adaptation plan may be relevant to highlight current trends and main goals of adaptation in Italian urban environments. The BLUE AP project (Bologna Adaptation Plan for a Resilient City) is a Life+ project, running from October 2012 to September 2015. The main aim is to implement the Adaptation Plan of Bologna, capital city of the Emilia Romagna region. Bologna is located at the foot of the Apennines in the Po Plain. Its urban area covers about 60 km$^2$ (Zauli Sajani et al., 2008). Bologna has about 380,000 inhabitants and is a strategic infrastructural link between Northern and Southern Italy. The BLUE AP project aims to test local measures to decrease the vulnerability of Bologna to floods, heat waves and other climate change impacts.

BLUE AP consists of six pilot actions:

- integration of adaptation measures in the City’s Building Codes;
- definition of guidelines for threatened infrastructure to improve their coping capacities in case of extreme events;
- improvement of the drainage system in waterproof areas;
- launch of a communication campaign for the greening of rooftops;
- collection of rainwater to be utilised in different ways, from water channels drainage to the irrigation of green areas;
- promotion of insurance schemes, by informing enterprises and citizens about the opportunities offered through public/private partnerships by insurance policies against extreme climate events.

The priorities are:

- integrating adaptation strategies within water policies and urban planning, limiting urban and productive water consumption in the most vulnerable areas;
- slowing soil consumption;
- maintenance of water basins through interventions of cleaning of river beds;
- increase the efficiency in wastewater management;
- improving soil management in areas most exposed to landslide risk;
- decreasing the vulnerability of the energy sector (e.g. through diversifying primary sources, promoting renewable energy and energy efficiency, developing energy stock systems);
- promoting climate change-oriented strategies within planning tools, establishing energy standards for built-up areas, buildings and public spaces;
- improving green areas through the maintenance and the conservation of natural and semi-natural areas, also promoting sustainable mobility;
- improving woodland management;
- using scientific knowledge about climate change for urban programming and planning.

These pilot actions and the related priority interventions show that the main risks in Bologna, as well as in Genoa, are related to heat waves and floods.

In terms of heat waves, recent evidences by Zhou et al. (2013) highlight the UHI intensity in summer is strongly correlated with the cluster size. The UHI intensity results as seasonally
dependent. The saturation is maximal in summer (mean up to 3°C), while it is considerably smaller in winter. Furthermore, Zhou et al. (2013) present two main findings about the UHI intensity of individual clusters as a function of the boundary temperature. On the one hand, not all clusters exhibit increasing UHI intensities with increasing boundary temperatures. For several clusters, the opposite, inverse UHI effect is found, i.e., decreasing cluster temperature with increasing boundary temperature. On the other hand, seasonal differences are highlighted. For the same boundary temperature, different UHI intensities are measured in spring and fall. A pronounced seasonality is found for many clusters, mirroring a characteristic signature and regional heterogeneity due to climate conditions (Zhou et al., 2013). In Bologna, measured and projected temperatures are increasing. In a comparative study on heat waves in Italian urban areas in 2003, comprising Bologna, Conti et al. (2005) reported the mortality rates particularly for elderly people, while Zauli Sajani et al. (2008) report the existence of an urban-rural gradient for UHI in Bologna. Major differences exist between the urban texture of Bologna and close plain rural areas, in average of app. 4°C, with values up to 8°C measured during the night. The annual trend of minimum and maximum temperatures shows a tendency to increase during the period 1951-2011, with a value of 0.3°C in 10 years for minimum temperatures and 0.2°C in 10 years for maximum temperatures. Figure 20 shows the evolution of anomalies in temperature as measured in Bologna during the period 1951-2011. This tendency becomes more pronounced after the 1990s, when peaks of annual anomaly of 2.5°C have been recorded, for both minimum and maximum temperatures, as for example in 2000 (BLUE AP, 2013a).

![Figure 20: Trend of anomalies of annual minimum and maximum temperatures. Bologna (BLUE AP, 2013a, p. 12)](image)

The projected increasing temperatures for the periods 2021-2050 and 2071-2099 are reported in Table 11. They show that projected trends will dramatically increase in the period 2071-2099.

<table>
<thead>
<tr>
<th>Period</th>
<th>Winter</th>
<th>Spring</th>
<th>Summer</th>
<th>Autumn</th>
</tr>
</thead>
<tbody>
<tr>
<td>T. min. 2021-2050</td>
<td>1.2°C</td>
<td>1.6°C</td>
<td>2.5°C</td>
<td>1.7°C</td>
</tr>
<tr>
<td>T. max. 2021-2050</td>
<td>1.5°C</td>
<td>2.1°C</td>
<td>2.5°C</td>
<td>2.0°C</td>
</tr>
<tr>
<td>T. min. 2071-2099</td>
<td>2.8°C</td>
<td>3.7°C</td>
<td>5.5°C</td>
<td>3.4°C</td>
</tr>
<tr>
<td>T. max. 2071-2099</td>
<td>3.0°C</td>
<td>4.1°C</td>
<td>5.5°C</td>
<td>4.0°C</td>
</tr>
</tbody>
</table>


Furthermore, Figure 21 reports the maximum number of consecutive days without precipitation during the summer in Bologna, in the period 1951-2011, and shows increasing trends from 2006 with a peak on 2010. On the other side, the phenomenon of days with intense precipitation in the summer seems to report more balanced trends, even though its frequency is increased, with some peaks since the late 1990s (Figure 22).
In terms of flood risk, a dramatic increase in flow rates of rivers is projected for the Emilia Romagna region (as the very recent urban and rural floods in January 2014 have shown) and Bologna. This may become a challenging issue considering that more than 50% of the Municipality of Bologna is characterised by very low hydrological response capacities, particularly in the most urbanised areas. The soil sealing caused by urban development over the last 60 years has led to the rapid growth of surface runoff, overloading the network of plain artificial channels, designed for a less extended urban texture. The current urban texture is not able to ensure an adequate drainage, and thus floods in Bologna are expected to increase (BLUE AP, 2013a). Table 12 shows the urban sprawl in Bologna in the period 1951-2003, pointing out that the urbanised area as well as the ratio of urbanised area on the total municipal area is more than doubled.

<table>
<thead>
<tr>
<th>Year</th>
<th>Urbanised Area (km)</th>
<th>Urbanised area/Total Municipal Area (%)</th>
<th>Average Annual Rate of Growth (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1951</td>
<td>19.4</td>
<td>14</td>
<td>n.a.</td>
</tr>
<tr>
<td>1961</td>
<td>24.3</td>
<td>24</td>
<td>2.5</td>
</tr>
<tr>
<td>1971</td>
<td>32.6</td>
<td>23</td>
<td>2.3</td>
</tr>
<tr>
<td>1981</td>
<td>39.4</td>
<td>28</td>
<td>2.8</td>
</tr>
<tr>
<td>1989</td>
<td>45.0</td>
<td>32</td>
<td>4.0</td>
</tr>
<tr>
<td>2003</td>
<td>47.7</td>
<td>34</td>
<td>2.4</td>
</tr>
</tbody>
</table>

Table 12: Urban Sprawl in Bologna. Period 1951-2003 (BLUE AP, 2013a, p. 27)
Based on these statements, even though a specific action plan has not been prepared, the Municipality of Bologna has considered the issue of climate change in many of the policies and actions undertaken in recent years:

- the Metropolitan Strategic Plan (Piano Metropolitano Strategico) (MeSP)\textsuperscript{10} joins public and private stakeholders, structured at the metropolitan scale to build and share a vision for the social and environmental sustainability of Bologna. In July 2013, 66 projects included in MeSP have been developed by the participation of about 500 private and public stakeholders. They discussed both social and environmental issues, these latter terms in terms of urban amenities and mobility for climate change adaptation;

- the Municipal Structural Plan (Piano Strutturale Comunale) (MuSP) establishes innovative guidelines for the urban environment of Bologna. The MuSP identifies “Seven Cities” within the municipality, corresponding to seven “visions” of Bologna, based on the homogeneity of the main spatial, social and planning characteristics to obtain homogeneous development strategies toward sustainability. The most significant “Cities” are the Città del Reno, the Città di Savena and the Città della Collina. Reno and Savena are two main rivers of Bologna. Main targets are water management and green spaces. Città del Reno identifies the river landscape of the Reno river to be connected to the city mainly through cross-connections, pedestrian and bicycle paths. Città di Savena claims the necessity of a river park in Bologna, however showing differences between the Savena and Reno environments. It underlines the different role that open spaces can play in these two different contexts. Città della Collina aims to integrate the residential areas of Bologna within the everyday urban life through different typologies of infrastructure. The strategic focus is to re-establish a system of nodes and connections (corridors, footpaths, railway stations, parking lots) for the diversification of urban and metropolitan accessibility;

- Urban Building Regulations (Regolamento Edilizio Urbano) (UBRs) translate the spatial planning strategies into land use rights and buildings, integrating planning rules and building regulations also for climate change adaptation (e.g. energy saving and efficiency). For example, UBRs aim to improve the urban and environmental quality of Bologna. Attention is given to the transformation of public space, urban interventions and building incentives for pursuing energy efficiency, saving water, permeability of soil;

- the Municipal Operative Plan (Piano Operativo Comunale) (MOP) aims at strengthening the recovery and urban redevelopment, leading to the reduction of soil consumption and sealing, to energy saving and safety of existing buildings. It also aims at promoting the regeneration of dismissed areas, and at involving private citizens and entrepreneurship in the management of public spaces. The policies approved by the City Council have to show high performance levels in terms of water saving, recovery of permeability and improvement of the urban microclimate.

Furthermore the Municipality of Bologna has joined the Covenant Of Mayors (Patto dei Sindaci) (COM) in 2008, promoted by the European Commission. To reach this goal, in May 2012 the City Council approved the Sustainable Energy Action Plan (SEAP), that is based on an inventory of emissions by sector. It depicts the activities already developed and in progress, and outlines goals, guidelines and actions to be implemented in the coming years. SEAP intervenes on six areas, ranging from mobility to the production of energy from renewable sources. As mentioned, climate change adaptation is a cutting-edge goal to be reached within the environmental goals of the described plans. Main climate change adaptation measures in Bologna are specifically addressed to heat waves and flood risks, as reported in Table 13.

\textsuperscript{10} The metropolitan areas is not limited to the Bologna boundaries, but also involves the first suburban area, that is integrated in the city due to that its functioning, networks and infrastructures are strictly connected and dependent by those of Bologna.
<table>
<thead>
<tr>
<th>Strategies</th>
<th>Risk</th>
<th>Main actions</th>
<th>Main goals</th>
</tr>
</thead>
<tbody>
<tr>
<td>GAIA Project, through the creation of public-private partnership</td>
<td>HW</td>
<td>Planting 3000 trees in the municipal area by 2013</td>
<td>Combating climate change; improving air quality</td>
</tr>
<tr>
<td>“Villa Bernaroli”, a project for an already existent rural-urban park of Bologna, designed to preserve part of the western agricultural plain of Bologna</td>
<td>HW</td>
<td>Planting of hedges, rows of trees and areas left green for free use by visitors on 45 ha farmland</td>
<td>Landscape restoration</td>
</tr>
<tr>
<td>Ecological Network and the green system of Bologna</td>
<td>HW</td>
<td>The completion and enhancement of the ecological network; greening interventions</td>
<td>Preserving the biodiversity of natural environments and habitats</td>
</tr>
<tr>
<td>Warning system and assistance to citizens at risk</td>
<td>HW</td>
<td>Construction of a solidarity network of voluntary associations, social centers, pharmacies</td>
<td>Providing care services in support of the elderly and their families in case of heat waves</td>
</tr>
<tr>
<td>Green spaces along the River Rhine Park: “Lungo Navile” Project</td>
<td>F</td>
<td>Redesigning and enlarging the network of urban paths</td>
<td>Restoring the landscape; rebalancing the permeability of green spaces</td>
</tr>
<tr>
<td>Structural measures</td>
<td>F</td>
<td>Public-private partnerships for sewage management; multi-objective interventions for water quality: reduction of water consumption for civil aims and of drains; re-use of rain water</td>
<td>Rebalancing the permeability of green spaces</td>
</tr>
<tr>
<td>Non-structural measures</td>
<td>F</td>
<td>Improving civil protection activities within urban planning</td>
<td>Improving water management in planning</td>
</tr>
</tbody>
</table>

Table 13: Adaptation measures for Heat Waves (HW) and Flood (F) risks in Bologna (BLUE AP, 2013b).

Generally, adaptation measures both for heat waves and flood risks target to strengthening the greening and the environmental quality for both pre-existing green spaces (such as Villa Bernaroli, River Reno Park and the green system of Bologna) and new ones (such as in the GAIA Project). This would allow to preserve the ecological networks and the biodiversity functioning, as well as the landscape and soil and water resources, both within the city and along main rivers. Furthermore, a significant initiative is the implementation of a warning system for the citizens most exposed to UHI, that generally are elders or people affected by illnesses that warm can worsen (e.g., cardio-vascular or respiratory diseases). Finally, in terms of flood risk, structural measures aim to intervene on facilities (such as sewages and infrastructure for water consumption), while non-structural measures aim to intervene in civil protection planning and in the improvement of water management. BLUE AP represents one of the most integrated climate adaptation plans in Italy. Adaptation measures are not limited to environmental issues, but recall also broad social aspects, targeting to the local development of the neighbourhoods, particularly those close to the rivers, and to the integration of the different parts of the city in a better connected transport and mobility network.

9 Concluding remarks

The present review addressed several issues concerning climate change adaptation at national and urban scale in Italy. After proposing an overview of the current state-of-art in Italy, it deepened main issues related to damage costs, vulnerability and adaptation strategies in the Italian city of Genoa after the 1970 and 2011 floods. Based on these
statements and according to the research questions, five preliminary conclusions were developed.

First, climate change adaptation has been added only recently to the Italian policy agenda. Climate change adaptation history within the country is relatively short and a NAS has still not been adopted, even though a very advanced draft has been assessed and shared with stakeholders. In terms of adaptation costs assessments, just recently the topic has emerged within worldwide literature. Updated results about the assessment of adaptation costs in Italy are lacking, although studies provided by NCCC since 2007 represent a seminal contribution to provide preliminary results particularly for sea level rise on Italian coasts. Also according to OECD (2013), the development of a robust and integrated evidence of climate change impacts for Italy would help to identify, assess and monetise main climate change risks and opportunities. Costs and benefits analysis of climate change adaptation would further allow to understand priority areas of intervention with very constrained budgets, and to indicate the size and the scale of the main challenges. The assessment of long-term climate change impacts would be crucial in addressing the further steps of the national policy, especially in terms of spatial and urban planning. Adaptation strategies should also include a structured review process, to assess progress towards implementation and effectiveness in mainstreaming adaptation into national policies, based on an agreed set of monitoring indicators.

Second, some Italian cities and metropolitan areas have adopted climate change adaptation plans, even though preliminary and comprehensive adaptation costs are still not definitively integrated within these plans. The review of Italian experiences of adaptation plans as reported in Table “Italian Cities” is just exemplificative and does not intend to provide a complete perspective of adaptation policies in Italian cities. However, it reveals that these strategies mainly aim to cope with risks regarding to floods and heat waves, of which effects are dramatically increasing in the last decades also due to the chaotic development of urban structures and the increase of vulnerability of human settlements. River management and land use will result as decisive in addressing effective adaptation strategies. Most of these strategies regard the greening of river stripes, the restoration of fluvial landscapes and the maintenance of green urban spaces, as prevention of heat waves effects, and a more rational use of water and soil resources. Part of these strategies is also integrated in ordinary urban planning tools and civil protection activities. In the case of heat waves, the activation of warning systems and solidarity networks among associations for the most vulnerable people is considered a valuable adaptation strategy.

Third, the Mediterranean area represents a hotspot in terms of climate change. Settlements are at risk of severe consequences in the near future due to the effects of climate change, including the interruption of the essential functions of main urban systems. This is blatant in case of recurrent severe floods, as happened in Genoa during the last decades. Genoa is a crucial hub for road, railway and maritime infrastructure networks in Southern Europe and in the Mediterranean basin. It has been taken as an example of a city which will likely experience huge losses related to climate change effects, due to its exposition to the “Genoa low” effect – a low pressure phenomenon favoured by sea temperature rise – responsible of heavy rainfall events concentrated in a very short time. The large monetary losses value – without considering intangible losses – as experienced in 1970 and the 2011, has shown that the inaction option, or Business As Usual (BUA) scenario, is unsuccessful. In fact, inaction could trigger heavy damages, deeply undermining the expected outcomes of sustainable development.

Fourth, damages occurred in 1970 and 2011 events have been higher due to some vulnerability conditions characterising the urban context of Genoa. These two events have been in-depth analysed for pinpointing vulnerability factors to be accounted for future urban climate change adaptation policies, to which RAMSES aims to provide a useful contribution in terms of knowledge, assessment tools and methodologies. The analysis has highlighted
that urbanisation and related issues (such as urban sprawl, land take and soil sealing, abandonment of rural areas) contributed to exacerbate extreme events damages. Moreover, urbanisation strictly depends on choices of policy-makers, planners and engineers. This can lead to a relevant form of institutional vulnerability. Furthermore, some losses have been exacerbated due to the lack of an effective monitoring and early warning system and due to a missed prompt implementation of the Civil Protection Plan by the Municipality and other administrations. All these aspects have played a key role in the disruptive 1970 and 2011 events. Thus, they should be analysed also in the main RAMSES case studies, in order to define specific adaptation measures. Genoa has not yet adopted an adaptation plan, but can take advantages by a considerable set of data collected by other initiatives and research projects, recently developed in terms of both mitigation and adaptation measures.

Fifth, in the Italian context, apart from Genoa, climate change adaptation has still not been included in a comprehensive framework/plan. However, a successful experience of an adaptation plan is the Bologna Local Urban Environment Adaptation Plan for a Resilient City, one of the most comprehensive and exhaustive within the Italian scenario of adaptation plans. BLUE AP identifies the targeted areas according to spatial, social and planning characteristics in the way to obtain homogeneous development strategies, inspired by sustainability goals. BLUE AP poses attention to the transformation of public space and to incentives for pursuing saving water, soils drainage and energy efficiency of public and private buildings. Main strategies aim to integrate river infrastructures, such as the green spaces along Reno and Savena rivers, within the everyday urban life, for example considering them as cross-connections, pedestrian and bicycle paths. This would also serve to reduce the marginalisation of some residential areas of Bologna, integrating them within the urban everyday life. The creation of green spaces within the urban environment would ensure a more sustainable management of water resources for the prevention of river floods and heat waves and the conservation of biodiversity. Furthermore, the BLUE AP is successfully integrated into urban planning tools, such as the strategic metropolitan and municipality plan, and into urban building regulations. Finally, it is also part of the Covenant of Mayor.

According to the aforementioned results, main recommendations for the next step of RAMSES are those to consider Genoa and Bologna as compact cities to test the estimation of climate change damage impacts and adaptation costs under different climate change scenarios over different time scales.
10 References


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<table>
<thead>
<tr>
<th>City-Urban area</th>
<th>Main strategies</th>
<th>Main goals</th>
<th>Vulnerability</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ancona Municipality, Local</td>
<td>Increasing the integrated territorial governance focusing on climate change; monitoring coastal erosion through remote sensing; prevention maps for roads; prevention maps for cultural heritage; early warning system for landslides; system of surveillance and alarm system for the prevention of the effects of heat waves on health; maintenance of roads and railways; conservation of biodiversity and habitats</td>
<td>Risk reduction for heritage and infrastructure</td>
<td>Rainfalls and sea level rise leading to coastal erosion and landslides to roads, railways and cultural heritage; Rising summer heat waves</td>
<td>ACT (2011a; 2011b)</td>
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<tr>
<td>Adaptation Plan</td>
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<tr>
<td>Genova Province Adaptation Action Plan</td>
<td>Integrated approach for river flooding; Green and blue infrastructure along the main streams Scrivia and Pocevera (e.g., plant trees)</td>
<td>Landscape restoration; Sustainable water resource management; Ecosystems renaturation</td>
<td>Built environment and infrastructure exposed to river flood and heat waves</td>
<td>Kazmierczak and Carter (2011); Provincia di Genova (2014)</td>
</tr>
<tr>
<td>Faenza Municipality</td>
<td>Bio-neighborhood incentive programme in Town Planning Regulations, through extending the cubature of buildings in excess of approved standards, if buildings meet criteria of sustainability (including green roofs, green walls, water retention systems, the creation of continuous public green spaces by developers). The development conditions are negotiated case-by-case</td>
<td>To achieve energy savings; to promote aesthetic qualities of neighbourhoods; to create better microclimate conditions to cope with rising temperatures</td>
<td>Built environment and infrastructure exposed to and heat waves</td>
<td>Kazmierczak and Carter (2011)</td>
</tr>
<tr>
<td>Padua: to improve the environmental and urban climate quality; to mitigate the mobility infrastructure impact</td>
<td>To reuse the natural elements (rivers, wetlands, agriculture areas, woods) to structure a settlement model based on the historical existing urban area</td>
<td></td>
<td>High urbanization rates leading to environmental degradation and heat waves</td>
<td>UHI Project (2014)</td>
</tr>
<tr>
<td>Urban corridor of Venezia–Padova: UHI - Urban Heat Island project (2011-2014)</td>
<td>Brenta river riviera: to integrate historical landscapes in solutions to reduce urban traffic, improving functions of networking, social and cultural visiting. Brenta Riviera refers to the area of Dolo, including ten municipalities of Venice Province. Water path are communication link between the Venice lagoon and Padua. The area is characterised by the presence of XVI and XVIII centuries villas</td>
<td>To reuse the natural elements (rivers, wetlands, agriculture areas, woods) to structure a settlement model based on the historical existing urban area</td>
<td>Unbalances between linear urbanization and garden and rural spaces, leading to environmental degradation and heat waves</td>
<td></td>
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<tr>
<td>Venice: save the lagoon environment, limiting the impact on urban environment of the tourism pressure (also with limitation)</td>
<td>Lagoon system is a wetland with a high environment, landscape and ecosystem value. It is</td>
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<tr>
<td>Area</td>
<td>Project/Plan</td>
<td>Description</td>
<td>Outcome</td>
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<tr>
<td>Metropolitan cluster of Bologna–Modena: UHI - Urban Heat Island project (2011-2014)</td>
<td>Improvement of buildings energy efficiency, reduction of pollution and improvement of environmental quality</td>
<td>Improvement of the air quality; preservation of underground water resources; increase in biodiversity</td>
<td>Damaged by the urbanization; potential heat waves</td>
<td></td>
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<tr>
<td>Alba, EU Cities Adapt – Adaptation (2012-2013)</td>
<td>To increase institutions/citizenship relations for spreading awareness about climate risks; to improve the system of alert and emergency management, maintenance for river management</td>
<td>To provide capacity building in developing adaptation strategies; raising awareness on the importance of preparing for climate change; exchanging knowledge and good practices; developing tools and guidance for cities on adaptation; stakeholder-dialogues identify challenges and needs</td>
<td>High rate of urbanization and infrastructure environmental alterations linked to the critical traffic conditions, potentially leading to heat waves</td>
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<tr>
<td>Padova EU Cities Adapt – Adaptation (2012-2013)</td>
<td>Adaptation Team; involvement in a project on Urban Heat Island Effect (see above); participation in the Italian Local Agenda 21 for Sustainability; to strengthen Environmental Communication and Training activities</td>
<td>To provide capacity building in developing adaptation strategies; raising awareness on the importance of preparing for climate change; exchanging knowledge and good practices; developing tools and guidance for cities on adaptation. Stakeholder-dialogues identifying challenges and needs</td>
<td>Built environment and infrastructure exposed to floods, storms and heat waves</td>
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<tr>
<td>Province of Turin – Civil Protection Plan (2008-ongoing)</td>
<td>Sustainability Plan; rational resources (water and soil) and resource networks management; combating urban sprawl</td>
<td>Hydrogeological risk reduction and preparedness to cope with extreme events (heat waves, snow storms)</td>
<td>Built environment and infrastructure exposed to floods, snow storms and heat waves</td>
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<tr>
<td>Reggio Emilia – Climatic Plan</td>
<td>Increase and promotion of renewable energy and energy efficiency for public and private buildings and industrial plants, maintenance and river management; increase multifunctional areas, also strengthening protected areas network</td>
<td>Reduction of gas emissions; reduction of flood risk; landscape and biodiversity preservation</td>
<td>Built environment and infrastructure exposed to floods, storms and heat waves</td>
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</tbody>
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