WP 5: Development of a cost assessment framework for adaptation

D5.4: Cost Assessment Framework

Reference code: RAMSES – D5.4

This project has received funding from the European Union’s Seventh Programme for Research, Technological Development and Demonstration under Grant Agreement No. 308497 (Project RAMSES).

Project Acronym: RAMSES
Project Title: Reconciling Adaptation, Mitigation and Sustainable Development for Cities
Contract Number: 308497
Title of report: D5.4: Cost assessment framework
Reference code: RAMSES – 5.4

Short Description:
This report presents a cost assessment framework that follows a hierarchical approach for prioritising and financing adaptation, aimed at helping policy makers make adaptation decisions more effectively and efficiently.

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Made available to: Public

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Quality check
Internal Reviewers: Alistair Ford, Gerardo Sanchez Martinez
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<tr>
<td>ACC</td>
<td>Adaptation Cost Curve</td>
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<td>CGE</td>
<td>Computable General Equilibrium</td>
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<td>CBA</td>
<td>Cost Benefit Analysis</td>
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<td>CEA</td>
<td>Cost Effectiveness Analysis</td>
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<td>GVA</td>
<td>Gross Value Added</td>
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<td>IAM</td>
<td>Integrated Assessment Model</td>
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<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
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<td>I-O</td>
<td>Input-Output model</td>
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<tr>
<td>LVC</td>
<td>Land Value Capture</td>
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<tr>
<td>MSOA</td>
<td>Mid-level Super Output Area</td>
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<tr>
<td>NACE</td>
<td>Statistical classification of economic activities in the European Community</td>
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<tr>
<td>PACE</td>
<td>Property Assessed Clean Energy financing</td>
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<td>PPP</td>
<td>Public-Private Partnership</td>
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<tr>
<td>PRTP</td>
<td>Pure Rate of Time Preference</td>
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<td>RCP</td>
<td>Representative Concentration Pathway scenario</td>
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<td>ROA</td>
<td>Real Options Analysis</td>
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<td>UAST</td>
<td>Urban Adaptation Support tool</td>
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1. Executive Summary

In order to utilise limited public finance resources and mobilise private finance effectively, city governments will need appropriate processes and resources for sound investment planning and execution. Despite this, most cities lack the tools for performing economic assessments of damages, adaptation, and financing options.

To help policy makers make adaptation decisions more effectively and efficiently, RAMSES has developed a cost assessment framework that follows a hierarchical approach for prioritising and financing adaptation (Figure 1). The RAMSES Transition Handbook and the Urban Adaptation Support Tool (UAST) represent a comprehensive process for dealing with adaptation decision-making that include social, political, technical, environmental, economic and other considerations. The cost assessment framework is designed to provide much of the economic and financial assessment for the Transition Handbook, specifically supporting phases 2 to 5 of the Handbook.

The cost assessment framework is divided into three key iterative phases that follow a hierarchical process across four levels: describing the RAMSES Transition Handbook phases 2 to 5 (level 1), quantifying costs (level 2), cost assessment methods and financing mechanisms (level 3) and a range of inputs (level 4). The three phases define a procedure for [1] assessing risks and vulnerability based on damage costs, [2] identifying and assessing adaptation options based on their economic net benefits, and [3] planning and implementing city investments based on a range of financing mechanisms and funding models.

Figure 1 Cost assessment framework for adaptation in cities
2. Introduction

2.1. The challenge of adaptation investments in cities

2.1.1. City adaptation and the Paris climate agreement

Climate change is one of the main challenges for policy making worldwide. The socio-economic costs of climate change are predicted to be relatively high in urban areas as they represent concentrations of people, assets, and productive activity. The joint effect of the increase in the number of people living in cities and a predicted rise in the probability of hazardous events due to climate change means that the potential for adverse effects from climate threats in cities is increasing. Indeed, even without the amplifying effects of climate change, many cities are already highly vulnerable to existing weather-related risks. In Asia, for example, where urban population has been projected to double between 1994 and 2025, much of this population will flow to megacities with populations of 5 million or greater - 65% of which are located in “low elevation coastal zone” regions that are particularly susceptible to climate-related flooding damages (Telesetsky and He 2016).

Climate change adaptation can be defined as the processes and actions through which people and systems are better able to cope with climate change. It is common to use the concept of adaptation interchangeably with that of climate-resilient development (Fankhauser 2017). Urban adaptation addresses the distinct features and related risks to cities, such as:

- flood risk from an increase in impervious surfaces alongside changing precipitation patterns;
- seawater intrusion and coastal area flooding from sea level rise;
- rates of urbanisation and commensurate exploitation of natural resources leading to the loss of protective ecosystems; and
- urban density and a lack of green space, coupled with more severe and frequent extreme heat, increase the urban heat island effect in cities resulting poor air quality exposes greater numbers of people to health risks (UNFCC 2016).

The Paris Climate Agreement signed in 2015 places unprecedented importance on investing in climate resilience, effectively placing an equal emphasis on climate adaptation and mitigation efforts. This is reflected in the structure of the Green Climate Fund with its target capitalisation of USD 100 billion. It has a stated commitment to aim for a 50:50 balance between mitigation and adaptation investments over time (Green Climate Fund ND). Similarly, the UN Sustainable Development Goals, the Habitat III New Urban Agenda and the Sendai Framework for Disaster Risk Reduction have all demonstrated the need for a more strategic approach to investing in public infrastructure that leverages private and institutional capital more effectively.

2.1.2. The challenge of assessing costs and financing options

Developing more climate-resilient cities is necessarily becoming a greater priority for governments and businesses. However, increasing investment flows for adaptation is a major financing challenge. The UN Environment Programme has estimated that by 2030, global adaptation costs are likely to be in the range of USD 140-300 billion per annum (Richards and Schalatek 2017). Some of this
investment will come from private actors as a way to protect or increase the value of business operations and physical assets, and decisions by private individuals over their health and wellbeing. However, the need for public sector investments is also essential given the present-day social and intergenerational equity, and geographic dispersion, features of climate change impacts.

In order to utilise limited public finance resources effectively, mobilise private finance, and reduce the risk of maladaptation\(^1\), city governments will need appropriate processes and resources for sound investment planning and implementation. Despite this, most cities lack the tools for (1) estimating damage costs, (2) assessing the economic benefits of alternative adaptation options or (3) identifying and prioritising mechanisms for accessing finance to fund measures.

Key challenges in assessing costs and benefits of climate impacts and adaptation investments include uncertainty (e.g. in the timing and severity of climate-related impacts, the assets exposed, and the price of materials required for installing adaption measures), the cost-optimal timing of an investment, and thresholds or tipping-points beyond which adaptation measures are ineffective. The long-term, multivariate and probabilistic nature of climate change assessments makes perfect knowledge impossible. The damage cost and adaptation benefit assessment methodologies presented in this report are aimed to provide decision-makers with better guidance on viable tools and processes to prepare cost-effective adaptation strategies given the inherent information limitations. Use of these will require capacity building and engagement with a wide range of stakeholders.

### 2.1.3. Key questions for policy makers

This report aims to assist policy makers, particularly at the municipal level, in approaching the following questions:

1. How can policy makers estimate damage costs in a city?
2. How can policy makers prioritise urban adaptation options in terms of economic benefits?
3. How can policy makers prioritise financing options for delivering adaptation in cities?

For adaptation planning and implementation, government officials will include a wide range of variables in their decision-making that go beyond cost assessment. Examples include social and political acceptability, technical efficacy, time to implement, whether the effect of intervention can be measured, and whether a measure can offer co-benefits beyond climate adaptation. This suggests that considerable flexibility and cross-sectoral and stakeholder collaboration is needed so that cost and finance variables are integrated as part of an iterative process. In practice, this means drawing in inputs on non-cost factors, as well as examining the three questions above in parallel.

### 2.1.4. Importance of integrated policy programmes

The majority of adaptation measures are not specific to climate change, but aim to reduce vulnerability to impacts that climate change will exacerbate. Thus in cities, rather than being thought of as an additional goal, climate adaptation can be mainstreamed into existing governance and investments

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\(^1\) Defined in the UNFCCC Fifth Assessment Report as: Actions that may lead to increased risk of adverse climate-related outcomes, increased vulnerability to climate change, or diminished welfare, now or in the future. (https://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIAR5-AnnexII_FINAL.pdf)
related to urban management. At the same time, evidence suggests that citizens are more likely to take action on climate change, or more likely to support governments that do so, if the wider co-benefits for those actions are also emphasised (Bain et al. 2015).

Experience from national governments offers useful examples of integrating adaptation into wider government actions and responsibilities. Examples from several OECD countries show a pattern for pursuing sectoral adaptation programmes that align adaptation duties with existing ministerial responsibilities, combined with additional efforts to address cross-cutting issues, such as water and infrastructure (Mullan et al. 2013).

At the city level, this integration of adaptation needs to align with core responsibilities and spheres of influence of local government, while also recognising that existing features of urban development and urban growth need a shift in focus and priority in light of resource- and pollution-reduction imperatives. For example, in many cities, sprawling suburbs have spread into flood plains or landslide-prone areas, exposing assets and infrastructure to higher risks. The high commuting costs of sprawling urban form become even higher during or following natural disasters such as storms or floods, when severe transport disruptions take place. Similarly, the cost of replacing public infrastructure after a disaster is higher in these expansive areas than equivalent costs in more densely settled districts. A recent study has also found that urban sprawl is an important factor in influencing the level of emergency public assistance spending, including post-disaster relief efforts, in the United States (Lambert and Catchen 2013). This demonstrates that while the complexities of developing climate resilience in a rapidly urbanising world are daunting, there are potential co-benefits that can be exploited.

In order to emphasise the importance of an integrated policy approach to sustainable urban policy, the Global Commission on the Economy and Climate, in association with the United Nations Secretary General, suggests an alternative model of well-managed urban growth underpinned by three distinct but interconnected pillars: compact urban growth; connected infrastructure; and coordinated governance (Floater et al. 2014). While this approach, known as the 3C model, requires further testing and refinement, initial empirical evidence suggests that the model can deliver substantial benefits, not only for economic growth and low carbon, but also for social inclusion, health, quality of life and the urban environment.

Improving resilience while simultaneously delivering the 3C model of urban growth requires an integrated approach that combines economic and social development with climate resilience capacity building. Figure 2 summarizes how climate resilience can be integrated into the 3C model to capture the co-benefits of urban growth and resilience policies, while at the same time recognizing some of the tensions between them (Costa et al. 2016).
2.2. Developing a cost assessment framework for cities

2.2.1. Urban Adaptation Support Tool (UAST)

The RAMSES Project has produced an immense and highly valuable collection of reports and resources on climate change adaptation and resilience in cities. The project has developed cutting-edge research on some of the most relevant topics for urban climate change adaptation. These include:

- modelling climate projections and scenarios to understand future climate impacts and illustrate the effects of specific adaptation measures for cities (Work packages 1, 2, 3 and 4);
- understanding how to make architecture and infrastructure more resilient to climate change and how to assess the effects of improved architectural design on cities (Work packages 1, 2, 3 and 4);
- estimating the costs of climate change and the benefits of different adaptation measures (Work Packages 1, 3, 4, 5 and 6);
- understanding the costs that climate change has on health and how different adaptation measures can reduce climate impacts on public health (Work Packages 5 and 6);
- conducting high-level vulnerability assessments in order to understand which the climatic trends in European macro-regions are and consequently which are the main risks that cities in these regions are exposed to (Work packages 7, 8 and 9);
- conducting detailed vulnerability analyses in the cities of London, Antwerp and Bilbao at a high spatial resolution to draw lessons from these cities’ experiences (Work packages 7, 8 and 9); and
- understanding existing political frameworks and decision-making tools that support adaptation, and drawing lessons from those (Work packages 7, 8 and 9).

Source: Costa, Floater and Finnegan (2016) and Floater et al. (2014)
These outputs form the foundation of the RAMSES Transition Handbook, which embeds the key RAMSES findings into a process management cycle to assist cities in their understanding of climate change and response to it. The Handbook is set out in RAMSES Deliverable 10.2 and draws on the transition model developed in RAMSES Deliverable 8.2 along with all other research Work Packages of the project (WP 1 to 8).

The Transition Handbook is a guide to the process of urban climate change management based on the Urban Adaptation Support Tool (UAST) developed by the Covenant of Mayors for Climate and Energy. The UAST lays out step-by-step actions for decision-makers to manage climate risks, and the handbook has been structured according to the six UAST phases (Figure 3). The phases can be adjusted according to specific city strategic objectives, needs and resources.

![Figure 3 RAMSES transition model based on the Urban Adaptation Support (UAST)](image)

Source: RAMSES Deliverable 10.2 (Mendizabal et al. 2017)

The RAMSES Training Package (Deliverable 10.2) complements the Transition Handbook by taking stock of existing toolkits to support adaptation management in cities and proposes worksheets and exercises that cities can use to progress on their adaptation endeavours. The worksheets are cross-referenced in the Transition Handbook so as to complement the information contained in it and to offer cities a clear path towards becoming more climate adaptive. The Training Package is complemented by a slide deck, available on the RAMSES website (www.ramses-cities.eu/results), which will summarise the most policy-relevant project findings to support cities in raising awareness on climate adaptation.

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3 Covenant of Mayors for Climate and Energy is a voluntary programme where city and regional government signatories pledge to reduce CO2 emissions by at least 40% by 2030 and to adopt an integrated approach to tackling mitigation and adaptation to climate change. Originally started in 2008 as an EU programme, the initiative now includes more than 7,000 local and regional authorities across 57 countries. More information can be found at: [http://www.covenantofmayors.eu/index_en.html](http://www.covenantofmayors.eu/index_en.html)
2.2.2. **RAMSES cost assessment framework: an overview**

The aim of this report is to develop a cost assessment framework that can support policy makers in their adaptation decision making, following a hierarchical approach for prioritising and financing adaptation. The framework is designed to be integrated into the RAMSES Transition Handbook (Work Package 10) and draws on RAMSES deliverables in Work Packages 1, 2, 3, 4, 5, 6, 7 and 8. The cost assessment process supports three key phases of the Handbook as follows:

- Handbook Phase 2: assessing risks and vulnerability, based on damage costs;
- Handbook Phase 3/4: identifying and assessing adaptation options, based on the economic net benefits of adaptation measures; and
- Handbook Phase 5: planning and implementing, based on effective city investments.

Figure 4 provides an overview of the cost assessment framework.\(^4\) The individual phases of the framework are discussed in detail in Chapters 3, 4, and 5. Each of the three phases (2, 3/4 and 5) comprises four levels. Level 1 corresponds directly to the phases of RAMSES Transition Handbook (see Figure 3). Level 2 corresponds to the quantified costs and investments that support the Handbook. At this level, policy makers may decide on which type of costs to include (e.g. direct and/or indirect costs, market and/or non-market costs) in order to support level 1 decisions that include wider evidence than costs alone. Level 3 corresponds to the methods and mechanisms used to assess costs, estimate economic benefits and channel city investments. Finally, level 4 corresponds to inputs that are required to perform assessments of damage costs (e.g. hazards and exposure, vulnerability, risks and uncertainty), economic net benefits of adaptation (e.g. types of adaptation measures, their implementation costs, timing and discount rates) and the effectiveness of alternative financing options (e.g. sources of finance). These inputs are also required to determine the most appropriate costing methods and financing mechanisms available to the policy maker.

The three phases are overlapping and interrelated, requiring an iterative process of costing and decision making. For example, adaptation cost assessment methods (Phase 3/4) need to take account of damage costs in the absence of adaptation (Phase 2) in order to estimate averted losses, while the economic benefits of adaptation options (Phase 3/4) will both influence and be influenced by the finance mechanisms and city investments chosen by the city (Phase 5). For these reasons, the framework should not be regarded as a linear process, but one with feedback loops across the three phases.

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\(^4\) Unless otherwise noted, all tables and figures are original work of the authors for the Deliverable.
The remainder of the report is structured in line with the three phases of the cost assessment framework:

- **Chapter 3: Assessing risks and vulnerabilities: damage costs** – as relates to Phase 2 of the RAMSES Transition Handbook.
- **Chapter 4: Identifying and assessing adaptation options: economic benefits** – as relates to Phase 3 and 4 of the RAMSES Transition Handbook.
- **Chapter 5: Planning and implementation: city investments** – as relates to Phase 5 of the RAMSES Transition Handbook.
- **Chapter 6: Conclusions.**

In terms of scope, the cost assessment framework is designed to be sufficiently flexible so as to include a wide range of damage costs, adaptation benefits and finance mechanisms. The aim is to provide policy makers with guiding principles and methodological options that can support them in the decision making process rather than providing a prescriptive approach that is unable to be tailored to city-specific circumstances and wider policy priorities. For example, the cost assessment framework can include very different types of damage costs. Ideally, policy makers would include direct and indirect costs, market and non-market costs, and estimated in terms of expected costs rather than total costs. However, in many cases a range of data, capacity and policy constraints will prevent the full range of costs being analysed. Where indirect costs cannot be estimated with any precision, the policy maker may decide that an analysis of direct costs only is nonetheless a useful exercise. Similarly, an estimation of market only costs can still provide important insights into damages, while total costs can be used as an alternative to expected costs where capacity and data are lacking. In all these cases, it is important that the policy maker recognises that the estimate of damages is likely to be an underestimate, and that this should be considered when assessing economic net benefits.
3. Assessing risks and vulnerabilities: damage costs

3.1. LEVEL 1: Transition Handbook Phase 2

3.1.1. What is Phase 2?

The RAMSES Transition Handbook presents a sequential process for decision-makers to integrate adaptation into urban management and governance (see Section 2.2 of this report for an overview). Phase 2 of the Handbook aims to develop a comprehensive picture of current and future risks in a given urban area as well as further stress factors that can be expected (Deliverable 10.2). It is also important to note that this phase will help identify not only risks but also opportunities arising from climate change. Phase 2 is based on the reasoning that adaptation cannot be planned solely on the basis of climate projections; information on risk and vulnerabilities is also needed to determine how the climate interacts with socio-economic circumstances. RAMSES is following the risk and vulnerability framework defined by the IPCC in the 5AR (IPCC 2014). In this phase of the process the aim is to address the following questions:

- How is climate change going to affect my city?
- Which areas and sectors of activity would potentially be more affected?
- Which are more vulnerable?
- To what extent is the city capable to cope with it and react?

As set out in Figure 5, the RAMSES Transition Handbook Phase 2 includes three steps. These are discussed in more detail in the Handbook (Deliverable 10.2). The first step is devoted to the identification of the key hazards that a city may face (e.g. flooding, heat waves) and the level of the city’s exposure to those hazards. The second step assesses vulnerability. Not all impacts are felt equally by all exposed elements of the urban system. For example, small children and elderly people are more vulnerable to extreme heat than others in society. Similarly, small and medium-sized companies (SMEs) tend to be more vulnerable to disruptions than larger companies due partly to smaller profit margins and financial cushions. The characterisation of vulnerability is therefore crucial in order to understand how the socio-ecological system at city level could be affected by certain hazards, and so establish and deploy the adequate mechanisms and effective policies to respond and adapt. The last step in phase 2 is identifying the risk and assessing the likelihood of being affected by a specific climate threat. Recently and according to the latest IPCC 2014 definition, risk is expressed as the function of threat, vulnerability and exposure (IPCC 2014).
3.1.2. How cost assessments can support Phase 2

Cost assessments form an important component of assessing risks and vulnerability. Governments can use damage cost estimates alongside non-monetised, qualitative assessments to prioritise policy actions. Climate-related impacts with a higher risk and level of damages to a city economy should receive higher consideration for adaptation actions by government.

As set out in section 2.2.2, the cost assessment framework has four levels. For phase 2, these levels are set out in Figure 6. Level 2 quantifies the damage costs of different hazards, which can feed into the Handbook Phase 2 alongside other quantitative and qualitative evidence for risks and vulnerability that are not included in the cost assessment framework. At level 3, policy makers will need to make choices between different assessment methodologies for estimating damage costs. These choices will depend in part on the level 4 data and information available on hazards and exposure, vulnerability, and risk and uncertainty. Each of these levels is discussed in more detail in the following sections of Chapter 3.
3.2. LEVEL 2: Quantifying damage costs

In order to support level 1 of the cost assessment framework – the Handbook phase 2 “Risk and vulnerability” – level 2 focuses on identifying different types of damage costs. Similarly, to quantify level 2 damages, it is necessary to make use of assessment methods described in level 3. Damage costs are defined here as the quantified, monetised impacts of climate events. They include direct and indirect costs, market and non-market costs, and may be estimated as total or expected costs. A qualitative assessment of damages should complement any policy analysis.

Measuring the impact of climate events to the urban economy requires estimating the physical impacts of these events to a city. For example, how a flood will affect the road system or building infrastructure, or how a heat wave will affect the railway system. An assessment of how hazards physically impact a city is usually performed with the aid of climate models and engineering models (see RAMSES Work Packages 1, 3, and 4 for guidance on these). It is necessary to understand that each hazard will affect the economy in often complex ways. To understand a city’s overall economic vulnerability it is important to account for all components of socio-economic activity and their interdependent relationships (Hallegatte et al. 2011a).

In order to estimate the costs of climate change, it is necessary to understand the metrics that can be used to assess them. Determining the metrics will be done based on the costing methodologies employed (described in 3.3 below), data availability, and goals of local government policy makers and other key stakeholders. It is recommended that decision makers take into account their specific context when choosing which costs to measure. For example, in warm cities the impact of heat on morbidity or mortality can be high, and therefore measuring non-market impacts are important. In cities lacking information where uncertainty is a big issue, basing decision on the expected cost might be more accurate than on less precise total cost estimates.
3.2.1. **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 and may occur over the longer term. Examples include firm costs to production due to transport disruptions, interruptions in production due to energy shortages and knock-on effects through the supply chain. These costs may be borne by sectors of the economy that are not directly impacted by the extreme weather event.

Indirect costs can include the diffusion of costs into the wider economy both in the short term (for example, disruption of basic services) and long term (for example, inflation due to a surge in demand, increased energy costs, bankruptcy, increased public deficit, change in housing prices). Other indirect costs include responses to the economic shock (for example, loss of confidence, change in expectations, increased inequality); financial constraints that slow or prevent reconstruction (for example, limited access to public funding and private capital); and technical constraints that hinder reconstruction (for example, lack of skilled workers or materials) (Hallegatte et al. 2011b).

While direct costs are more straightforward to measure and quantify and thus can be assessed with a smaller error margin, an encompassing estimation of the full extent of damages to the city economy is only possible when accounting for indirect costs as well. Indirect costs have the potential of in many cases surpassing direct costs.

When data and technical capacity do not allow for a full measurement of indirect costs, direct costs can still provide a useful method on which to base adaptation decisions. In Section 3.3 we describe methods that measure both direct and indirect impact costs. In the absence of data or technical capacity to use methods to estimate indirect costs, Hallegate (2015) proposes approximating indirect costs by using a simple formula to assess the total consumption loss of a disaster, based on the interest rate and reconstruction duration.

3.2.2. **Market and non-market costs**

Another important distinction is between market and non-market costs. Market impacts can be described as damage to capital or resource flows that can be easily specified in monetary terms based on prices that the market sets to a particular good or service. Non-market impacts can be described as damage to assets that are not traded in a market and are difficult to transfer to monetary values. Examples include 1) the loss of human life, 2) reductions in quality of life (including forced migration, conflicts over environmentally dependent resources, loss of cultural diversity, loss of cultural heritage sites, etc.), 3) loss of species/biodiversity, and 4) increasing inequity in the distribution of material well-being (McCarthy et al. 2001). Together with monetary loss, they are what Schneider et al. (2000) refer to as “the five numeraires”.

For a policy maker deciding on which climate hazards to focus adaptation efforts, using market costs alone has the straightforward benefit of being easier to measure. In addition, it provides an easy to understand metric that enables public support for action on climate change. However, it is important to include non-market considerations when assessing the costs of climate change to cities, particularly in
developing countries, which are more likely to experience more human suffering and mortality due to generally lower adaptive capacity, as opposed to absolute dollar losses.

In Section 3.3 we set out some of the main existing methods to measure and monetize both market costs, such as costs of transport disruption or costs of illnesses due to heat waves, and some non-market costs, such as mortality costs (Subsection 3.3.3). Most valuations of non-market costs are based on the concepts of willingness to accept (WTA) and willingness to pay (WTP). These quantities can either be elicited directly (by asking agents to state their preference) or revealed through their observable choices. A range of methods to monetise non-market costs, including hedonic pricing (a form of revealed preference) and contingent valuation (stated preference), is discussed in Baker and Ruting (2014).

Wherever possible, measuring non-market costs of a hazard along with market costs provides more encompassing estimated of the full costs of the hazard. However, non-market valuation tends to be expensive and time consuming (Baker and Ruting 2014), as well as highly dependent on the valuation method chosen. It can be argued that some non-market costs cannot be measured in purely monetary terms, and require a qualitative assessment (Rothman et al. 2003).

### 3.2.3. Total and expected costs

Finally a decision maker assessing costs of climate hazards might choose to focus on the total cost of an event, measured with certainty, or on the expected cost, which takes into account the uncertainty that often characterizes it. The total cost of a given climate event can be defined as the monetary cost incurred by the city’s economy in result of that event taking place. The expected cost of a given climate event can be defined as the total loss, or cost, generated by the event times the probability of that event taking place.

The notion of expected costs, and its dissection into cost and probability, is very useful in the context of climate change damage costing where events are often characterized by high uncertainty. Some hazards have high probabilities but medium to low costs (this is the case, for example, of a small pluvial flood), while others have low probabilities but very high costs (these are often called catastrophic events).

Although assessing expected costs provides a more detailed estimation of the damages of an event, estimating them often requires defining the probability of an event and projecting economic variables into the (sometimes far) future. In cases where this is not possible, or can only be done with a very large margin of error, the policy maker may need to fall back on using the total cost to estimate damages. We provide descriptions of methods to measure both types of costs in Section 3.3.

### 3.3. LEVEL 3: Damage cost assessment methods

The methods used to assess damage costs will depend on the types of costs to be quantified (level 2 as discussed in the preceding section) as well as the inputs and wider information available to the policy maker (level 4 as discussed in the next section). Many methods have been developed to estimate the costs of climate change. Albeit originally used mostly in the context of mitigation, these methods allow cost measurements of various climate change hazards. Based on Fankhauser (2017), we divide
the existing methods into four main categories: 1) Integrated assessment models (IAMs), 2) empirical/econometric analyses, 3) the science-first approach, and 4) economy-wide simulation models.

Most of these methods can be adapted to measure all of the costs described in Section 3.2. For example, all of them can incorporate uncertainty so as to give us the expected cost of a given hazard. Yet some of them will be better suited to measure this uncertainty. Some are specifically used to deal with market costs, while others can incorporate valuations of non-market costs. Table 1 summarizes how well-suited each category of methods is to measure each type of costs, where no * means the method is not suitable for measuring those costs, one * means they are able to, and ** means they are particularly relevant for measuring a given type of costs.

Table 1 Methods and resulting costs

<table>
<thead>
<tr>
<th></th>
<th>IAMs</th>
<th>Empirical analyses</th>
<th>Science first approach</th>
<th>Economy-wide</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct</td>
<td>*</td>
<td>*</td>
<td>**</td>
<td>*</td>
</tr>
<tr>
<td>Indirect</td>
<td>**</td>
<td>**</td>
<td></td>
<td>**</td>
</tr>
<tr>
<td>Market</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Non-market</td>
<td></td>
<td></td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>Total</td>
<td>*</td>
<td>*</td>
<td>**</td>
<td>*</td>
</tr>
<tr>
<td>Expected</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
</tbody>
</table>

Many methods overlap in some areas. For example, many input-output models follow a science first approach, many IAMs involve a Computable General Equilibrium (CGE) model (a type of economy-wide simulation), and some static or dynamic science first methods cover the entire economy. Thus the categorizations are not necessarily mutually exclusive. Table 2 summarizes the methods, which are discussed in the following subsections, their main uses and types, and sets out some examples.

Table 2 Methods to quantify costs of climate change

<table>
<thead>
<tr>
<th>Methods</th>
<th>Use</th>
<th>Types</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrated Assessment Models</td>
<td>Captures direct and indirect costs; market; total or expected</td>
<td>Traditional</td>
<td>Weyant et al. (1995)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DICE</td>
<td>Nordhaus &amp; Sztorc (2013)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FUND, PAGE, E3ME</td>
<td>Hope et al. (1993)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Uncertainty</td>
<td>Gollub et al. (2014)</td>
</tr>
<tr>
<td>Empirical/econometric analysis</td>
<td>Can capture direct and indirect costs; total and expected; usually market costs</td>
<td>Cross section, panel methods</td>
<td>Dell et al. (2012), Burke et al. (2015), Kocornik-Mina et al. (2015), Lavy et al. (2015)</td>
</tr>
<tr>
<td>Science first approach</td>
<td>Usually focus on direct costs, may include non-market costs, can measure total and expected costs</td>
<td>Static or dynamic</td>
<td>Fankhauser (1995), Boettle et al. (2014), Costa and Floater (2015), Sanchez et al. (2015)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Uncertainty</td>
<td>Boettle et al. (2014)</td>
</tr>
<tr>
<td>Economy-wide simulation models</td>
<td>Include direct and indirect costs; market costs; total or expected</td>
<td>CGE</td>
<td>Boselo et al. (2006, 2007)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Input/output models</td>
<td>Rosenberg (1993), Ford et al. (2017)</td>
</tr>
</tbody>
</table>
3.3.1.  Integrated assessment models (IAMs)

Traditional IAMs (Weyant et al. 1995) feature a stylized representation of climate impacts. These models estimate the social cost of carbon\(^5\) and evaluate different abatement policies. IAMs can be policy evaluation models, which generate paths for the adaptation variables of interest, or policy optimization models, mainly concerned with maximizing an adaptation objective. Traditional IAMs can include adaptation can in the damage function, they are used as a policy evaluation model, as the policy optimization in these models concerns only the mitigation decision.

IAMs couple stylized representations of different systems (e.g. climate, land-use, and economic growth), allowing for an integrated system perspective. The Dynamic Integrated Climate-Economy (DICE) model is the most well-known IAM (Nordhaus and Sztorc, 2013). It is mainly a policy optimization model, which aims at maximizing welfare measured as consumption, but can also be used to generate simple projections. Examples of policy evaluation models, which do not attempt to optimize the economy, are FUND, PAGE and E3ME (Hope et al., 1993, Tol, 2006).

Although IAMs are able to provide an overarching view of impacts and feedback effects between different systems, their calibration is based on large sets of assumptions, and they are not tractable. They have been subject to severe criticism (Pyndick 2013), and processes to evaluate the plausibility of IAMs’ explanatory power have only more recently started to emerge (Schwanitz 2013). Critics focus on the difficulties in calibrating certain inputs (like the discount rate), the lack of theoretical foundations for the prescribed impacts of climate change (the damage function), and the impossibility to study catastrophic climate outcomes, as opposed to moderate ones.

Despite the critics, IAMs can be a useful tool for assessing trends and relationships related to climate change, for example the dynamic ramp-up of adaptation over time (Fankhauser 2017). They are less useful for providing precise estimations that can be directly used in decision making. Thus, when prioritizing hazards, IAMs can be a useful tool for decision makers at an initial stage to help identify high-level relationships, but not for providing a local-scale detailed analysis.

3.3.2.  Empirical methods

Empirical (econometric) studies use historic data and econometric techniques to isolate and quantify the causal effect of a climate hazard to various traditional economic outcomes: for example, agricultural production, country-wide growth, or employment. Some studies judge the effects of temperature shocks (Dell et al. 2012) or catastrophic natural disasters (Cavallo et al. 2013) on economic growth. Other studies evaluate the costs of pollution on educational outcomes and human capital (e.g. Sanders 2012 and Lavy et al. 2015), or on health outcomes (e.g. Currie and Neidell 2005). An overview of existing studies is given by Dell et al. (2014).

These studies have been either cross sectional, time series, or more often, panel data studies. Cross sectional studies compare different regions or settings at only one period of time. They therefore cannot capture adjustments as the economy moves from one state to another. Time series estimates compare the same geographical unit throughout time. Since observable variations tend to be short

\(^5\) The social cost of carbon is the economic cost caused by an additional ton of carbon dioxide emissions or its equivalent (Nordhaus, 2017).
term, the estimated effect is more likely to be of variation in weather patterns as opposed to long-term climatic factors (Fankauser, 2017). Panel data studies use both different geographical units and time units. This allows to surpass the drawbacks of the former two studies, while facilitating the identification of the causal link.

Few studies have been performed at the city level. An exception is Kocornik-Mina et al. (2015), who study the impact of large scale floods in urban settings. They focus on flood events that displaced at least 100,000 people each, in over 1,800 cities in 40 countries from 2003-2008. They use annual data and the timing of the flood events to understand the impact of the flood, the economic dynamics following the flood (if the economy recovers and how long this process takes), and whether there is displacement of economic activity following the flood (if populations adapt by moving productive activity to safer areas).

Well specified empirical studies have the potential to provide an encompassing estimate of the overall economic cost of a climate change event. However, they require large sets of data and technical capacity in order to provide estimates that are robust and isolate the causal impact of a given hazard. Thus it is often not possible to provide robust estimates for one single urban centre, unless the analysis is performed at a disaggregated level (e.g. household). Furthermore, results from empirical studies performed on one geographical area may not be generalizable to a different areas or settings.

### 3.3.3. Science-first approach

Another class of models belong to what we call the science first approach. In these, physical damages are given by climate and engineering models, impact models, and laboratory experiments (Tol 2009). These damages are then used as an input and given a monetary valuation. Methods to value damages depend on the impact. For example, while costs of sea level rise can often be valued by identifying the productive activity taking place in the land lost, health costs require the use of concepts such as the Cost of Illness (COI) or the Value of a Statistical Life (VSL).

These models do not include optimizing behaviour by agents and are usually static, although they can estimate costs across different time periods. They allow users to estimate the direct or indirect impact of a given hazard through one or more specific channels that are chosen a priori.

RAMSES has used the science-first approach to measure the costs of climate change hazards in the city context. Specifically, RAMSES Deliverable 5.2 (Costa and Floater 2015) developed a transferable method to estimate impacts of climate change related hazards to the city economy through various channels. The idea is that each hazard will affect a given productive channel and this productive channel will affect the city’s economy. For example a flood might decrease the capital used in productive activity (by affecting the building stock) or labour by affecting the transport system and causing delays; and a heat wave might affect the labour input by impacts on the transport system or causing productivity decreases. Focusing on one hazard and one productive channel at a time provides a more accurate estimate of costs – though it is only a partial estimate of the full cost of a given hazard to the city economy.

The methodology was used to assess the impact of heat to the urban economy through decreased labour productivity. The model starts from the micro-level evidence that heat induces a decrease in productivity at the individual level and shows how this decrease aggregates into production losses at
the macro/city level. Box 1 presents an example of the model to compute an estimate of future production costs in three case study cities: Antwerp, Bilbao, and London.

Box 1 Heat waves and labour productivity costs

The methodology developed in RAMSES Deliverable 5.2 (Costa and Floater 2015) is used to examine the impact of urban heat waves on productivity loss in three cities: Antwerp, Bilbao and London.

Results suggest that the impacts of heat on the urban economy are highly variable and depend on characteristics of production, such as the elasticity of substitution between capital and labour, and the sectoral division of production. Under certain assumptions, in a warm year in the far future (2081-2100), the total losses to the urban economy could range between 0.4% of Gross Value Added (GVA) for London and 9.5% for Bilbao in the absence of adaptation. The figure below presents an estimation of GVA losses at different points in time. In addition to differences in temperatures, the structure of the city’s economy – in terms of the size of different sectors of the economy - has a major influence on the magnitude of damages, with large urban construction sectors being particularly vulnerable to heat effects.

Heat related GVA losses across time through decreases in productivity (years 2005, and warm and cold years in the near – 2026-2045 – and far – 2081-2100 future); Source: RAMSES Deliverable 5.2, Costa and Floater (2015)

An important consideration when quantifying damages is the uncertainty with which they can be measured (see Section 3.4.3 for a discussion on uncertainty and risk). RAMSES Deliverable 1.2 (Boettle et al. 2014) provides a stimulus and inventory based science first approach to measure damage costs of hazards in incremental units (for example, sea level rise or temperature) and accounting for uncertainty. Here, macro-scale damage functions (at the city scale) are expressed in terms of micro-scale damages to each subset of the city (unit). In that Deliverable, the method has been applied to, amongst others, flood damages in Lisbon and Bilbao.

In this method, a hazard threshold plays a crucial role since it determines at which hazard magnitude the micro-scale damages begin for each unit (measured in km²). The threshold can be modelled by a distribution, and in addition for some cases it exhibits correlations with another quantity – for
example, because elderly people are usually more vulnerable to heat stress (see Section 3.4.2 for a discussion on vulnerability). General uncertainty measures are attached to the expected damages and the different sources are elaborated.

**Box 2 Damage functions and risk ranges: coastal flooding and storms**

The panels (a-c) show damage function components for the case study of coastal flooding in Lisbon, Portugal. The panels (d-f) demonstrate the methodology for storm damage within a building portfolio of 5000 individual buildings. The shaded areas around the damage functions indicate 95% confidence intervals. The insets in (a) and (d) show the damage function on a log-log scale.

In order to translate damage to costs, Deliverable 1.2 uses land cover and land use information to identify the location of assets for determining the associated economic value at risk. Relative damage functions are taken from the Joint Research Centre-Institute for Environment and Sustainability (JRC-IES), who analysed large sets of damage functions across Europe and derived country-specific damage functions covering the direct damages from flooding for a set of land use classes (Huizinga 2007). The values are adjusted by a factor reflecting the economic output of a country measured in terms of GDP per capita using Purchasing Power Standards (PPS). See Box 3 for an example of the results of the method for the city of Bilbao.

**Box 3 Damage costs in the city of Bilbao**

The method conducted in RAMSES Deliverable 1.2 (Boettle et al. 2014) has the advantage of delivering reasonably-detailed flood and damage maps for the regions in question. For the case of Bilbao, the spatial distribution of land cover, inundation depth and expected damages is shown in the graphic below.

The maps also illustrate the work-flow of the approach: (a) data on land cover is combined with (b) hypothetical inundation heights. By applying corresponding damage functions, (c) the resulting damages can be mapped.

The flood depth and damage maps refer to the hypothetical occurrence of a 5 meter flood, a value that is close to the 100-year event in that region. It is evident that the effect of land cover and land use is shaping the overall damages. While the port areas in the north of the map present the highest in-land inundation depths, the economic value to be lost is typically low - between 50 to 100 EUR/m2. The areas at which higher economic damages are expected are those characterized by a continuous urban fabric or industrial land cover types. It can
also be observed that potential damages to the city of Bilbao are somehow confined to immediate surroundings of the Nervion river. One has to keep in mind that the flooding algorithm does not distinguish between coast and river hydrology, that is, the flood that started at the coastal zone penetrates though the river.

Maps of the workflow: from land cover to flood depth to damage. Source: Boettle et al. 2014.

An alternative approach less demanding of modelling, RAMSES Deliverable 6.2 (Sanchez et al. 2015) provides a science-first tool for estimating the economic costs of the health impacts of climate change. It provides a relatively straightforward method for local level decision makers using in a bottom-up approach. Starting from evidence of consequences of different temperatures – for example, illnesses caused by different temperatures – it provides guidance and methods to monetize these consequences. Thus an estimation of the impacts on health of climate change or specific climate-related exposures is needed as basis for the cost assessment.

The tool takes the morbidity and mortality effects of increased temperatures as an input that is external, and measures their costs. However, it provides some guidance on how to attribute health outcomes to climate change. The tool then measures the costs of morbidity (i.e., cases of illness) and premature mortality.

Several methodologies have been developed for the calculation of both market and non-market costs of morbidity which can be readily applied to climate change or climate-related exposures. A commonly used approach is the “Cost of illness” (COI) method which commonly consider direct costs, including health care costs and other costs directly caused by illness like the cost of a caregiver time or direct economic losses; indirect costs, mainly resulting from the loss of productive time or impaired ability to work; and non-market costs reflecting the value associated to the avoidance of pain and suffering. Sanchez et al. (2015) focus on the first two categories, specifically measuring healthcare-related costs and the cost of productive time lost to disease.

Various techniques can be used to ascertain the acceptability of trade-offs at the societal level between risk of death and money. Frequently, these techniques rely on surveys from which a “value of a

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6 In cases where local level data is not available or not reliable, Sanchez et al. (2015) provide sources of European national-level data that can be tailored to the local level.
Statistical life” (VSL) is derived, representing the economic benefit for a given time that a population places on preventing the risk equivalent to one case of premature mortality value. An application of the tool to estimating the economic costs of health impacts of climate change in the city of Skopje, Macedonia, is given in Box 4.

Box 4 Costs of heat-related mortality in Skopje, Macedonia

RAMSES Deliverable 6.2 (Sanchez et al. 2015) conducted a case study on health impacts of heat under climate change in the metropolitan area of Skopje. Using a science first approach, the average annual cost of heat-related mortality is estimated for the periods 2026-2045 and 2081-2100.

Sanchez et al. (2015) use the relationship between ambient air and mortality at baseline (years 1986-2005) and the evolution of the city population and of ambient temperatures, which was modelled under a Representative Concentration Pathway scenario (RCP8.5) in two future time windows: 2026-2045 and 2081-2100. The projected average annual mortality attributable to heat was calculated during those time windows.

In the absence of local studies in Macedonia, EU-wide values from the background studies for the revision of the EU air policy (Holland et al. 2005 and Holland 2014) were used, and the Value of a Statistical Life (VSL) extrapolated through “benefits transfer” (OECD 2010):

\[ VSL_{p} = VSL_{s} \left( \frac{Y_{p}}{Y_{s}} \right)^{\beta} \]

Where VSLs is the original VSL estimate from the study, Ys and Yp are the income levels in the study and policy context, respectively, and \( \beta \) is the income elasticity of VSL (in terms of willingness to pay for reducing the mortality risk). \( \beta \) was assumed to be 1.0 for the general public as suggested by Viscusi (2010). The resulting VSL used for calculation is €571,604 (Low: €376,465; High: €766,744).

This results in the following average annual projected mortality costs in Skopje in million Euros of 2005 without adaptation during the timeframes of 2026-2045 and 2081-2100:

<table>
<thead>
<tr>
<th>Period</th>
<th>Average annual cost of heat-related mortality, in million €</th>
</tr>
</thead>
<tbody>
<tr>
<td>2026-2045</td>
<td>70.87 (48.01 – 97.17)</td>
</tr>
<tr>
<td>2081-2100</td>
<td>154.90 (93.17 – 221.78)</td>
</tr>
</tbody>
</table>

Source: RAMSES Deliverable 6.2, Sanchez et al. (2015). Note: Median VSL value was used; Confidence intervals in parenthesis come from epidemiological evaluation, with population projected through an exponential model.

Finally, in RAMSES Deliverables 3.2 (Ford et al. 2015) and 3.3 (Ford et al. 2017) a science-first approach is used to quantify costs of floods in cities that contains: 1) hazard definition, by means of climate projections and flood modelling; 2) estimation of the hazard impact in terms of disruptions to a city’s transportation network performance, assessing the delays affecting traffic flows; and 3) estimation of cost implications of delays, by assigning a monetary value to the delayed time. A last step is added in the analysis to assess adaptation options (see Section 4).

An alternative approach to assessing the economic costs of disruption is to estimate indirect impacts through the reduction in productive hours at employment locations served by commuting trips. The total reduction in production at a given zone caused by a disruption to a given mode is assumed to be the sum of all delays from all origin locations from where workers travel to that employment zone by that mode. To calculate the economic disruption in that zone, the proportion of the working time for all employees lost due to commuting delays is calculated. This is given by the ratio of total lost time
from disruption to commuting journeys to that zone to the sum of all daily working time in that zone (employees in the zone multiplied by the average working hours in a day (8 hours)). This value is then multiplied by the proportion of all jobs in the zone served by the mode of transport being disrupted. This gives a measure of the cost of disruption to that zone’s economic output. Options to calibrate these values are presented in RAMSES Deliverable 3.3 (Ford et al. 2017).

The models described in this subsection have the benefit of being tractable, but they do not offer a complete picture of the full macroeconomic or dynamic effects that take place when the economy readjusts to equilibrium. They are therefore less suitable to make long term predictions about trends. Contrary to IAMs, they can easily be used at the city level to cities of any size. Specifically, they can be useful for smaller sized cities, while IAMs are more useful at a more aggregate level.

3.3.4.  Economy-wide simulation methods

3.3.4.1. Computable general equilibrium

Computable General Equilibrium (CGE) models for climate change have been mainly concerned with assessing impacts of damages. Some have also started to include adaptation (see Section 4.3.1. CGE models usually model a shock to an exogenous variable (for example, an increase in temperature) and how it affects several endogenous economic variables (for example, employment, output or prices). CGE models are often, but not necessarily, part of IAMs.

CGE models consist of a system of equations that define the microeconomic behaviour of several agents of the economy, who optimise their consumption (households) or profit (firms). These agents interact in different markets that are interconnected. For example, Bosello et al. (2007, 2008) use CGE modelling to assess the economy-wide impact of climate change through its impact on, respectively, sea level rise and health. They use estimates of the effects of climate change on their variable of interest and introduce them in their modelled economy.

Relative to the science-first approach described in Section 3.3.3, CGE models have the benefit of including feedback processes between the effects in different markets and therefore can offer a long-term perspective. However, it is more difficult to trace the causes of final effects due to the computational complexity required. The latter also means that for local governments, often with limited technical capacity, this type of model might not be feasible. Furthermore, results are highly dependent on the choice of growth model used, as well as on the estimated physical damage which is taken as given from the perspective of the analysis. As in the case of IAMs, CGE modelling can be useful to identify general relationship, particularly at an aggregate level, but are less valuable to provide local-level precise estimates, specifically for small and medium sized cities.

3.3.4.2. Input-output models

Input-output (I-O) models apply multipliers to estimate the economy-wide impact of an initial change in economic activity. They study how the initial shock propagates through the economy through intermediate consumption and demand.
I-O models take into account how outputs of one industry or sector become input of another industry or sector. For this, they use a matrix representation of a national or regional economy - the input-output matrix - which describes the monetary value of each sector’s inputs and outputs relative to every other sector.

Input-output tables have very large data and computational requirements. Nevertheless, sources exist for national level input output tables, as well as inter country tables. The World Input-Output Tables (WIOT) cover 43 countries and a model for the rest of the world for the period 2000-2014. Data for 56 sectors are classified according to the International Standard Industrial Classification revision 4 – ISIC Rev. 4 (Timmer et al. 2015). The OECD offers harmonised national I-O tables with matrices of inter-industrial flows of goods and services (produced domestically and imported) for all OECD countries and 27 non-member economies (including all G20 countries), covering the years 1995 to 2011, as well as Inter-Country Input-Output (ICIO) tables.

In RAMSES Deliverable 3.3, Ford et al. (2017) apply an I-O methodology to measure the impact of pluvial flooding to the London economy. They use the results of the modelling of flooding to estimate its impact on the London transport network and its costs as measured by lost time at work, and use I-O tables to assess the economy-wide, direct and indirect, economic impact. Box 5 presents the results of this analysis.

**Box 5 I-O estimation of flood costs in London**

<table>
<thead>
<tr>
<th>Sector</th>
<th>Description</th>
<th>Total disruption cost through one channel</th>
<th>Economy-wide costs (I-O)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>Manufacturing</td>
<td>£6.550 million</td>
<td>£4.972 million</td>
</tr>
<tr>
<td>F</td>
<td>Construction</td>
<td>£10.631 million</td>
<td>£10.238 million</td>
</tr>
<tr>
<td>G</td>
<td>Wholesale and retail trade</td>
<td>£17.562 million</td>
<td>£16.509 million</td>
</tr>
<tr>
<td>H</td>
<td>Transportation and storage</td>
<td>£10.847 million</td>
<td>£8.924 million</td>
</tr>
<tr>
<td>I</td>
<td>Accommodation and food</td>
<td>£5.432 million</td>
<td>£6.676 million</td>
</tr>
<tr>
<td>J</td>
<td>Information and communications</td>
<td>£16.187 million</td>
<td>£18.484 million</td>
</tr>
<tr>
<td>K</td>
<td>Financial and insurance activities</td>
<td>£24.819 million</td>
<td>£31.341 million</td>
</tr>
<tr>
<td>L</td>
<td>Real estate activities</td>
<td>£19.037 million</td>
<td>£18.975 million</td>
</tr>
<tr>
<td>M</td>
<td>Professional, scientific, technical</td>
<td>£16.909 million</td>
<td>£18.858 million</td>
</tr>
<tr>
<td>N</td>
<td>Administrative and support</td>
<td>£10.603 million</td>
<td>£10.301 million</td>
</tr>
<tr>
<td>O</td>
<td>Public administration and defence</td>
<td>£6.043 million</td>
<td>£7.381 million</td>
</tr>
<tr>
<td>P</td>
<td>Education</td>
<td>£11.070 million</td>
<td>£10.486 million</td>
</tr>
<tr>
<td>Q</td>
<td>Human health and social care</td>
<td>£10.201 million</td>
<td>£9.999 million</td>
</tr>
</tbody>
</table>

Source: RAMSES Deliverable 3.3 (Ford et al. 2017)
For the economy-wide impact of adaptation, Hallegate (2008) proposes the Adaptative Regional Input-Output (ARIO) model. It accounts for changes in productive capital loss following a climate disaster, but also for adaptive behaviour following the disaster (see Section 4.3.1).

I-O models are a type of science first approach, as they require an initial estimation of the impact of the damage a given hazard would cause in a given productive input. For example, in Ford et al. (2017) an assessment of the impact of a flood on transport disruptions in a city needs to be modelled prior to the economic estimation. However, they are distinguished from the models in Section 3.3.3 because they aim at estimating not only the impact of the hazard through one channel, but how it propagates through the whole economy. In this sense, they are more comprehensive but also much more demanding in terms of detailed economic data.

I-O models are particularly useful to understand the scale of indirect costs relative to direct costs. Estimates of climate change impact costs using I-O tables often give rise to indirect costs that are much larger than the initial direct impact. Relative to CGE models, I-O is more suitable for detailed, bottom-up analysis. However, it is not able to capture the equilibrium behaviour of prices, markets, and substitution between production inputs (Rose et al. 2000).

3.4. LEVEL 4: Inputs

In order to decide which climate hazards represent a larger impact to the city’s economy and therefore represent more need for adaptation, decision makers need to understand how current and future climate is going to impact the urban centre. This section describes the city-specific hazards affecting the economy and how to assess a city’s vulnerability to them. It also introduces the concept of risk, and how it affects the estimation of climate hazard damages.

3.4.1. Hazards and exposure

Different cities are exposed to different climate change hazards. According to RAMSES Deliverable 8.2 (Mendizabal et al. 2016), exposure refers to the presence of people, livelihoods, species or ecosystems, environmental services, resources, infrastructure, or economic assets, social, or cultural sites that could be affected or adversely impacted by a hazard.

Climate-related hazards affecting cities include extreme weather events, such as sea and tidal flooding, inland flooding (fluvial and pluvial), heat waves, storms, drought, landslides, wild fires and snow storms; as well as slow-onset events such as sea level rise, mean temperature increase, rising air pollution, or the spread of invasive species and diseases. Each city is affected by different hazards in specific ways that will dictate which threats are most costly to the city. Globally, three of the main economic threats of climate change affecting cities are heat stress/heatwaves, floods, and droughts. The remainder of the section focuses on identifying the costs related to each.
3.4.1.1. **Heat waves**

Higher temperatures tend to be more frequent and prolonged in cities than in rural areas. This is known as the urban heat island effect (IPCC 2007). The relative warmth of cities is due in part to the extensive use of concrete and asphalt, a lack of shade-bearing vegetation and moisture-trapping soils, and the production of excess heat from equipment such as air conditioning. Built surfaces are composed of a high percentage of non-reflective and water-resistant construction materials that absorb sunlight and incident radiation, releasing heat. The urban heat island effect is expected to be exacerbated by climate change. Indeed, the difference in temperature between cities and rural areas could increase by 1°C per decade (Voogt 2002).

One of the most important consequences of increased urban heat waves is the impact on human health. Higher temperatures result directly in increased mortality rates, and indirectly through famine, exacerbation of non-infectious health problems and the spread of infectious diseases (OECD 2010). In addition, heat exhaustion and heat stroke can exacerbate a wide range of medical conditions, particularly in vulnerable groups such as the elderly and children.

Another major impact of high temperatures is a decrease in labour productivity through its impact in individual body temperature. As temperature increases above a certain threshold, workers become less able to perform both physical and cognitive tasks, thereby decreasing their productivity. RAMSES Deliverable 5.2 (Costa and Floater 2015) finds that reduced worker productivity due to heat waves could translate by 2100 into annual costs of up to 10 per cent of a city’s economic output in northern Europe without associated adaptation measures (Costa et al. 2015). Higher temperatures may also possibly affect health by exacerbating air pollution (Harlan and Ruddell 2011), though the evidence for this is as yet uncertain.

Heat waves can damage transport infrastructure with associated disruption costs. If temperatures reach between 39 and 43°C, railway tracks can buckle and deform (Dobney et al. 2009). In addition, increased temperatures tend to increase energy demand through the intensified use of air conditioning. Global energy demand for air conditioning is projected to increase rapidly over the 2000–2100 period, while overall winter heat demand may decrease in cities in cooler regions.

Finally, changes in temperatures could also affect health by increasing the concentrations of outdoor air pollutants, such as ozone and acid aerosols (Bernard et al. 2001), as well as by decreasing water quality because the flow of warmer waters into area streams increases stress on their ecosystems.

Effects of temperature increases are heterogeneous and can usually be felt across economic sectors. It can be therefore challenging to measure its impacts across the entire urban economy. While econometric studies based on historic data can be projected into the future to estimate overall costs (see Section 3.3.2), it can be useful to focus on one channel alone (for example, labour productivity losses) to understand the impact to different sectors and under which conditions (see Section 3.3.3).

3.4.1.2. **Floods**

Urban flooding is a major climate change hazard. Costs of flooding include direct damage to buildings and their contents (both residential and commercial), disruption of transport networks due to flooded rail tracks, roads and underground systems, and associated disruption of business activities (Floater et al. 2014c). Severe flooding may limit access to water and electricity, with important impacts to the urban economy, while human health can be affected as sewage systems overflow and water-borne diseases are spread more extensively. It can be sea flooding or pluvial and fluvial flooding.
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. This will be exacerbated as sea levels are predicted to increase significantly by 2100 (IPCC 2014). Globally, damages from sea flooding are thus expected to rise substantially over the coming decades, both due to the urban growth of coastal cities and increased threats from climate change. Recent research suggests that damages from sea flooding in the 136 largest coastal cities in the world could exceed $993 billion a year by 2050 (Hallelegatte et al. 2013). With city ports being central to international trade, costs in wider regional economies are also likely to increase.

Inland flooding occurs as a result of rainfall (pluvial flooding) or due to river overflows (fluvial). Due to the large amount of sealed surface areas in the urban landscape, more frequent and severe precipitation causes a larger incidence of flash floods in cities. Flash floods are rapid inland floods caused by intense rainfall, with the fast flow of water resulting in high destructive potential (EM-DAT 2014). As with the case of sea flooding, the impacts to the city are felt mainly in terms of destruction of infrastructure and human health. The increase of precipitation and related floods in cities could cause sanitation problems as well as a reduction of water quality, with important consequences in terms of health risks for its population. Hence, an increase of the intensity and frequency of floods requires a response at the city level in terms of better drainage infrastructure, water treatment facilities, surface water management, and sewage systems. New developments can minimise the negative effects of inland flooding through a combination of avoiding the highest risk locations and flood proof building design (Houston et al. 2011).

During the past 10 years, in the European Region, 1000 persons are reported to have been killed by floods and more than 3.4 million affected (Jakubicka 2010). These events also have an impact in mental health. The occurrence of adverse psychiatric outcomes as a result of natural disasters – such as post-traumatic stress disorder, major depression, or somatoform disorder – is well documented (Norris et al. 2002).

### 3.4.1.3. Droughts

The EEA (2011, p.54) defines a drought as the “sustained and extensive occurrence of below average water availability, caused by climate variability”. It originates from a low precipitation and high evaporation rates over an extended period of time and can be of various durations (from months to years).\(^7\)

Drought can lead to a range of impacts in cities, including building subsidence, water shortages, power failures as less water is available for hydro generation and for cooling nuclear plants, and increased health risks. Drought in the surrounding agricultural region of a city can also result in food shortages, along with increased rural to urban migration.

One of the main impacts of drought in cities is water shortage, particularly in developing countries. Today, around 150 million people are estimated to live in cities with perennial water shortages, and this figure could rise to 1 billion people by 2050, largely due to rapid urbanization in Asia (McDonald et al. 2011; IPCC 2014). The health impacts associated with droughts also include increased risks of diseases, malnutrition and famine (Logar and van den Bergh 2011).

Drought can lead to extensive subsidence as the ground under buildings changes in volume due to water loss. Drought can also have less obvious effects on building stock. For example, despite being

\(^7\) Although in cold areas droughts can also originate from temperatures below zero (van Lanen et al. 2007).
located on a canal system, the City of Amsterdam has become increasingly aware that a large proportion of the city’s buildings are at risk from periods of reduced rainfall, as the traditional houses are built on wooden piles that dry out and crumble if the water level drops.

### 3.4.2. Vulnerability

Cities are vulnerable to climate change hazards in specific ways that differ from non-urban areas (IPCC, 2014). Climate vulnerability can be defined as the ‘inability to cope with external changes including avoiding harm when exposed to a hazard’, which includes ‘people’s inability to avoid the hazard, anticipate it, and take measures to avoid or limit its impact; cope with it; and recover from it’ (Revi et al. 2014, p. 547). In accordance to this, the RAMSES Handbook (Mendizabal et al. 2017) states that the vulnerability of a territory depends on the sensitivity or susceptibility to damage and the ability of such territory to cope and adapt.

Compared to rural or small urban areas, cities have large and concentrated populations, a high concentration of buildings, extensive and interdependent infrastructure networks and concentrated economic activity (Satterthwaite et al. 2007; OECD, 2010). These all pose specific risks for cities. The effectiveness of health and emergency services also determines a city’s vulnerability where high concentrations of people may be affected by a natural disaster. Furthermore, cities in developing countries are often more vulnerable due to rapid urban population growth, higher levels of poverty, extensive slums, low quality infrastructure and greater future exposure to climate hazards (Hunt and Watkiss 2011).

Given the large combination of characteristics that affect a city’s vulnerability, and the extensive data and information required for its analysis, assessing the vulnerability of any one city is a major task (Hallegatte and Corfee-Morlot 2011). For example, damages from a hurricane will likely depend on a city’s proximity to the coast, the quality of its buildings, the location of populations and key infrastructure within the city, the main economic sectors of the urban economy and the preparedness of people and government services to respond. In this subsection, we attempt to simplify this complexity by examining four broad characteristics that make cities particularly vulnerable to climate-related hazards: location, infrastructure, economic activity and people.

#### 3.4.2.1. Location

At the regional scale, cities lying in a hurricane belt, on a low-lying river delta or in a high temperature zone will tend to be more vulnerable to climate-related hazards simply due to their geographical location. One of the highest socio-economic risks from climate change is urban coastal flooding, with 65 per cent of large cities located in low elevation coastal zones (McGranahan et al. 2007). Coastal assets exposed to climate risks are an estimated $3 trillion globally, and this could rise to $35 trillion or 9 per cent of global gross domestic product (GDP) by 2070. Coastal infrastructure assets in rapidly developing Asian port cities, such as Guangzhou, Shanghai and Kolkata, are particularly vulnerable (Nicholls et al. 2008; OECD, 2010).

The topography of a city and its surrounding environment can also increase its vulnerability to climate hazards. Low-lying districts are more prone to flooding, while neighbourhoods located on or near steep slopes may have higher risks of landslides following storms and flooding. For example, the mountains around Rio de Janeiro have been progressively deforested over time and as a result are now prone to landslides, decomposition and erosion (Sherbinin et al. 2007).
3.4.2.2. **Infrastructure**

Cities rely on extensive infrastructure systems to support them, making them more vulnerable to climate impacts than less urbanized areas (OECD 2010). Well-functioning urban infrastructure is essential for providing public health and safety, supporting economic productivity, reducing social exclusion and promoting the overall well-being of residents (Rode et al. 2014).

Buildings, water distribution networks, sewage systems, energy networks, transport systems and communication grids are all potentially vulnerable to extreme weather events (Revi et al. 2014). Furthermore, a disruption in one system produces cascading effects across others, reducing economic efficiencies and imposing costs on the local and national economy. For example, a disruption to energy infrastructure can impede the delivery of electricity to homes, offices and factories, as well as transportation networks and electronic communication.

The quality and positioning of infrastructure also influences its vulnerability to hazards. For example, transport networks located in low-lying areas and underground are more vulnerable to flooding. Flooding of the underground metro system in London cost more than $12 million in passenger delays between 1999 and 2004 (Arkell and Darch 2006). At the same time, heat waves in London are now an increasing threat to buckling rail lines that are not manufactured to withstand high temperatures. Similarly, the quality of a city’s storm water drainage and sewage system can determine its vulnerability to pluvial flooding.

Energy and digital networks are key to a city’s resilience as many other types of infrastructure and economic sectors rely on energy. For example, in New York City, flooding from Hurricane Sandy disrupted a third of the city’s electricity generating capacity and parts of its natural gas distribution system, leaving 2 million city-dwellers without electricity and 80,000 households without gas (City of New York 2013). The New York Stock Exchange closed for two days, while hospital patients had to be evacuated as emergency power failed.

Flooding and storm damage to poorly adapted buildings is one the highest risks that cities face from climate change. Elevation, construction materials, number of floors, presence of a basement, shape and age all influence a building’s vulnerability to flooding and storms (Acero et al. 2013). Buildings are also often the first line of protection for people. Housing protects people from weather-related injuries, damage and displacement, especially infants, the elderly and those with disabilities or illness (Revi et al. 2014). Consequently, people living in low-quality housing face higher risks. For example, a United Nations study on the slums of Ethiopia’s capital, Addis Ababa, found that half of the houses had mud floors, and most had corrugated iron roofs or no ceiling at all (UN Habitat 2006). These fragile shelters are typical of informal settlements around the world.

3.4.2.3. **Economic Activity**

Cities concentrate economic activity (Hallegatte et al. 2011a). As a result, natural disasters can lead to an immediate contraction in economic output, reduce tax revenue, limit investment opportunities, deteriorate fiscal balances and exhaust funds for infrastructure and innovation (OECD 2010). Additional costs of climate-related hazards include productivity loss, provision of emergency and post-disaster aid, transport disruption, increased healthcare expenses, relocation and retraining, lost heritage and urban ecosystem damage; all of which can reduce a city’s competitiveness.

The composition of a city’s economic activity can play a significant role in the vulnerability of an urban economy. For example, a city with a large manufacturing sector may be more vulnerable to...
disruptions in electricity supply and transportation networks due to pluvial flooding. While a city with a large construction sector may suffer disproportionately from reduced worker productivity due to outdoor heat exhaustion. Cities with a large tourism sector may become less attractive to visitors in peak summer seasons (Revi et al. 2014). Similarly, if vulnerable to climate hazards, cities with large finance or high-tech sectors may become less attractive to international high-skilled workers, who may compare cities on their quality of life.

### 3.4.2.4. People

Vulnerable individuals and social groups tend to be less able to avoid a hazard, anticipate it, limit its impact, cope with it or recover from it (Revi et al. 2014). Factors that influence social vulnerability include a lack of access to quality housing; basic infrastructure and services such as water, transportation, energy and sewage; income and technological resources; social networks and connections (Cutter et al. 2003). In addition, age, illness, disability, gender and ethnicity can all increase individual vulnerability.

Poverty increases people’s vulnerability. Residents of informal settlements often occupy the cheapest land, which may be prone to flooding such as the Dharavi slums in Mumbai (Ranger et al. 2011) or landslides such as the favelas of Rio de Janeiro. Globally, the numbers of people at risk are substantial. In 2001, 924 million people lived in slums: 32 per cent of the world’s population (UN Habitat 2003). In Mumbai alone, half the population live in slums. As the global population grows rapidly over the next decades (particularly in sub-Saharan Africa and Asia), the concentration of urban poverty, inadequate services and informal settlements are likely to increase substantially (Floater et al. 2014b).

The urban poor typically live in substandard housing made of cheaper materials such as mud, corrugated iron and wood, which increases the likelihood that they will be damaged or collapse from high-intensity storms (OECD 2010). Even in the richest countries, lower income groups tend to be more at risk. For example, the poorer communities in New Orleans were disproportionately impacted by Hurricane Katrina (Logan 2006; Masozera et al. 2007). Extreme weather may also increase urban poverty if income levels drop, home enterprises are destroyed or government benefits and services are constrained following a disaster.

Children and the elderly tend to face higher risks of extreme weather due to their physiology. Older people are more prone to heatstroke and are more susceptible to disease. Similarly, children have a higher disease risk as their respiratory and immune systems are not fully developed (Bunyavanich et al. 2003), while they are also less able to care for themselves, communicate effectively and employ coping skills during a disaster (Wisner et al. 1994).

### 3.4.3. Risk and uncertainty

Climate change impact costing is subject to a wide range of uncertainties. First and foremost, there are large uncertainties in the forecast of future climate conditions. This stems from uncertainties over natural climate fluctuations, future emissions of greenhouse gases by human society (uncertain future scenarios), and the climate’s system’s response to concentrations of greenhouse gases (imperfect representation of climate and engineering models).
Additionally, future demographic and economic scenarios are difficult to predict, and models of economic behaviour are subject to an additional layer of uncertainty, and these uncertainties interact with each other. Climate change is associated with conditions of deep uncertainty, describing a situation where the probability distributions can be unknown and there is scarce knowledge about the possible outcomes (Lempert et al. 2004).

One reason for the difficulty in measuring costs of climate change and evaluating adaptation options is the fact that each step of the evaluation is associated with some degree of uncertainty, which implies that the uncertainty is multiplied at each step, to the extent that the estimated impacts to the economy are measured with potentially very large error. This is often called the cascade of uncertainty (Schneider 1983) or uncertainty explosion (Henderson-Sellers 1993).

Figure 7 represents the cascade of uncertainty when measuring the costs of climate related hazards. Added to the uncertainty over climate, economic and demographic scenarios, and climate, engineering and economic models, is uncertainty related to measurement error and subjective judgement. In order to prioritize climate hazards, it is necessary to understand the exposure and vulnerability of the urban economy, but also to account for this uncertainty. Methods that account for uncertainty, giving rise to expected as opposed to total costs, are described in Section 3.3.

Figure 7 The cascade of uncertainty in measuring costs of climate change

The UNDP (2005) defined climate risk as ‘the result of interaction of physically defined hazards with the properties of the exposed systems – i.e., their sensitivity or (social) vulnerability. Risk can also be considered as the combination of an event, its likelihood, and its consequences – i.e., risk equals the probability of climate hazard multiplied by a given system’s vulnerability’.

A risk analysis would, at a first stage, assess exposure. Where historic data is available, it might be possible to quantify the uncertainty, that is, to assess the probability associated with a given event. This can be done with the help of statistical methods that analyse the mean and variance of time series data, such as maximum likelihood. Monte Carlo simulations can also be used based on fitted time
series models: by simulating the time series many times one can calculate the probability of an extreme event occurring.

Where good time series data is not available, it might still be possible to identify upper and lower bounds to risk using available information, which can be used to describe risk. In other cases it might be necessary to base decisions on the subjective judgement of the level of risk by experts (Willows et al. 2003). Wherever possible, this should be done by pooling several experts and analysing different judgements of risk. These approaches predict risk in order to assess which is the best policy option.

Recently some approaches have been proposed for decisions under deep uncertainty that proceed in the opposite manner, called assess-risk-of-policy, as opposed to predict-then-act. They start with available policy options and compare uncertainties associated with these (Lempert et al. 2004). This approach can be useful in cases where uncertainty is hard to quantify, as it provides a wider range of options for decision-makers to hedge risk, and an estimation of residual risks. However, it can also be more computationally challenging, and it requires more subjective judgement. Whenever data and models are available to provide reasonably robust estimations of probabilities, predict-then-act approaches such as the one followed in this deliverable tend to be more rigorous.

3.5. **Conclusion: estimating damage costs**

Levels 2, 3 and 4 of the cost assessment framework describe a process for estimating damage costs to a city’s economy. The process is iterative, and starts from the bottom up, first by providing guidelines for identifying relevant climate hazards and judging a city’s exposure and vulnerability (level 4 inputs). These are complemented with a process for identifying uncertainty and thereby assessing risk either quantitatively or qualitatively.

Following this analysis, it becomes necessary to identify a method for quantifying economic costs (level 3 methods). The method should be chosen according to the hazard in question and its characteristics in terms of risk and uncertainty, the type and quality of data available, and the type of costs most relevant for the decision maker (level 2). Only after quantifying these damages is it possible to compare the relative costs of given hazards and thereby estimate damage costs based on their associated risk.

The process for prioritising which climate hazards a decision maker should target with adaptation efforts cannot be performed in isolation. The results in Phase 2 feed into the analysis of Phase 3/4 for costing the net economic benefits of adaptation. Similarly, the analysis of net economic benefits of adaptation, as well as the analysis of finance mechanisms in Phase 5, will to some extent determine which hazards limited resources should be directed at.
4. Identifying and assessing adaptation options: economic benefits

4.1. Level 1: the Handbook Phase 3 and 4

4.1.1. What is phase 3/4?

While Phase 2 of the RAMSES Transition Handbook provides guidance on assessing hazards and vulnerability, Phase 3/4 focuses on how to identify and assess adaptation options in response to those hazards and vulnerabilities. The Handbook splits the assessment of adaptation options into two phases: Phase 3 – identifying adaption options, and Phase 4 – assessing and selecting adaptation options. For the cost assessment framework, these are integrated into one phase which we call Phase 3/4. The various steps in Phase 3/4 of the Handbook are set out in Figure 8 and Figure 9. Figure 8 shows the steps for identifying adaptation options, while Figure 9 shows the steps for assessing those options.

Phase 3/4 aims to identify a wide range of adaptation options to address the risk of climate-related damages or to take advantage of any positive opportunities that arise from climate change. In the first stage, the aim is to identify alternatives and possibilities to respond to challenges and opportunities, among which policy makers can choose those that best suit the nature of the threats faced and the territorial and institutional context. This phase facilitates an exploration of potential adaptation options and helps identifying relevant actions, and their potential co-benefits.

When adaptation options have been identified, the second stage is to assess and prioritise the compilation of options based on a detailed description and criteria. Based on the outcomes of the previous phase, the aim here is to assess and prioritize the most efficient and appropriate measures to be implemented for climate change adaptation in the city. The selection of preferred adaptation options should be conducted in close interaction with all actors involved in the adaptation process.

Figure 8 Transition Handbook Phase 3/4: identifying adaption options
4.1.2. How cost assessments can support Phases 3 and 4

Cost assessments form an important component of identifying and assessing adaptation options. As set out in section 2.2, the cost assessment framework has four levels. For phase 3/4, these levels are set out in Figure 10. Level 2 quantifies the economic net benefits of different adaptation options, which can feed into the Handbook Phase 3/4 (level 1) alongside other quantitative and qualitative evidence for decision making that are not included in the cost assessment framework. Economic net benefits include averted losses due to adaptation alongside the implementation, opportunity and other costs associated with the adaptation measure. At level 3, policy makers will need to make choices between different assessment methodologies for estimating economic net benefits. These choices will depend in part on the level 4 data and information available on the range of available adaptation measures, their implementation costs and the timing of adaptation together with decisions on appropriate discount rates to use. Each of these levels is discussed in more detail in the following sections of this chapter.
Determining the optimal approach to adaptation needs to be an iterative process. While initial options can be suggested in the absence of the cost to implement, narrowing down those options will need to include some knowledge of the cost. In addition to just the ‘ticket price’ of the option, decision-makers will need to consider other costs such as the timing of the measure (short-term implementation for more immediate threats, versus more distant implementation timeframes for impacts/events considered less immediate) and the nature of the expenditure (e.g. one-off versus recurring). These can be balanced against estimates of the economic benefits of the action. With these costs and estimates of the avoided costs from adaptation, the initial listing and provisional prioritisation of adaptation options can be reviewed and refined.

4.2. LEVEL 2: Quantifying economic benefits

4.2.1. Costs and net benefits of adaptation

At level 2 of the cost assessment framework, adaptation options are costed. Interventions may range from cost-neutral / low-very low cost (e.g., wearing lighter clothes) to very high cost (e.g., large-scale investments required to deliver major infrastructure projects such as flood barriers). The cost of the adaptation measure, however, is only one side of the knowledge needed for effective adaptation planning and implementation. The cost needs to be compared to the benefits (avoided costs / avoided damages) that the adaptation provides, thus leading to a net cost or benefit.

The cost of an adaptation measure refers to the cost that the city incurs in order to adopt that adaptation measure. The city cost may be borne by the municipal government, but may also be borne by private individuals or businesses (see Section 4.2.2). The cost may include the installation costs of the measure, maintenance and running costs (for example, the cost of running an air conditioning
system in terms of energy), or both. The installation costs usually include both the material and the labour cost. Section 4.4.2 provides examples of costing adaptation from the RAMSES project that can be used as level 4 inputs into the cost assessment method chosen.

The averted loss defines the loss that has been avoided due to the implementation of one or more adaptation measures and is calculated as the loss occurring in the absence of adaptation minus the residual loss after adaptation. The averted loss of an adaptation measure corresponds to the benefit of the measure. The two concepts are used interchangeably in the remainder of the document. These level 3 methods to assess the benefit of a given adaptation measure are set out in Section 4.3.

Finally, the net benefit of an adaptation measure corresponds to the full benefit/averted loss net of its cost. This quantity is essential in order to evaluate the effectiveness of adaptation, and methods to measure it are also described in Section 4.3.

The costs and benefits of adaptation, similarly to the damage costs, may be direct (for example, the cost of installing and using air conditioning, and its benefit in terms of increased productivity) as well as indirect (for example, the cost to the economy of a possible effect of increasing energy prices). They can be market (such as the benefit of increased productivity due to air conditioning use on GDP) and non-market (such as the cost of wearing lighter clothes to protect against heat), and total or expected (if measured accounting for uncertainty).

### 4.2.2. Who bears the costs and the benefits

An important issue when assessing the costs and benefits of adaptation is that of who incurs in costs of adaptation, and who collects its benefits. Adaptation might be a public good in the sense that it provides benefits for the population and individuals cannot be effectively excluded from its use (non-exclusion) and use by one individual does not reduce availability to others (non-rivalry). An example of this is a flood barrier. On the other side of the spectrum, adaptation might benefit uniquely an individual entity (whether this is an individual, a household, or a firm). An example of this is the use of lighter clothes in warm days.

In the absence of market failures or fictions, those who collect the benefits should bear the costs. But in reality the provision of adaptation goods is subject to externalities: for example, by protecting their own house, individuals might be increasing flood risk in neighbouring houses – negative externality; and by reducing productivity losses a firm will provide benefits to the larger economy through the supply chain – positive externality. There are also problems of lack of capacity, as many times the scale of the investment necessary means that private entities cannot bear its costs, or lack of information to make a case for adaptation. In these situations, while private individuals might accrue benefits of adaptation, the public sector might need to intervene either by providing adaptation goods or facilitating their provision.

The main barriers for market adaptation, requiring government intervention, are listed by Urwin et al. (2008):

- Transaction costs, information, and adjustment costs
- Market failures and missing markets
- Behavioural obstacles to adaptation
- Ethics and distributional issues
- Coordination, government failures and political economy
- Uncertainty

The role of the private sector in adaptation is discussed by Surminski (2013). The study discusses the lack of evidence of costs of climate change at the individual firm level, and the expectation of policy makers about private sector adaptation. In order to increase the role of private adaptation provision, the paper argues for the need for capacity for adaptation especially for small and medium enterprises, defining private role not only for extreme events but also slow onset events; and ways to measure the effectiveness of private-sector adaptation.

Finally, Tompkins and Eakin (2012) find that an increasing feature of climate change adaptation planning is privately provided adaptation public goods. An example of these is planting gardens with grass instead of pavement around private houses, thereby decreasing risk of flooding in the area around, as well as contributing to diminishing local temperature. In cases where private provision of adaptation public goods is possible, the government can intervene to facilitate the provision of these goods.

**Table 3 Bearers of costs and benefits of adaptation**

<table>
<thead>
<tr>
<th>Providers</th>
<th>Beneficiaries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Private</td>
<td><em>e.g.</em> buying sand bags to limit home flood damage*&lt;br&gt; <em>e.g.</em> urban flood risk reduction via intentional rural flooding</td>
</tr>
<tr>
<td>Public</td>
<td><em>e.g.</em> grants for house insulation to reduce cold / heat stress&lt;br&gt; <em>e.g.</em> global climate models; “Em-dat” hazards database</td>
</tr>
</tbody>
</table>

Source: Tompkins and Eakin (2012)

### 4.3. LEVEL 3: Adaptation cost assessment methods

Methods to evaluate adaptation economically (Phase 3/4 of the cost assessment framework) are more recent and relatively scarcer than those to measure the damage costs of climate change in Phase 2. However, they are closely related: in many cases the same methods can be used to measure both the damage costs of climate change and the relative benefits of adaptation actions, while in many other methods measuring the damage costs of climate events is a first step towards evaluating adaptation.

Given the overlap, and following Fankhauser (2017) and Watkiss (2015), both of whom focus on assessing adaptation, existing methods for adaptation cost assessment are divided into four main categories: 1) methods that are also used to measure costs of climate change as introduced in Section 3.3 (IAMs, empirical analysis, the science-first approach, and economy-wide simulation models; 2) traditional economic decision support tools (including cost-benefit analysis, adaptation cost curves, cost-effectiveness analysis, and multicriteria analysis); 3) uncertainty framing (iterative risk management; and 4) economic decision making under uncertainty (including real options analysis, robust decision making, portfolio analysis, and rule-based decision support for uncertainty). These are summarized in Table 4 and described in the following subsections.
An analysis of some of these and a critical assessment of their use and data requirements is offered by Watkiss (2015). Thus in this deliverable we only complement the information by adding other available methods, as well as offering a city perspective.

Table 4 Methods to evaluate costs and benefits of adaptation

<table>
<thead>
<tr>
<th>Methods</th>
<th>Types</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methods that measure costs and benefits together (methods also used to</td>
<td>Integrated assessment models (AD-DICE, AD-RICE, WITCH)</td>
<td>De Bruin 2011, de Bruin and Dellink 2011, de Bruin et al. 2009, Bosello et al. (2010)</td>
</tr>
<tr>
<td>measure damage costs)</td>
<td>Empirical (econometric) analysis</td>
<td>Kocornik-Mina et al. (2015), Burke &amp; Emerick (2016)</td>
</tr>
<tr>
<td></td>
<td>Economy-wide simulation models</td>
<td>Hallegate (2008), Ford et al. (2017)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traditional economic decision support</td>
<td>Cost-benefit analysis (CBA) – including ACCs</td>
<td>Graham (1981)</td>
</tr>
<tr>
<td></td>
<td>Adaptation Cost Curves (ACCs)</td>
<td>Grant et al. (2011), Costa et al. (2016)</td>
</tr>
<tr>
<td></td>
<td>Cost-effectiveness analysis (CEA) and</td>
<td>Boyd et al. (2016)</td>
</tr>
<tr>
<td></td>
<td>Multicriteria analysis (MCA)</td>
<td></td>
</tr>
<tr>
<td>Economic decision making under uncertainty</td>
<td>Real options analysis</td>
<td>Linquist and Vonortas (2012), Tourkolias et al (2013), Jeuland and</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Whittington (2013)</td>
</tr>
<tr>
<td></td>
<td>(robust decision making, portfolio analysis)</td>
<td></td>
</tr>
</tbody>
</table>

4.3.1. Methods that are also used to measure damage costs

Most damage cost assessment methods in Phase 2 can also be used to evaluate the merits of different adaptation options. These applications have become more widespread in the past years as interest in adaptation to climate change increases.

IAMs that specifically comprise adaptation include the AD-DICE and AD-RICE (De Bruin 2011, de Bruin & Dellink 2011, de Bruin et al. 2009) and the WITCH (World Induced Technical Change Hybrid) model (Bosello et al. 2010).

Empirical analyses often incorporate observed responses (adaptation) into the damage cost analysis, or focus specifically on identifying and quantifying adaptation responses. An example of the former is Kocornik-Mina et al. (2015), who study whether economic activity is moved to less risky areas following large floods. An example of the latter is Burke and Emerick (2016) who identify adaptation to weather patterns in US agriculture and use this to predict the future impact of climate change accounting for adaptation.

Similarly, most examples of the science-first approach can be extended relatively easily to include adaptation.
In RAMSES Deliverable 5.2 (Costa and Floater 2015), benefits of five adaptation measures are estimated by comparing the productivity losses under no adaptation and each of the adaptation scenarios. The benefits are measured in terms of reduced temperature with the aid of climate models, and the productivity loss functions (see Section 3.3.3) are used to estimate the impacts in each sector. Box 6 describes the main results for averted losses in the case study cities Antwerp, Bilbao, and London.

**Box 6 Averted losses of adaptation to heat stress**

In RAMSES Deliverable 5.2 (Costa and Floater 2015), averted productivity losses due to heat stress of implementing alternative adaptation measures are estimated. They are estimated for a warm year in the period 2081-2100. The four adaptation measures compared are:

- Behavioural adaptation, in the form of changing working hours. Several schedules are compared. The schedule with the highest productivity is 7h-11h; 17h-20h for Antwerp and London, and 6h-13h for Bilbao. The behavioural change presented is the most efficient working schedule for each of the three cities.
- Installation of solar blinds (exterior solar blinds)
- Installation of air conditioning
- Increasing mechanical ventilation (the study assumes a baseline of 22m3/h/p, the legal minimum in Belgium, and studies the increase to 50m3/h/p). In this scenario, the air in the office building is refreshed twice an hour.

The figure shows benefits only, without accounting for the costs of each measure, which would need to be included if policy makers aimed to examine cost effectiveness.

Under the assumptions used, air conditioning, increased ventilation and solar blinds all resulted in substantial reductions in productivity losses from heat stress. For London, solar blinds seem to have almost the same effect of air conditioning without many obvious drawbacks. For both Antwerp and Bilbao, solar blinds provide similar benefits to those of increased ventilation, without requiring energy. Furthermore, behavioural change presents itself in London as a viable alternative to the other measures, as it is able to protect both indoor and outdoor
workers. However, its costs are more difficult to measure than those of other adaptation measures.

- In RAMSES Deliverable 6.2 (Sanchez et al. 2015), the model described in Section 3.3.3 follows a similar process to assess the costs of heat related morbidity and mortality with and without adaptation, thereby calculating averted losses. It then calculates cost-effectiveness of adaptation and the cost-benefit ratio of adaptation (see Sections 4.3.2.1 and 4.3.2.3 for descriptions of these indicators). Box 7 presents the estimated adaptation benefits for the case study city of Skopje.

**Box 7 Averted health losses through adaptation (Skopje)**

RAMSES Deliverable 6.2 (Sanchez et al. 2015) estimates the benefits of adaptation to heat increases in Skopje, by estimating the damage costs when adaptation is in place and calculating the difference. Regarding the averted mortality costs through adaptation, it is unclear exactly how effective heat-health action plans are in preventing heat-related mortality and morbidity. However, a relatively recent French study (Fouillet et al. 2008) suggested an effectiveness of about 68% in excess mortality prevention.

The table below shows the average annual projected mortality costs in Skopje in million € of 2005 again without adaptation during the timeframes of 2026-2045 and 2081-2100, and the avertible heat-related mortality costs through health adaptation for the same period.

<table>
<thead>
<tr>
<th>Period</th>
<th>Average annual cost heat-related mortality</th>
<th>Avertible cost through adaptation</th>
</tr>
</thead>
<tbody>
<tr>
<td>2026-2045</td>
<td>70.87 (48.01 – 97.17)</td>
<td>48.19 (32.65 – 66.07)</td>
</tr>
<tr>
<td>2081-2100</td>
<td>154.90 (93.17 – 221.78)</td>
<td>105.33 (63.36 – 150.81)</td>
</tr>
</tbody>
</table>

Median value of a statistical life was used; the confidence interval (in parenthesis) comes from epidemiological evaluation, with population projected through an exponential model. Costs in million €. Source: RAMSES Deliverable 6.2 (Sanchez et al. 2015)

- Also the analysis developed in RAMSES Deliverable 3.2 (Ford et al. 2015) is designed to account for the averted losses of different adaptation options. This is performed by estimating the impact of different adaptation measures on the level of flooding, and repeating the steps of the analysis. Specifically, a last step is added to those presented in Section 3.3.3: Assessment of the output of these steps to identify urban interventions (adaptation options) to reduce disruptions and test again. The adaptation options included are: installation of rainwater tanks; flood adapted location - moving critical transport links in order to reduce flood risk by raising them above the level of flood water; flood adapted construction - reducing the impact of flood water on critical transport links through modification of the depth/disruption relationship; altering the transport networks and generalised cost formulation to make alternative, more resilient modes of travel more attractive; and spatial planning options, such as mixed-use developments, to reduce commuting distances and thus exposure to and reliance on transport networks of businesses and the labour force.

- Similarly, the analysis in RAMSES Deliverable 1.2 (Boettle et al. 2014) can be extended to include not only the damage costs, but the benefits and costs of adaptation. Here, the effect of a considered measure is reflected in an altered damage function. The damage function of a useful adaptation measure for any magnitude below the damage function without adaptation
(since the loss is to be reduced). In the case of coastal floods, a dike that is planned for a specific design flood avoids any flood below that magnitude and therefore the damage function should be zero up to the maximum level held back by the dike. In this simple case, the adaptation measure is parameterized as a function of one variable, namely the magnitude. In other contexts the manipulation of the damage functions via adaptation can be more complex and it represents an essential ingredient of adaptation research. The modified damage function leads to a modification of the distribution of losses, i.e. to smaller values in the case of a useful adaptation measure. Finally, the costs of an adaptation measure are analogously estimated as a function of the magnitude to which the measure is designed for. Again for the case of coastal floods, one estimates the costs of a dike which protects the case study city against a flood of certain maximum flood level. By varying the maximum level of the flood, one obtains a function relating adaptation cost and magnitude (RAMSES Deliverable 1.2, Boettle et al. 2014).

Note that using coastal floods as hazards and dikes as adaptation creates an additional uncertainty of dike breach, i.e. an uncertainty of the threshold value up to which the protection works. An estimated 95% of the uncertainty lies within the range from 1/3 to 3 times the typical adaptation cost. To be more specific, uncertainties of adaptation costs have been modelled via log-normal distributions (Lenk et al. 2017). Finally, I-O models can be useful in estimating the impact of adaptation. Similar to the spreading of damage costs, adaptation actions in one sector will have benefits that spill-over into other sectors. For example, Hallegate (2008) developed the Adaptive Regional Input-At the city level, Output (ARIO) Model and used it to estimate the impacts of hurricane Katrina, net of adaptation. Also at the city level, Crawford-Brown et al. (2013) developed a variant of the ARIO model to explore the sensitivity of the London economy to loss of production capacity in sectors affected by climate change related damage during a recovery process that is either demand-led or investment-led.

These approaches are subject to the same drawbacks and advantages described in Section 3.3. When including adaptation however, there are some added difficulties. First, the data requirements are even larger. Second, the science-first approach requires that specific adaptation options are identified. Before the analysis, however, it may be difficult to assess which adaptation options are most promising for a given scenario. Third, in econometric studies where observed data may not make clear whether adaptation actions took place, it may be difficult to identify what constitutes adaptation. Finally, adaptation adds an additional layer of uncertainty. This means that methods that are less suitable in the context of uncertainty will provide even more biased estimates when studying the impact of adaptation.

### 4.3.2. Traditional economic decision support tools

#### 4.3.2.1. Cost-benefit analysis

Simply put, a Cost-Benefit Analysis (CBA) consists of measuring the monetized cost of adaptation, its benefits, and comparing the two. It thus makes use of the two quantities described in Section 3.2 and 3.3 directly: the costs of adaptation and the benefits of adaptation, measured as its averted losses, and takes a difference of these, or their ratio (cost-benefit ratio). The averted losses rely on an estimated baseline scenario, i.e., what would happen in the absence of adaptation.
CBA may be deterministic in the absence of uncertainty, or use expected values (expected costs and benefits). Estimating cost benefit ratios might additionally involve the following steps, depending on the timing and uncertainty of the adaptation, and the distributional concerns of the decision maker (HMT 2003):

- Adjusting the valued costs and benefits for inflation and rising relative prices;
- Adjusting further for the timing of costs and benefits by discounting to calculate present values (see Section 4.4.3 on further discussion on discounting);
- Adjusting for risk and uncertainty (see Section 3.4.3 for further discussion on uncertainty);
- Adjusting for distributional impacts (the incidence of adaptation costs and benefits on different stakeholder groups); and
- Considering non-quantified and non-valued impacts (positive and negative).

The use of CBA is complicated in the presence of large amounts of uncertainty. It has been reported that the hazard magnitude and asset value have the strongest effect in many cases (ibid). The adaptation costs are as well affected by uncertainty. Taking again the example of coastal floods, an estimated 95% of the uncertainty lies within the range from 1/3 to 3 times the typical adaptation cost (Lenk et al. 2017). Uncertainties of loss as well as adaptation costs can be modelled via log-normal distributions (Prahl et al. 2012 and Lenk et al. 2017, respectively). Such modelling is also suitable for avoided loss.

With uncertainty affecting the cost-benefit ratio, one cannot simply use the ratio of adaptation costs and benefits since there is no single value of both but rather a distribution. This is particularly relevant in cases of large uncertainty.

Graham (1981) addresses the cost-benefit analysis under uncertainty and identifies two major issues:

1. A magnitude must be identified for the future which appropriately represents the value of the uncertain benefits (costs) to accrue in that year.
2. An appropriate discount rate must be identified, relating the future value into present value.

As a consequence, as the uncertainties of the input quantities propagate through the cost-benefit analysis, the resulting cost-benefit ratio will be uncertain. Result should be expressed then in terms of probabilities, e.g., “a 17% probability the cost-benefit ratio will be larger than 1”. This, in turn, might represent a challenge for decision making (Reckhow 1994).

CBA are easy to interpret and the process to construct them is transparent, thus valuable to decision makers. It makes it easy to understand the implications of the assumptions used. However, in addition to the challenges noted above related to uncertainty, CBA also does not take into account the risk profile of the decision maker (i.e., how risk averse she is). Additionally, it does not account for equilibrium behaviour, and so does not incorporate the adjustments the economy would make in the long-term. Therefore CBA is often more useful for short term analyses and for initial stages of adaptation.

4.3.2.2. Adaptation cost curves

- Adaptation Cost Curves (ACCs) are a particular type of cost-benefit analysis. ACCs plot the cost-benefit ratio of each adaptation measure within a range of measures, against their benefit. They therefore allow an options comparison for a single climate change hazard and a single region or sector. For example: the study by Grant et al. (2011) constructs adaptation cost curves for the residential building sector. It focuses on three key climate change hazards at a
time and measures to address them: flooding, and corresponding flood resistance and resilience measures; water stress, with water efficiency measures; and overheating, with measures to reduce thermal discomfort. The purpose is to identify low-regrets adaptation options.

- Economics of Climate Adaptation Working Group et al. (2009) and Economics of Climate Adaptation Working Group et al. (2010) estimated cost curves across various sectors and hazards including those affecting urban areas:
  - Hull (UK) with a focus on wind, inland flood, and storm surge;
  - Miami and South Florida (USA) with a focus on hurricane risk;

- Adaptation cost curves can also feature in Integrated Assessment Models. De Bruin et al. (2009) use integrated assessment models, AD-DICE (Dynamic integrated model for Climate and the Economy accounting for adaptation) and AD-RICE (Regional Integrated model for Climate Change and the Economy accounting for adaptation), to construct ACCs using optimal adaptation options. This allows to compare different optimal adaptation options with each other.

- In RAMSES Deliverable 5.3 (Costa et al. 2016) ACCs for small scale adaptation measures are estimated. The study uses the results from the analyses in Section 3.3 (damage costs of heat stress through temperature loss) and Section 3.3 (benefits of two adaptation measures – air conditioning and solar blinds – in averting productivity losses deriving from heat stress). It couples this analysis with estimated costs of these adaptation measures for three case study cities (Antwerp, Bilbao, and London), measured by installation cost necessary per square meter times an estimation of approximate office space. The results are presented in Box 8.

### Box 8 Adaptation cost curves, Antwerp, Bilbao and London

Deliverable 5.3 (Costa et al. 2016) estimates ACCs for the installation of air conditioning and solar blinds, as adaptation measures to protect against heat related productivity losses. The analysis assumes the measures can be used for a total period of ten years, so the cost is divided accordingly. The cost of adaptation includes only installation cost. Graphs for the cities of Antwerp, Bilbao, and London are presented, assuming losses are the same as those estimated for a warm year in the period 2081-2100.
Adaptation cost curves for installation costs for three cities; warm year in the period 2081-2100. Source: Deliverable 5.3 (Costa et al. 2016).

The graphs show one column for each adaptation measure. The width of the column measures the benefit of the measure in million euros. The height of each column measures the cost per euro of benefit of each measure (that is, the cost-benefit ratio). The columns are organized by most to least costly per euro of benefit. The curves show that the total benefit of air conditioning tends to be higher, but that the cost per unit of benefit of solar blinds is always lower than that of air conditioning. This is particularly striking given that we do not account for any maintenance costs or energy costs, which can be substantial for the case of air conditioning. Thus, even though the total benefit from air conditioning is higher, its relative efficiency tends to be lower.

Relative to cost-benefit ratios, adaptation cost curves have the advantage of allowing for a comparison of the effectiveness of several adaptation measures at the same time. They give an overview of potential benefits and costs for adaptation options for a specific climate hazard, and in that they have the potential to stimulate debate. Additionally, the cost-benefit ratios behind the curves can be weighted to take into account other concerns, for example, their impact on inequality or vulnerable population (Economics of Climate Adaptation Working Group et al. 2009).

Adaptation cost curves do, however, have a number of drawbacks:

- Being region and time specific, they cannot be easily generalised. The results are highly dependent on scenario choice (both in terms of climate change and the economic and demographic evolution) and on existing levels of adaptation. So their utility beyond the specific region for which they were built is small. A very good example of this is the flood-cost curve (Ranger 2011). The effectiveness of adaptation measures will depend heavily on the hazard level, existing adaptation measures in place, and specific characteristics of the region (as for example the building types).
- Adaptation cost curves also do not address interdependencies between different adaptation measures. This implies that synergies or conflicts between adaptation measures are not taken into account. Additionally, intersectoral, intertemporal, and international interactions are generally not accounted for.
- In terms of measurement of benefits and costs, the measures employed in ACCs are not comprehensive: the direct financial cost of an adaptation options does not account for implementation barriers and wider cost definitions. Adaptation cost curves tend to measure costs and benefits in monetary terms, without including non-monetary or indirect costs. Furthermore, being based on cost-benefit ratios, adaptation cost curves assume risk neutrality from the decision maker.
Finally, adaptation cost curves are hazard specific. This implies that it is not possible to create an ACC for climate change that encompasses all hazards, even when taking all the caveats above into account.

For all the reasons listed above, adaptation cost curves have not been taken up by academics or policy makers in the same way that abatement cost curves have. An adaptation cost curve is not in itself sufficient to make policy decisions, but it can be useful as a basis for the debate on adaptation options, as well as a starting point for the discussion of implementation issues and social acceptance.

4.3.2.3. Cost-effectiveness analysis (CEA) and Multicriteria analysis (MCA)

Cost-effectiveness analysis (CEA) is a relative measure. It estimates different adaptation options to reach the same outcome and compares them. It does not require monetization of costs or benefits, as it can be based on alternative metrics. For example, settling on an acceptable level of flooding risk due to sea level rise, and comparing different adaptation actions that achieve this level of risk.

CEA has been mostly used in the mitigation assessments, with the exception of Boyd et al. (2006) that use it in the context of adaptation. It is more suitable to evaluate technical options, as they more easily quantified (Watkiss 2011).

Multicriteria analysis (MCA) also provides an alternative to monetizing adaptation options. It is a method based on the fact that a decision can be made based on different criteria. The analysis of this tool is beyond the scope of the deliverable, but a detailed step by step guidance is provided by Dodgson, et al. (2009).

4.3.3. Uncertainty framing: iterative risk management

Iterative risk management (IRM), also called adaptation pathways, is an application of adaptation management. It is based on a process that allows for revising and reassessing adaptation decisions. It is therefore particularly useful for making long-term adaptation decisions, namely in contexts of high uncertainty. It allows practitioners to adjust decisions over time as new information arrives, avoiding potentially harmful lock-ins.

Iterative risk management requires an economic appraisal using CBA, CEA or multicriteria analysis, and the identification of risk thresholds. Because of the difficulty in identifying risk thresholds, it is easier to apply to adaptation decisions that address gradual changes, such as sea-level rise, although Watkiss et al. (2013) apply it to the agriculture sector. The iterative risk management approach is described in much more detail in RAMSES Deliverable 8.2 (Mendizabal et al. 2016). The deliverable provides step-by-step guidance and offers advice on how to apply the approach and overcome some of its drawbacks, like the need for technical knowledge to identify risk thresholds.
4.3.4. Economic decision making under uncertainty

Given the uncertain character of the payoff of most economic investment, much has been written about economic decision making under uncertainty. Drawing from this, most of the methods and models can be applied in the context of climate change adaptation.

4.3.4.1. Real options analysis

Real options analysis (ROA) is based on the concept that when future outcomes (whether these are profits, damage costs, or adaptation benefits) are uncertain, it might be optimal to wait for more information to arrive before making an investment decision. ROA quantifies the investment risk, and assesses the value of flexibility.

- When an investment is irreversible (e.g., hard/fixed infrastructure not able to be removed or only done so at a very large, if not prohibitive cost), an ROA might predict that even if a traditional CBA finds that the investment is beneficial it might make sense to delay the investment (Dixit and Pindyck 1994).
- Alternatively, ROA has different applications when an adaptation investment is considered reversible or flexible, e.g., the use of air-conditioning. While the installation cost is not reversible, the energy costs are only incurred if the air-conditioning is turned on. So if future temperature is lower than expected, or energy prices higher, the decision maker has the option of not turning the air conditioning on. As uncertainty increases, these investments are predicted to increase as well, as they offer an option to adapt (in this case by turning the air conditioning on) and incur in energy costs only in the future.

ROA is consistent with iterative risk management, but is much more data intensive. It requires detailed probabilistic climate information and quantified impacts, making it technically challenging (Watkins 2011). At the same time, it requires less subjective interpretation than IRM, and relative to other economic costing methods provides additional insights to help prioritize short-term adaptation necessary for long-term investment.

4.3.4.2. Portfolio analysis

Portfolio Analysis (PA)’s application to adaptation investment is based on the idea that each adaptation option carries a certain level of risk, and by spreading the investment across different adaptation options risk is also being spread. If the co-variance of adaptation options is low (i.e, the risk related to the adaptation options is not highly correlated), then the total variance of the portfolio of investments will be lower, for a given level of return (net benefit of adaptation in this case) than the variance of each option taken separately. PA thus selects a set of adaptation options that are effective when taken together over a range of possible future climates.

The benefit of PA for hedging risk is particularly meaningful for adaptation investments where uncertainty can be very large. A review of applications of PA for adaptation, with information on problem types, data needs, resource requirements, and good practice lessons is provided by Hunt and Watkins (2013).
For a decision maker, PA requires a considerable data collection or generation effort and the technical and data requirements make PA’s applicability to adaptation investment limited. Compared to ROA, it is a much more static approach. It does not introduce different timing for investment decisions. It has a similar approach to IRM, with the benefit of a more structured objective analysis, but the drawback of additional data requirement.

4.4. LEVEL 4: Inputs

In order to measure the economic potential of different adaptation actions, decision makers need to understand how to identify prospective adaptation options and their implementation costs. This section distinguishes different types of adaptation that the decision maker needs to take account of, and provides references for identifying adaptation options and measuring implementation costs. It also introduces the concepts of timing and discounting, and how these affect the assessment of costs and benefits of adaptation options.

4.4.1. Adaptation measures

According to the RAMSES Transition Handbook (Deliverable 10.2, Mendizabal et al. 2017), two activities are needed in order to identify potential adaptation options. The first is the consultation of available inventories of adaptation options to respond to the expected impacts. The second is for the decision maker to characterize them in terms of benefits and potential uses. In order to conduct this, RAMSES Deliverable 2.4 (Kallaos et al., 2016) provides a taxonomy of adaptation measures and corresponding indicators for resilient architecture and infrastructure that can be implemented by public authorities at the building, neighbourhood and catchment scales of the city. It focuses solely on structural and physical adaptation options for blue, green, and grey infrastructures, and so abstracts from social and institutional adaptation forms. The latter are identified in RAMSES Deliverables 7.2 and 7.3 (De Paula et al., 2015, and De Paula et al., 2016).

According to Smith et al. (1996), adaptation can be classified based on its purposefulness, timing, temporal scope, spatial scope, function, form, and performance (see Figure 11). In RAMSES Deliverable 8.2 (Mendizabal et al. 2016), adaptation is categorized according to the IPCC fourth assessment report (IPCC, 2007): as either anticipatory or responsive adaptation, and as either autonomous or planned adaptation. A closely related distinction is that of public and private adaptation.

Figure 11 Types of adaptation
Anticipatory adaptation takes place before impacts of climate change are observed and is also referred to as proactive adaptation. An example is the building of a sea wall in anticipation of predicted sea level rise. This type of adaptation involves long-term decision making and reduces long-term impacts, risk and vulnerability caused by climate change. For this reason, anticipatory adaptation is more effective and involves generally planned interventions (Markandya and Chiabai 2009). For a decision maker, planning adaptation far in advance might not be possible because of uncertainty constraints, and as such it is important that early action on long term decisions remains flexible and efficient. Further discussion on the timing of adaptation decision making is provided in Section 4.4.3.

Autonomous adaptation is adaptation that does not constitute a conscious response to climatic stimuli but is triggered by ecological changes in natural systems and by market or welfare changes in human systems. Examples of autonomous adaptation in urban settings include the insulating or building flood protection for individual houses, wearing lighter clothing in warm days, and buying insurance. This adaptation is often private, taken by individual institutions, households, or other private agents independently. See Section 4.2.2 for information on costs of private and public adaptation.

Finally, planned adaptation is the result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state. This type of adaptation progresses from the top-down, through regulations, standards, and investment schemes. An example of planned adaptation is increasing green public space in a city to face temperature increases.

It is of high importance to account for all these types of adaptation. Although planned adaptation will be the direct subject of the decision maker’s planning, any adaptation planning should include some consideration of the level of existing or expected autonomous adaptation. Autonomous and planned adaptation may be complements – if one increases the marginal benefit of the other – or substitutes –
if the opposite is true (Fankhauser et al. 1999). In selecting damage cost and adaptation cost assessment methods, some will implicitly account for autonomous adaptation – for example, empirical methods or computable general equilibrium models that identify equilibrium behaviour – while others need to account for autonomous reactions explicitly – for example, most science-first and static approaches.

Finally, adaptation may be public or private, according to the nature of the agent that provides it. Public adaptation is normally provided by a public body, such as government or an aid agency. Examples are the development or early warning systems, flood barriers that protect large portions of urban territory, or post-flood compensation payments. Private adaptation is provided by individual agents, such as firms and households. The purchase of insurance and migration due to reduced agricultural production resulting from climate change are two forms of private adaptation.

Who may be expected to provide adaptation depends on who collects its benefits or averted losses. A discussion on public and private costs, benefits, and provision of adaptation is provided in Section 4.2. It is important to understand the limitations of privately provided adaptation, and, as with the case of autonomous adaptation, the interaction between private and public adaptation.

### 4.4.2. Implementation costs

After identifying potential adaptation options according to the main climate related concerns of a city, as well as the relevant quantities needed to evaluate their economic effectiveness, an essential input into this analysis are the costs of implementing a given adaptation measure.

RAMSES Deliverable 1.3 (Heidrich et al. 2016) provides a cost inventory for the installation of nine infrastructure components, including adaptation infrastructure, with a particular focus on RAMSES case study cities and countries. The methods followed in the Deliverable to collect costs of infrastructure are transferrable to other adaptation infrastructure options. Note that costing activities may include first and recurring costs.

Box 9 presents a summary of collected costs for countries where RAMSES case study cities are located.

**Box 9 Cost inventory for adaptation infrastructure, RAMSES cities**

The availability of adaptation costs in Deliverable 1.3 varied between the 7 case study cities. Data on installation of air conditioning and solar panels was available for all cities. Loft insulation costs were available for 6 of the cities, mechanical ventilation and double glazing costs for 5 of the cities, and costs of green roofs and permeable paving in 3. Costs for solar blinds were available only for one of the case study cities. Though the sample is limited (number of cities, number of measures), these results suggest that data is relatively more available for measures to adapt to temperature increases than to flooding.

The tables below present respectively for adaptation to heat waves and flooding, a summary of average, minimum, and maximum costs for each of the adaptation measures for which data was collected for each of the

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8 See Sections 3.2 and 3.3 for respectively, guidance for identifying key quantities, and methods to evaluate adaptation.
## 4.4.3. Timing and discount rates

### 4.4.3.1. Timing

Climate change hazards will impact the local economy at different points in time, and in general differ in their duration of their impacts. Some impacts are more likely to be felt in the short term – for example, a drought has immediate impacts on agricultural production – and some impacts are more likely to have costs that are incurred at some point in the more or less distant future – for example, sea level rise might cause floods in some areas that are expected over a decade into the future.
Similarly, adaptation measures might have an impact in the short or long run. For example, while large infrastructure investment has benefits that are reaped in the long term, farmers can switch to more heat-resilient crops relatively quickly to adjust to higher temperatures, or a firm can install air conditioning units to protect its workers from increasing indoor temperature.

The fixed or long term nature of urban infrastructure, and the decades necessary for land use changes, highlights a problematic mismatch: the need for long term planning in terms of infrastructure adaptation means that costs need to be incurred immediately while uncertain benefits are delayed.

Adaptation measures might also have different effects throughout different time frames. A measure that has a positive short-term impact might lead to a negative impact in the long run. An example is an increase in the use of air conditioning, which in turn affects efforts for carbon mitigation, and in cities might increase local ambient temperature further. Thus it is necessary to address short term priorities while at the same time taking early action on longer term decisions.

According to Smith (1996), adaptation measures should be prioritized if they fulfil at least one of the following criteria:

- If they address impacts that are irreversible or costly.
- If they are urgent, that is, if current trends make adaptation less likely to succeed in the future.
- If they address long-term solutions.

Additionally, anticipatory adaptation should be both flexible and economically efficient. A further discussion of timing of adaptation adoption is available in RAMSES Deliverable 8.2 (Mendizabal 2016).

In many cases, action can be taken in the short term to begin the adaptation process without locking in the decision maker to a path of adaptation that has a high level of uncertainty. Measures can be identified that:

- Are cost-effective now and under a range of future climate conditions and possess no hard trade-offs with other policy objectives (no-regret actions).
- Are relatively low cost and produce relatively large benefits under predicted future climates (low-regret actions).
- Contribute to adaptation while having other social, economic and environmental policy benefits, including in relation to mitigation (win-win actions).

Examples include reducing the risk of flooding by avoiding building in flood prone areas (low-regret actions), or reducing leakage from water utility infrastructure, which helps improve water efficient while at the same time reducing drought risk (win-win actions).

A complete identification of no-regret, low-regret and win-win actions should be conducted taking into account the specific context of each urban centre. A key benefit of these actions is that they enable decision makers to implement early adaptation actions, rather than taking a ‘wait and see’ approach (Martin 2015). Further examples of these types of actions are collected and described in Martin (2015).
4.4.3.2. Discounting

An important issue when measuring the costs and benefits of adaptation to climate change is that of discounting, that is, how to convert future costs/benefits into present values. Much discussion has been had on the importance of the choice of discount rates for estimating the impacts of climate change, mostly in the context of mitigation (Gollier and Hammitt 2014).

A discount factor measures a trade-off between future and present income, and discounting is based on the idea that in general agents prefer income in the present. Most economic models use the Ramsey rule to calculate the financial discount rate (Ramsey 1928). This includes the pure rate of time preference (PRTP), which is the rate at which agents discount future income over present assuming income will remain constant over time, and a second term that includes the growth rate of GDP and the elasticity of marginal utility of consumption. The latter captures the idea that as agents expect consumption to increase with time, they value the marginal consumption in the future less.

While the DICE model (Nordhaus 2012) uses a PRTP of 1.5% and an elasticity of 1.45, the UK Treasury (UK Treasury 2003) uses a PRTP of 1.5% and elasticity of 1, the Stern review (Stern 2007) uses a PRTP of only 0.1 and elasticity of 1 (Agrawala and Fankhauser 2008).

The discussion on discounting is less pressing in the context of adaptation than that of mitigation (Watkins 2015). That is because a large bulk of the adaptation investment being considered is low-regret adaptation, made for shorter timeframes – for example, ten or twenty years, as opposed to the end of the century. Agrawala and Fankhauser (2008) conclude that in the absence of mitigation policies the discount rate does not have a major influence on the level of damages in percentage of GDP. Furthermore, in many cases it is appropriate to use the standard public sector discount rates. However, it is important to note that very high discount rates can prevent long-term adaptation investment, and, in some cases, even short term investment.

4.5. Conclusion: prioritising urban adaptation options

The three levels identified in the previous sections describe a decision-making process for prioritising urban adaptation measures based on economic net benefits. The damage costs of hazards identified in Phase 2 serve as an input into Phase 3/4: depending on the hazards to be targeted, their costs and risk profiles, different adaptation actions will be necessary and have differing net benefits.

The process starts from level 4. As a first step, it is necessary to define what constitutes adaptation and to identify the most suitable available adaptation options based on cost and efficacy. Section 4.4.1 and Section 4.4.2 distinguish different types of adaptation measures and provides guidance for identifying relevant adaptation actions developed in the RAMSES project.

Implementation of adaptation will depend crucially on the timing of the adaptation action and of its expected benefits. This is particularly relevant in the context of uncertainty, when uncertain benefits that are realised in the future delay adaptation efforts with immediate costs. Section 4.4.3 provides guidelines for prioritising short-term adaptation action. Additionally, in order to assess quantities of adaptation measures with different timings, the section describes the concept of discounting.
Following this identification process, the policy maker can begin to quantify the economic costs and net benefits of adaptation options. The methods most suitable will, in turn, depend on who bears these costs and who benefits (Sections 4.2.1 and 4.2.2).

Finally, it is worth noting that a complete prioritisation of adaptation cannot be made in isolation, and requires an assessment of the resources available at the city level and the capacity to raise finance. Phase 5 deals with identifying and prioritising sources of funding that are suitable for financing adaptation. Which adaptation strategy is most economically effective for a given city will thus depend both on the assessed costs and net economic benefits and on the city’s capacity for raising appropriate finance and its associated costs. These financing questions are discussed in the next section under Phase 5.

5. Planning and implementation: city investments

5.1. LEVEL 1: Transition Handbook Phase 5

5.1.1. What is Phase 5?

In phase 5 of the RAMSES Transition Handbook, the policy maker defines the strategic objectives and the approach to be followed based on the results of Phase 2 and 3/4 (Figure 12). This includes the definition of the nature and scope of the Adaptation Plan, whether it has to be developed autonomously, how a large range of municipal policies can be integrated, and how cross-cutting policies can be developed within the framework of another policy such as urban planning.

In terms of implementation, policy makers can use phase 5 to identify effective, efficient and equitable policy instruments for delivering adaptation measures, mainstream adaptation into existing instruments, develop new instruments if required, and assess the relative benefits of these different policy instruments.
Phase 5 recognises that there may be limitations to which adaptation options can be implemented based on political/governance, economic, technical, and social realities. Some of these limitations will have been considered previously in the preceding steps, but become more apparent in this phase when stakeholders are more actively solicited. This chapter continues the work of the preceding sections for decision-making based on economic and cost considerations. More specifically it focuses on how to finance the proposed adaptation investment thereby incorporating consideration of some of the political/governance and economic realities faced by cities.

5.1.2. How financial assessments can support Phase 5

Finance mechanisms and funding models form an important component of planning and implementing adaptation pathways. As set out in Section 1.2, the cost assessment framework has four levels. For phase 5, these levels are set out in Figure 13. Level 2 quantifies the level of city investments that could be raised, steered and blended from various public and private sources using a range of financial mechanisms and economic policy instruments. These investments then feed into the Handbook Phase 5 alongside other quantitative and qualitative planning and implementation actions that are not included in the cost assessment framework. At Level 3, policy makers will need to make choices between different financing and economic policy options, such as public spending, debt financing, land value capture or regulations. In order to assess the effectiveness of these different mechanisms and policy instruments, level 4 of the process will require an understanding of the sources of finance potentially available, including public funds, private debt financing and equity options.

Investment in adaptation should be part of a process for scaling overall investment flows to city systems and networks, shaped by a government’s finance capacity and resources and that of other potential investors. For this, improved information for government decision-makers is required, for example on sources of finance (public, private or blended) that can be mobilised and finance actions within government’s fiscal, regulatory and strategic remit.

*Figure 13 How city investments in adaptation can support the Handbook Phase 5*
5.2. LEVEL 2: City investments

5.2.1. Financing adaptation

Level 2 of the cost assessment framework is designed to provide effective financial investments in urban infrastructure and services to support the planning and implementation phase of the Transition Handbook (phase 5). Cities need to scale up investment in public infrastructure and services if they are to meet the UN’s Sustainable Development Goals – particularly SDG 11 (“Make cities and human settlements inclusive, safe, resilient and sustainable”) and SDG 13 (“Take urgent action to combat climate change and its impacts”). The SDGs combined with the Paris Climate Change Accord, the Habitat III New Urban Agenda and the Sendai Framework for Disaster Risk Reduction show the need for a more strategic approach to investing in public infrastructure that leverages private and institutional capital more effectively. However, many cities in both developing and developed countries face increasing challenges to invest in the infrastructure required given substantial fiscal constraints (UNEP 2016). Infrastructure development in the developing world especially, where it is needed most, has been limited except in certain parts of East Asia (Fay et al. 2011).

In many European cities, old infrastructure for basic services and transport needs to be replaced in the next 10 years, and this will require significant investments (EEA 2017). Many of these investments will need to incorporate different technologies and system configurations compared to past investments based on the need for low-carbon, resource-efficient, and climate-resilient urban development and management. With this innovation comes a level of uncertainty and technical complexities that can make financing a challenge. Partly as a consequence of this uncertainty, lack of finance has been cited by mayors, city managers and planners as one of the main reasons that adaptation is not being taken up at the speed necessary in European urban areas given the actual and perceived risks of investments.
In many cases, adaptation investments may be inseparable from spatial planning actions and infrastructure investments that are taking place anyway. Optimally, the adaptation element is part of decision-making related to infrastructure or development siting and orientation, or design standards and features. These can be no-cost or low-cost incremental changes to finance. Other investments may relate only to a discrete adaptation need brought on by climate impacts and thus are considered an added investment above other infrastructure and development needs. In either case the finance process will mirror that of any public or public-benefit investment and is thus consistent with barriers cities presently face to finance infrastructure, and steps needed to overcome those barriers and increase finance flows from public and private sources.

Identifying and engaging with a wide range of stakeholders to transmit signals on investment needs and longer time investment intent, and draw in lessons from investors on what is needed from government to create investment opportunities, can help activate a wider range of finance sources. Individual city governments may as a result seek out non-traditional sources of finance than historically been the case – some of whom will be new to the urban infrastructure finance sector (e.g., certain institutional investors or newer vintage specialised private equity funds/sources).

As stated in the RAMSES Transition Handbook, adaptation should not be performed in isolation from existing policies, management structures or processes. It should also strive to create public policy co-benefits and synergies with other government priorities. The cross-cutting nature of adaptation makes multi-departmental and budgeting (capital and operational) collaboration critical. To the extent that the adaptation investment enhances the functioning and performance of the targeted area, it will be more attractive to investors in that it creates long-term value or contributes to economic growth (ICLEI 2011).

5.2.2. Barriers to adaptation finance

A range of barriers to public and private investment in urban infrastructure are faced by city governments. Many of these will apply to adaptation given the synergy with existing mandates and ways in which investment decisions are made as described above. Some of these barriers, however, may be more acute for adaptation; for example, identifying income/revenue streams from adaptation investments to finance the investment.

Investment barriers collated from a range of literature sources and stakeholder discussions relate to the fiscal realities faced by city, state, and national governments; institutional and governance factors; and the appetite of private investors to invest in projects or assets traditionally outside their investment focus. These barriers can be grouped as:

1. Lack of upfront public capital
2. Institutional boundaries
3. Institutional capacity
4. High risk and low returns
5. Imperfect information

Definitions and examples of these barriers are described in Table 5.

9 In Phase 5 of the RAMSES Transition Handbook it is stated that “Typical barriers for adaptation at the local level: 1) Lack of awareness; 2) Lack of data and of specialized knowledge, and of platforms to exchange experiences; 3) Lack of human and financial resources; and 4) Lack of a multi-level adaptation framework” (58). These four relate specifically to barriers 3 (Institutional capacity) and 5 (Imperfect information) from the list above and further described in the table. The more comprehensive list of barriers presented in this paper thus reflect finance-specific challenges beyond broader assessments of devising and implementing adaptation solutions.
**Table 5 Adaptation investment barriers**

<table>
<thead>
<tr>
<th>Barrier</th>
<th>Definition</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of upfront public capital</td>
<td>Government lacks the upfront capital to fund its investment priorities.</td>
<td>• Local governments lack of borrowing capacity due to credit worthiness from factors such as high debt ratios, low capital reserves, limited revenue sources, etc. The limitations on raising or controlling local revenue may be statutory, macroeconomic, or political.</td>
</tr>
</tbody>
</table>
| Institutional boundaries      | Governance arrangements that hinder collaborative investment across departments in single jurisdictions or across jurisdictions. | • ‘Green’ and ‘Blue’ infrastructure that serves multiple purposes may require capital and operating budget support from several agencies.  
  • Investments that have wider benefits beyond municipal boundaries may require funding from multiple sources.  
  • Institutional arrangements and governance within and between public entities that favour maintenance of existing assets and systems over introduction of new ones (e.g., ‘grey’ infrastructure in favour of ‘green’ and ‘blue’).  
  • Trade-offs (including budgetary rules) between one-off and recurring expenditures. |
| Institutional capacity        | Governments are limited in their ability to cost options, structure finance. | • Institutional lack of knowledge and skills, inclusive of adaptation costing, innovative financing mechanisms, co-benefit investments (e.g., address mitigation and adaptation simultaneously), etc.  
  • Government institutions have inadequate budgeting and accounting skills and resources to scale local investments.  
  • There is a lack of long-range adaptation planning, resulting in a lack of signals to market participants about investment needs and intent. |
| High risk and low returns     | Investors forecast that an investment will generate insufficient returns, e.g. through debt repayments, asset appreciation or income streams as a return on equity, relative to other sectors and asset classes. | • A limit or lack of income from adaptation assets.  
  • Uncertainty on climate variability/climate change impacts makes investment risk hard to price.  
  • Limited mechanisms for pooling, sharing risks.  
  • High capital reserve requirements placed on investors.  
  • Shallow capital markets and/or rising cost of capital.  
  • ‘Free-rider’ problems where benefits accrue to non-payers/funders reduce incentive to invest. |
| Imperfect information         | Investors (public or private) possess insufficient information on risks from inaction and benefits from adaptation. | • Uncertainty on economic impacts from climate change vulnerability, costs of adaptation measures due to insufficient number of case study projects, and projected benefits of adaptation.  
  • Uncertainty on optimal timing for investment. |
<table>
<thead>
<tr>
<th>Barrier</th>
<th>Definition</th>
<th>Examples</th>
</tr>
</thead>
</table>
|         |            | • Lack of market data on investment opportunities, technologies, and/or partners.  
|         |            | • Lack of ‘resilient’ valuation criteria and measurements to assign higher values to assets that have incorporated adaptation measures.  
|         |            | • Performance track-record, evidence base for new technology or systems.  |

Investment planning actions taken by government should be aware of these barriers and seek to create finance solutions to overcome them.

5.3. **LEVEL 3: Finance mechanisms**

5.3.1. **Government actions for adaptation finance: raising, steering, and blending**

Level 3 of the cost assessment framework provides guidance on potential finance mechanisms and funding models that municipalities and national and regional governments may wish to explore. Moving from the economic rationale for adaptation investment based on the net benefits to aligning investment sources to the adaptation options requires government to accelerate and scale up direct and indirect investment flows for adaptation. It can do so in many ways, for example by:

- influencing or mandating adaptation investment through strategy, policy and regulations;
- using its purchasing power to set resiliency performance metrics for services and facilities used in its operations, or procuring public infrastructure; and
- collecting data and sharing information on climate and risks, damages and costs incurred, best practices, etc. to improve market conditions for adaptation investment.

Government actions for financing adaptation measures can be grouped into three key areas: **raising, steering and blending finance**. These actions yield investments through a range of finance mechanisms that can be deployed. Figure 14 shows these areas of action from government and some of these finance mechanisms (noting that the mechanism list is not comprehensive).

*Figure 14 Phase 5: Raising, steering and blending adaptation finance. The seven examples of finance mechanisms are discussed in the next section.*
The goal of adaptation in cities is to add resiliency to the built and natural environment that support economic and social systems. Given the mix of public and private assets across the city, adaptation investment will thus fall within a spectrum of fully public to fully private. In general, direct government expenditure will be required where the public good broadly distributed exceeds private gains, and where network effects and equity considerations necessitate public financing. Such investments will rely on raising and blending finance. Indirect expenditure will result from government steering finance, and secondarily blending finance. This may be where private actions and markets are generally functioning to finance the adaptation need, but cannot do so exclusively without some level of government support. There will also be cases of direct private expenditure in adaptation, driven by their immediate goals and private gains, but that in turn create adaptation benefits for a broader community (Tompkins & Eakin 2012). Government should recognise and encourage these investments.

These three areas of government areas of action are further defined below:

- **Raising finance**: Due to government’s mandate to provide public goods and services; its historical role in infrastructure investment; and the temporal and distributional equity challenges of adaptation, it is likely to have a significant and sustained role in adaptation finance. In fact, government’s ability to discern investment priorities aligned with constituents’ needs and policy frameworks; raise revenue from multiple sources; and borrow at attractive (below commercial) terms from capital markets and spread repayments over long time horizons, make public finance indispensable. For this, it draws on its own-source revenue and capacities to deploy capital for broader public benefits/objectives.

- **Steering finance**: While direct government investment remains critical, there is a substantial role for governments in setting standards and shaping the market conditions to steer private investment into adaptation measures. This can be delivered through strategic policy and regulatory levers, taxation, building standards, subsidies and other incentives.

- **Blending finance**: National, and increasingly subnational, governments’ ability to use targeted public funds to leverage and ‘crowd-in’ private finance to specific investment projects or finance facilities is increasingly being viewed as a primary tool in infrastructure

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finance. Blended finance is optimally applied to projects and finance structures marginally below real or perceived commercial viability, and that cannot be unlocked by an enabling policy and institutional environment alone (UN General Assembly 2014). Blended finance encompasses a large portfolio of potential instruments and finance sources that can draw from local, national or even international finance institutions or special purpose funds. For example, public finance sources such debt or equity contributions from government entities can seed investment funds or provide a partial contribution alongside an additional investment partner. Risk mitigants such as loan loss reserves, loan guarantees, liquidity facilities, etc. are additional public finance elements which can incentivise private investment. Public-Private Partnerships (PPPs) are another form of blended finance based on the mix of public and private capital and/or role of public agents in repaying investments made by private actors.

Table 6 gives examples of how government’s use of raising, steering and blending finance can result in direct government investment and indirect private or public-private adaptation.

**Table 6 Investment outcomes from raising, steering, and blending**

<table>
<thead>
<tr>
<th>Government action</th>
<th>Public adaptation investment</th>
<th>Private adaptation investment</th>
</tr>
</thead>
</table>
| Raising (direct role in adaptation) | • Tapping capital reserves  
• Establishing, using credit-worthiness (sufficient own-source income, management capacity) to access debt and capital markets  
• Borrowing from state, central governments  
• Enacting PPP legislation |  |
| Steering (indirect role in adaptation) | • ‘Nudge’ policies to improve resilience, e.g., tax incentives, design guidelines, etc.  
• Information resources produced / disseminated (e.g. downscaled climate projections and impacts)  
• Strict regulations to limit exposure, e.g. asset location restrictions, design standards | • Investment decisions influenced (where to build, how to build)  
• Asset owners upgrade / retrofit assets for resiliency (i.e., seeking value protection or uplift)  
• Resiliency improvements become cost-effective where economic case is marginal (e.g., shorter payback period for energy, water efficiency upgrades)  
• Insurance products available and affordable to consumers / asset owners (due in part to government reducing risk through its direct investments) |
| Blending (direct and indirect role in adaptation investment) | • Government guarantees (e.g., insurance loss reserve funds)  
• Concessional finance accompanying market finance  
• At-risk asset buy-downs | • Strengthening insurance markets  
• Increase investor appetite in new markets (e.g., adaptation finance) and in new finance products (e.g., catastrophe bonds)  
• Financing PPP projects |
These actions are not mutually exclusive in that government may be acting in more than one capacity simultaneously.

### 5.3.2. Finance instruments and mechanisms

A literature review conducted by the London School of Economics of finance instruments for urban infrastructure highlighted 72 major finance instruments and funding models that have been used or could potentially be used for investment in city-level projects and programmes. Of these instruments and models, 51 (71%) were found to be public finance or policy instruments, while 21 (29%) were private finance instruments. This shows the wide range of mechanisms for adaptation investments that are potentially available, while accentuating the continued importance of public finances and government policy frameworks for delivering these investments.

In order to prioritise promising finance mechanisms from the list of 72, the LSE consulted with experts from the World Bank, OECD, Global Commission on the Economy and Climate, United Nations Environment Programme, sovereign wealth funds, investor associations, and a range of commercial banks and global property developers. Following these consultations, combined with additional interviews with finance and policy experts, and taking account of additional evidence from the literature, the following seven finance mechanisms were identified as promising tools for future examination by national governments:

1. Fiscal decentralisation
2. Bonds and debt-financing
3. Land value capture
4. Pricing, regulation and standards
5. National investment vehicles
6. International finance
7. Public private partnerships

These finance mechanisms support investment in sustainable urban infrastructure, have potential for financing at scale, lie under national government control or influence, and have supporting evidence of previous effectiveness. All seven mechanisms have potential for raising finance, while two could support steering finance and five could be used for blending finance (Table 7). The relative effectiveness of different mechanisms will depend on country-specific and city-specific circumstances, and as such a policy maker should be open to exploring the full range of potential finance mechanisms. At the same time, the seven mechanisms identified here may provide a useful starting point for examination by city and national policy makers.

<table>
<thead>
<tr>
<th>Finance mechanisms</th>
<th>Raising</th>
<th>Steering</th>
<th>Blending</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiscal decentralisation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bonds and debt financing</td>
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</tbody>
</table>

Table 7 Finance mechanisms role in Raising, Steering, and Blending finance
5.3.2.1. Fiscal decentralisation

Fiscal decentralisation describes a set of capacity features and governance arrangements that place more revenue raising and spending authority at the sub-national level. This generally requires close collaboration and coordination with or assent of state and national governments. In practice, this can mean that national governments:

- increase the size and effectiveness of fiscal transfers to lower levels of government; and/or
- legislate and provide support for fiscal decentralisation so that city and regional governments become more economically self-reliant in raising and spending resources.

There are particularly strong reasons to promote decentralisation. These include allocative efficiency, as costs and benefits of public services are fully internalised; and preference matching, as information on local needs and preferences is better collected at the local level (Sow and Razafimahafa 2015). More so, fiscal decentralisation can be an effective tool to deal with climate change challenges: as impacts are felt locally, support for adaption actions can be easier to mobilise.

Decentralisation requires an adequate institutional environment, i.e., strong accountability at various levels of institutions, good governance, information sharing, and strong budgeting and accounting capacity at the local level. With this in place, local governments should be positioned to utilise a range of taxes, charges, and transfer payments to fund government operations and investments. A diversified portfolio of revenue sources is beneficial for local governments, as it improves risk sharing and reduces exposure to economic fluctuations (Veiga et al. 2016). This is particularly meaningful given the uncertainty of climate change and the disruption to economic activity it may cause. Property taxation is a particularly effective local revenue option. Land value capture – a form of property taxation described in subsection 5.3.2.3 below - can provide a reinforcing link between investments in adaptation and improved land and property economic returns, enabled through property taxation revenue.

5.3.2.2. Bonds and debt financing

National and municipal government borrowing (commercial loans and bonds) is a well-established mechanism for governments who, as principal developers of infrastructure, require long-term debt to deliver fixed capital assets. The capability of local governments to finance their infrastructure needs depends significantly on their ability to raise local revenue to secure loans or issue debt - particularly where capital is not easily available from the central government. The financial logic for government borrowing is premised on the role of adaptation in delivering/maintaining future growth and thus additional government revenues. Long-term repayments also play a role in equitable policy making, as
long-term investments have benefits for future citizens who should have a share in its financing (Habitat III 2016).

Green bonds are an emerging subset of the national, subnational, and institutional/corporate bond market and should be looked to for financing adaptation investments. Put simply, these are bonds issued with parameters or strict conditions on how the proceeds will be invested – i.e., for sustainable projects or assets. As with standard bonds, issuances can be tied to general revenue or specific income or asset backed revenues. Bond-labelling (certify the investment intent to investors) and post-investment measurement of impact does add to transaction costs relative to standard bond issuances. At present though, investor demand for green bonds generally outstrips the supply and yields have been favourable to the bond issuers, i.e., the cost of debt is on par or lower than comparable standard bonds (Lewis et al 2016). Note that green bonds also apply to corporate and quasi-governmental authority issuances and thus can drive investments in adaptation from these sources.

The ability to borrow successfully depends on the creditworthiness of local governments. In lieu of significant intergovernmental transfers, national governments can provide other forms of support to local governments. This includes: capacity building for achieving municipal creditworthiness and issuing muni-bonds; issuing national bonds for the purpose of funding adaptation investments where they have investment-grade credit ratings; or placing guarantees on municipal borrowing to reduce risk for private and institutional investors.

Compared to upper-income countries and cities, city-level borrowing is less common in middle- and lower-income countries. Local-level credit ratings are likely to be below investment grade (where ratings exist at all) which are proxies for financial maturity and ability to implement extensive adaptation investment programmes. In these instances, technical and capacity-building support from international donors or financial institutions can help cities improve their financial maturity.11

### Relationship between city and national level credit ratings

The graphic, based on London School of Economics analyses, shows a general correlation between city and national credit ratings. For national credit ratings, indices of 1 to 17 represent indexed ratings from the major international ratings agencies with 1 being the lowest rating and 17 being the equivalent of AAA. A credit rating of 8 or above (dotted line) indicates an investment grade rating. For city credit ratings, indices of 1 to 17 represent local ratings, some of which correspond to international ratings.

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Cities in the upper right quadrant (e.g. Stockholm, Mexico City, Mumbai) are relatively financially mature with sound municipal finances combined with highly rated sovereign debt of their respective countries. Cities in the bottom right quadrant (e.g. Denver) have the advantage of being in a highly rated country but are themselves underperforming in their reputation for municipal financial management. There are examples of cities such as Dakar and Kampala that have worked to increase their financial maturity despite being located in countries that are below investment grade internationally, as seen in the top left quadrant. Finally, the bottom left shows where both city and national level credit ratings are below investment grade.

5.3.2.3. Land value capture

Land value capture (LVC) refers to a broad range of tax and finance instruments which create revenues from property values. They range from one-time exactions in the course of a land development project to ongoing/recurring income sources, e.g., taxes paid by landowners to government authorities (see Table 7). LVC can be used to part-finance infrastructure in combination with public, debt or equity investments. Their importance goes beyond revenue-raising; LVCs are a tool for directing the shape of urban form and infrastructure. There is ample evidence that LVC can be used to drive more compact urban development (NCE Annual Report, 2016). In this way LVC can create an adaptation benefit, for example concentrating development activity in areas that are naturally protected from climate impacts or can be engineered to do so (i.e., away from flood plains or near flood defence systems).

<table>
<thead>
<tr>
<th>Method</th>
<th>Characteristics</th>
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</thead>
<tbody>
<tr>
<td>Land value</td>
<td>Land value tax is a type of value capture technique designed to capture the</td>
</tr>
</tbody>
</table>
taxation
value created by the provision of public services more generally, including adaptation.

Negotiated exactions
Negotiated exactions require developers to contribute, which may involve giving up part of their land or facilities in return for far greater off-site benefits, such as improved flood control.

Tax Increment Financing (TIF)
This funding method estimates the level of development that will occur as a result of a public investment (usually transport) and uses the expected growth in property tax revenues to fund the upfront investment via a TIF bond.

Special Assessments
This is a fee collected by the city for improvements of services the city provides that benefit property owners, e.g., green and blue infrastructure.

Joint Development
Joint Development is a partnership between public sector and private operator and developers in order to share the financial burden of an investment. This may include the incremental cost for added resilience.

Transportation Utility Fees
In TUF a transportation improvement is treated as a utility (e.g. water, electricity) and is paid for by a user fee. This may include the incremental cost for added resilience.

Impact Fees
These are one-time charges applied by local governmental to an applicant in connection with approval of a development project for the purpose of financing a portion of the cost of public facilities related to the development project.

Air rights
Air rights are a form of value capture that involves the establishment of development rights above, or in some cases below, a transportation facility that generates an increment in land value. Additional floor area allocations may help offset incremental resilience costs.

Based on Medda and Modelewska (2011).

There are many ways in which public investments can positively impact the value of the land and therefore create private gain for landowners, for example, investments in infrastructure and utilities, and public parks and open spaces. Investments that minimise damage risks to properties and business operations should be included in this list. It is appropriate, then, for these gains to fund at least a portion of the public investment that contribute to the land value.

Value-capture instruments are contingent on a functioning tax regime but also on well-functioning and transparent property markets with accurate property records and sound designation of land units or administrative areas (World Bank 2013). In practice, this may limit the use of LVC in middle- and lower-income country cities. More so, a large number of macroeconomic matters which are highly influenced by national policies (e.g., regulatory certainty, monetary policy) contribute to real estate and land asset value and thus the revenue potential from LVC (Sandroni 2010).

Collaboration between national and local government, LVC
Where statutory authority for local taxation is limited, national and local governments can work together to achieve the desired outcome. In the Nine Elms section of London, the UK Government is providing a £1 billion loan guarantee linked to a Tax Increment Finance (TIF) bond to fund a metro line extension (London Underground) that is controlled at the mayoral level. The debt will be repaid through a levy on the area’s development sites and through future growth in business rates revenue.
which will be retained locally. Traditionally, business rates are collected locally but sent to the national government. An independent economic study concluded that the wider economic benefits of extending the metro would pay for the scheme between three and nine times over.


5.3.2.4. Pricing, regulation, and standards

Authority vested with local government offers numerous ways to provide direction, incentives, and requirements to increase resilience in the delivery and operation of private and public assets. These actions, broadly grouped as steering finance, can be drawn from government’s role in taxation and fiscal policy, as a development and environmental regulator, and provider of public records and datasets. In other ways, government acting in a strategic planning and convenor role can be similarly important. For example, it can:

- coordinate multiple stakeholder groups such as companies, governments and community to solve collective problems. (e.g., regionalised insurance pools, conditioning infrastructure spending, drawing in private sector advisory/expertise resources);
- set an adaptation vision and roadmap to clarify how the private sector and citizens can engage and participate in the solutions; and
- identify adaptation projects “outside the fenceline” of corporate assets but with direct impacts on corporate operations to generate buy-in for shared investment (e.g., to transit/transport, communications, water and power assets) (GARI 2016)

Government has long used tax codes and subsidies to incentivise or dissuade behaviours and expenditures and influence investor appetite, and could do so for investments in adaptation. Along with pricing, regulations can be a highly effective instrument: for example, land development regulations that promote medium to high density developments around mass transit systems can incentivise low-carbon mobility, protect natural environments, and minimise exposure to climate-related risks. Building codes and standards can steer private finance to buildings that maximise passive design and minimise the need for active cooling, as well as promoting the generation of local, distributed renewable energy. Utility regulation can further accelerate the deployment of distributed infrastructure (e.g., energy, water, waste), often delivering improved and more resilient services at lower costs driven by private investments.

Where governments undertake actions to reduce climate impact risks via direct investments or in emergency preparedness, these indirectly support and improve the capacity of insurance markets to serve local areas. Put another way, increasing disaster risk will increase the cost of insurance and can ultimately make insurance unaffordable. This can lead to a market exit by the insurance industry and make government an insurer of last resort. Through actions of government to reduce disaster risk, insurance solutions become more viable, affordable, accessible and scalable.

**UNEP Finance Initiative: Principles for Sustainable Insurance (PSI)**

This industry-led initiative aims to, amongst other objectives, influence how the insurance industry
can work together with governments, communities and clients to deliver local, national and international solutions that build inclusive and disaster-resilient economies. In collaboration with ICLEI, PSI recently produced a declaration on “Insurance Development Goals for Cities”. These are captured in the “Bonn Ambition”, which aims to achieve three goals by June 2018 (when ICLEI hosts its World Congress in Montréal, Canada), namely:

1. Create “Insurance Development Goals for Cities”, which would harness the insurance industry’s triple role as risk managers, risk carriers and investors in the context of the SDGs, focusing on SDG 11—“Make cities inclusive, safe, resilient and sustainable”. The idea is for the PSI and ICLEI to convert SDG 11’s stated targets into Insurance Development Goals that would set the long-term global agenda for the insurance industry and cities.

2. Develop city-level sustainable insurance roadmaps to drive strategic approaches and collaborative action by insurers and local governments. This could be linked to the Insurance Development Goals for Cities, and would complement ongoing efforts to develop national sustainable insurance and finance roadmaps.

3. Organize the first-ever roundtable of insurance industry CEOs and city mayors at the 2018 ICLEI World Congress to accelerate global and local action. The Congress is held every three years and assembles hundreds of local governments and key stakeholders to set the course for globalising urban sustainability.

(UNEP FI, 2017)

5.3.2.5. National and subnational investment vehicles

National and subnational investment vehicles describe a range of institutions and facilities with a mandate to steer investment toward specific national policies or development objectives, including carbon reductions and climate resilience. They can be capitalised through multiple public (national, and potentially international donor funds and multilateral development banks) and private (commercial and institutional debt and equity) sources. Structures include:

- **Green Investment Banks.** GIBs can be considered an emerging subset of national or regional development banks. At present, there are 12 GIBs capitalised and operational. They are a mix of national (Australia, Japan, Malaysia, Switzerland, and United Kingdom); US state (five in total); and city-level (just one, Abu Dhabi) institutions (OECD 2016). Research on leverage ratios shows that the UK Green Investment Bank has mobilised an estimated USD 3 for USD 1 invested; and the US State of Connecticut Green Bank has attracted USD 10 in private investment per USD 1 of public capital (NCE Annual Report, 2016). GIBs tend to have a mandate to generate commercial returns, with governance structures to operate as independent institutions separate from direct government control. Though green investments can be mainstreamed within existing government-supported development banks, the experience to
date suggests the value of centralising expertise in an institution dedicated to leveraging and mobilising green investment can unlock larger private capital flows (OECD, 2016).

- **Green Funds**: Rather than establishing stand-alone institutions such as a Green Investment Bank, Green Funds can provide a pool of capital for targeting specific investments or class of investments. The intent is to provide early-stage market support to technologies or systems to advance government policy. Green Funds will be tied to/managed by existing agencies or ministries within government. Green Funds may be more limited in their scale or impact compared to a Green Investment Bank which has the ability to borrow and thus leverage its government seed capital. However, it will have a smaller impact on a government’s balance sheet compared to a Bank whose entire capitalisation will be counted as government debt (UK Parliament, 2011).

- **Aggregation Platforms**: Aggregation platforms can support the bundling and potential securitisation of multiple small investments. They address the key issue of scale that blocks private finance interest in certain new markets and/or markets defined by the perceived or actual small size of the project or asset. Distributed renewable energy and energy efficiency investments are prototypical markets that would benefit from aggregation. Even with larger infrastructure investments, the fragmented nature of the market (lots of small and medium size cities) means that many bankable projects escape the attention of large investors. In these circumstances, smaller cities can benefit from national platforms, which provide both independent technical advice and aggregate smaller infrastructure projects which may be of a similar nature (Floater et al., 2014). Aggregation platforms can provide a needed secondary market to recapitalise primary investors, and help promote project development and project contracting standardisation.

### New Jersey Energy Resilience Bank

Following the damages incurred from Hurricane Sandy in 2012, the US state of New Jersey sought a financing resource to build resilience to extreme weather events. The result was the creation of the New Jersey Energy Resilience Bank, whose mandate is to finance power projects that protect infrastructure from power outages. The bank focuses on infrastructure upgrades and the development of distributed energy resources that allow critical facilities, such as water plants, hospitals and schools, to operate independently during power outages, natural disasters or other emergencies.

The bank was created utilising $200 million of second round Community Development Block Grant-Disaster Recovery (“CDBG-DR”) funds allocated to New Jersey by the U.S. Department of Housing and Urban Development (“HUD”). Rather than a stand-alone institution, it is administered by the New Jersey Economic Development Authority (EDA). Applications for project finance were opened in 2014 and funds allocated in 2016 and 2017. Projects include installation of combined heat and power plants at three hospitals. Further application rounds have yet to be announced.

Sources: New Jersey Economic Development Authority; Renewable Energy World (2017)
5.3.2.6. **International finance facilities**

A range of other dedicated multilateral facilities or institutions for blending private and public infrastructure finance is emerging internationally. Most target middle- and lower-income markets, though this is not exclusively the case. It is likely that adaptation will become a growing focus for some of these existing funds/facilities, or that dedicated adaptation facilities will emerge.

### JESSICA (Joint European Support for Sustainable Investment in Cities Areas) Fund

The JESSICA (Joint European Support for Sustainable Investment in Cities Areas) fund, an urban renewal investment vehicle established by the European Community in 2008, allows for the blending of subsidies from the European Economic Community, State aid and transfers, the local governments’ own revenues, private sector investments, and loans or guarantees provided by the European Investment Bank (EIB) and other banking institutions. JESSICA offered a departure from typical EU grant-based transfer mechanisms as Member States (MS) were given the option of using some of their EU Structural Funds allocation to make repayable investments in projects as part of an integrated MS plan for sustainable urban development. These could take the form of equity, loans and/or guarantees, delivered to projects via Urban Development Funds and, if required, Holding Funds.


One present example of a dedicated adaptation facility is the Adaptation Fund, established under the Kyoto Protocol of the UN Framework Convention on Climate Change. The Fund is financed in part by government and private donors, and also from a two percent share of proceeds of Certified Emission Reductions (CERs) issued under the Protocol’s Clean Development Mechanism projects. Similarly, the Green Climate Fund (GCF), established in 2010 as an operating entity of the UN Framework Climate Change Convention’s financial mechanism, is presently capitalised at US$ 10 billion with a goal to achieve a 50/50 balance between mitigation and adaptation investment. Key features of the GCF include:

- ability to attract and channel direct private sector investments through a Private Sector Facility (PSF);
- its risk-bearing capacity, allowing the Fund to support innovation and leverage and crowd in additional financing; and
- the variety of financial instruments it can make available, e.g., grants, concessional loans, subordinated debt, equity, and guarantees.

The GCF held its first regional workshop for Eastern Europe and Central Asia in June 2017 to introduce finance modalities create better regional knowledge sharing on mitigation and adaptation investments.

5.3.2.7. **Public private partnerships (PPPs)**

A Public-Private Partnership (PPP) is a contract to utilise a combination of private-sector capabilities in the design, finance, construction, and operation of public infrastructure assets. PPPs were developed
so that the service delivery objectives of the government could be aligned with the profit objectives of the private partners, and where the effectiveness of the alignment depends on a sufficient transfer of risk to the private partners (OECD 2010). PPPs can be structured in several ways, ranging from franchising or operating agreements between government owners of infrastructure and services, and the private operator and delivery partners; to infrastructure and service assets that are built and operated by private entities to specifications/operating terms from contracting government agents.

PPPs offer a finance solution to public entities where private capital is less costly than public capital, and/or where the public sector lacks the technical development and operational/managerial resources to efficiently develop and operate a particular infrastructure asset or class of assets (UNCTAD, 2013). So as to meet the higher return expectations from private investors than is needed for public finance, the universe of suitable projects for PPS is limited principally to those which can generate sufficient income-backed returns (Habitat III 2016).

The policy frameworks and infrastructure planning documents governing PPPs generally do not require explicit consideration of climate change impacts, though some exceptions are found at the regional level in Australia and in North America. There are financial instruments that could be used to address climate risk in PPP contracts, however, such as index-based weather derivatives, catastrophe risk deferred draw-down options (CatDDO), sovereign insurance schemes and property catastrophe risk insurance. Ideally, infrastructure projects that consider climate risks and are designed to be less vulnerable to climate impacts should be more attractive to investors and cheaper to insure and thus improve the business case for potential investors (Vallejo & Mullan 2017).

5.4. LEVEL 4: Inputs

5.4.1. Sources of urban adaptation finance

One of the most important factors for determining the most effective financing mechanisms to use is the available range of finance sources, both public and private. Level 4 of the cost assessment framework provides guidance on the range of finance sources potentially available. The extent of public and private investment in climate adaptation measures, and the specific finance sources for the investment, is not presently well quantified nor identified (UNEP 2016). One reason is the lack of investment tracking where adaptation is a secondary or even tertiary driver of the investment, e.g. government expenditure that serves other purposes and is approved on those other grounds. The same can largely be said of private entities. While households and corporations do invest in adaptation – albeit generally in a reactive way to observed impacts, rather than in a proactive and strategic fashion - they do not typically label their actions as adaptation as it is implicitly bundled in broader risk management processes (Averchenkova et al. 2015).

There are areas of adaptation investment for assets that arguably will remain the remit of government solely, e.g., large-scale flood defence/flood barrier works (natural and engineered), emergency shelters and cooling centres, etc. Reasons for this public-sector exclusivity include scale, jurisdictional complexities, integration with core public services, or lack of income or asset appreciation from which private investors can generate returns.

Other types of investments or investment areas may be served from a mix of public and private sources such as distributed energy, smart grids, and energy storage; transportation infrastructure (road, rail, sea, air) designed with added resilience against future climate projections; and dual-purpose urban
landscape and amenity features (e.g., green and blue infrastructure in recreation areas, nature reserves, and public thoroughfares). In such areas, a range of market liberalisation, technology changes, or public and private finance and value capture mechanisms allow for public benefits and private returns to be realised simultaneously. Concurrently, many private investors and companies, seeing their own climate vulnerabilities, are recognising the importance of private finance and investment in addressing the physical impact of climate change. Examples of investments that will be solely made by private entities include properties elevated or with basements designed to withstand flooding or with passive cooling and ventilation. While these are largely made to avoid private losses, there is a broader public benefit justification which can be addressed through government regulatory powers.

Table 9 provides a sample of some of the presently utilised and prospective sources of adaptation finance and investment/asset resources that can be mobilised by public and private agents.

**Table 9 Adaptation finance sources**

<table>
<thead>
<tr>
<th>Source of investment</th>
<th>Source of adaptation finance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public only</td>
<td>Public-Private</td>
</tr>
<tr>
<td>Government agencies: operating budgets</td>
<td>• Intergovernmental transfers</td>
</tr>
<tr>
<td></td>
<td>• Local (own-source) revenue</td>
</tr>
<tr>
<td>Government agencies: capital budgets</td>
<td>• Capital markets: bonds, loans</td>
</tr>
<tr>
<td></td>
<td>• Intergovernmental lending</td>
</tr>
<tr>
<td></td>
<td>• International, national finance institutions, climate resiliency funds</td>
</tr>
<tr>
<td>Corporatised public or private regulated utilities and authorities</td>
<td>• Government grants</td>
</tr>
<tr>
<td></td>
<td>• Ratepayer recovery</td>
</tr>
<tr>
<td></td>
<td>• Special assessments</td>
</tr>
<tr>
<td></td>
<td>• Capital markets: bonds, loans from commercial financiers</td>
</tr>
<tr>
<td>Private individuals and operating companies</td>
<td>• Franchise service agreements</td>
</tr>
<tr>
<td></td>
<td>• PPPs</td>
</tr>
<tr>
<td>Private investors</td>
<td>• Infrastructure equity funds (private/institutional or listed)</td>
</tr>
</tbody>
</table>
Changes in government operations and capital spending over the past decades has resulted in more infrastructure either being operated or financed by the private sector or through collaborative actions between government and private industry. Yet there are presently no dedicated private investment vehicles for infrastructure focused on climate adaptation and resilience (GARI 2016). Thus it is a challenge of government to create underlying conditions and specific adaptation investment opportunities that could spur demand for such investment vehicles.

5.5. **Conclusion: prioritising financing options in cities**

Practitioners making adaptation investment decisions will need to go through an iterative process where damage costs, adaptation benefits and costs of adaptation are quantified, and provisional finance mechanisms are identified. It is iterative in that each informs another, leading to a determination of:

a) types of climate events and damages where a response should be prioritised;

b) the economic net benefit of the response; and

c) the feasibility of implementing the response.

The findings for b) largely answer: *is the adaptation measure cost-effective?* The findings for c) will partly depend on availability of finance at the local level, and the transaction costs (e.g., project structuring and steps to financial close; or process steps and political capital for a change in regulations) associated with the measure. More simply, it helps answer: *can it be implemented?*

Referring back to Phase 5 of the Urban Adaptation Assessment Tool (see section 5.1 above), the steps listed for implementation can be amended as:

- Identifying key *finance* instruments for adaptation,
- mainstreaming adaptation in existing *finance* instruments, and
- developing new *finance* instruments if required.

These are described further in the subsections below.

5.5.1. **Identifying key finance instruments for adaptation**

For the first – identifying key finance instruments – a number of finance mechanisms were described that generally are within the remit and resource base of local government. Not all will be available to cities, depending on their level of financial maturity.

Use of these mechanisms in adaptation finance has been limited - or certainly, specific adaptation investment case studies are limited. Where case studies do exist\(^{12}\), learnings can be drawn on the finance instrument(s) and these should be used. Short of those resources being available, a useful first

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\(^{12}\) See EEA (2017) for eleven European cases of financing urban adaptation. For example, the case study for Malmö’s new harbour district lists: Adaptation measures financed (Green roofs, Green areas, Stormwater management measures); Financing sources (private investors, National and EU funds); Financing type(direct financing of adaptation measures); and Financing mechanisms (stakeholder partnership; national and EU funding mechanisms).
The step is to compare the finance mechanism to the investment barriers faced at the local level as shown in the table below.

**Table 10 Examples of how finance mechanisms can overcome investment barriers**

<table>
<thead>
<tr>
<th>Lack of upfront public capital</th>
<th>Institutional boundaries</th>
<th>Institutional capacity</th>
<th>High risk and low returns</th>
<th>Imperfect information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiscal decentralisation</td>
<td>Establish new revenue collection and distribution authorities</td>
<td></td>
<td>Opportunity to match investor demand for green bonds</td>
<td>Aligns public and private investment / asset risk and appreciation strategy</td>
</tr>
<tr>
<td>Bonds and debt financing</td>
<td>Governments can borrow, repay over long-terms</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land value capture</td>
<td>Revenue raising tied to specific local-area investments</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pricing, regulation and standards</td>
<td>Supports well-functioning insurance markets</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(sub)National investment vehicles</td>
<td>Dedicated finance funds, instruments independent from existing governance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>International finance vehicles</td>
<td></td>
<td>Local entities can tap national-level expertise</td>
<td>Blends public and private finance to minimise risk of private losses</td>
<td></td>
</tr>
<tr>
<td>Public Private Partnerships</td>
<td></td>
<td>Local entities can tap international-level expertise</td>
<td>Risk shared between public and private participants</td>
<td></td>
</tr>
</tbody>
</table>

The cells are of the table are examples and not meant to be comprehensive. What is most important is whether there is a relationship between barrier faced at the local level and the finance mechanisms more generally. Where decision-makers have identified barriers – most of which will be known from their understanding of gaps in infrastructure and urban services investments overall – they can focus on the finance mechanisms available to overcome that barrier.
5.5.2. Mainstreaming adaptation in existing finance instruments

As discussed previously, adaptation investments will range from incremental changes to existing investment programmes and policies where adaptation is a co-benefit, to creation of discrete adaptation investments programmes or policies driven by the need to address a specific climate risk and in a way that adaptation is the driver for implementation. Mainstreaming the former involves skills and capacity to identify and understand the incremental difference and embed those differences in the existing investment or policy. The latter is likely to be more costly (in terms of process and funds invested). In either case, while the adaptation feature is new, the consistency with government processes for decision making is not likely to be so (though the tools and how they applied toward the decision-making, as described in sections 3.3 and 4.3, may very well be).

The table below summarises some of the key considerations for decision-makers against the potential adaptation finance mechanisms. Local government capacity to utilise these mechanisms for adaptation will vary and should be understood as part of an exercise to match prospective finance to an adaptation investment.

Table 11 Mainstreaming finance mechanisms for adaptation

<table>
<thead>
<tr>
<th>Instrument (mechanism)</th>
<th>Key considerations for mainstreaming instrument</th>
</tr>
</thead>
</table>
| Fiscal decentralisation| • Statutory rules on local government revenue raising  
                        • Local government technical capacity (optimal tariff/rate-setting, budgeting, collection)   
                        • Long-term certainty on local taxation powers |
| Bonds and debt financing| • Statutory borrowing authority of local governments   
                            • Creditworthiness of government entities as assessed by lenders, investors  
                            • Sufficient 'headroom' within borrowing limits   
                            • The repayment mechanism, i.e., will loans, bonds be repaid through project/asset or general revenue  
                            • Does the adaptation investment create an income stream |
| Land value capture      | • Government’s ability to levy, retain property-based taxes locally  
                        • Methods and capability to link and assign the tax or fee to the uplift in the property value resulting from the adaptation investment  
                        • Health of the local property market, e.g., are values generally depreciating or depressed, are storm events and other climate impacts causing discernible damages and financial stresses in the property sector  
                        • The extent of public land and property assets that can be utilised in LVC mechanisms   
                        • The need for one-off or short-term versus recurring income |
| Steering adaptation investment| • Level of local statutory control over land use/land planning decisions  
                            • Level of in-house technical capacity in climate risks, hazard assessments, design standards, insurance markets, etc.  
                            • Ability to offer tax incentives or concessions to influence purchase and investment decisions  
                            • Degree of public trust in government’s emergency preparedness (timeliness and equity) and adaptation priorities |
(sub)National investment vehicles
- Technical capacity to create finance products/funds, raise partner capital from private sources, and structure investments
- Balance sheet treatment of guarantees and other loss-reserve mechanisms based on accounting practices
- Ability to identify adaptation investment projects and deploy investment resources in a timely fashion
- Collaboration with national governments to steer investment for local-level needs

International investment vehicles
- Ability/eligibility of local governments to serve as investment counterparties to international funds and finance institutions
- Collaboration needed with national government to access international finance resources for adaptation

Public Private Partnerships
- Established public private partnership visions, policies, and strategies that create clarity in contractual matters such as climate hazards and damages (who bears the loss, how are climate events characterised and damages classified)
- Presence of enabling legislation to enter into counterparty agreements with private entities for goods and services delivery
- Presence of dedicated PPP units or stand-alone institutions, and/or defining organisational roles and undertaking capacity building within existing agency structures
- Understanding of risks, roles and responsibilities for government during different phases of the project lifecycle, i.e., feasibility, procurement, operations, and transfer/close-out, particularly in long-life contracts where climate variability and impacts are hard to predict

5.5.3. Developing new finance instruments if required

Cities may indeed be in a position to develop new finance instruments as a way to cost-effectively implement climate adaptation projects. PACE financing\(^\text{13}\), a tool used in the US for financing energy efficiency improvements in residential and commercial buildings, was started in one municipality in California and has spread nationally. It is more likely the case that cities can apply existing finance instruments to new investment types (e.g., using land value capture to finance adaptation); shift regulations and incentives (e.g., floor area bonuses in exchange for green roofs or permeable paving areas); or take advantage of financial product innovation that is helping to shift more mainstream finance into ‘green’ finance, (e.g., issuing green bonds or being anchor sponsors/investors in green banks).

Cities may also draw information from collaborative initiatives between the finance sector and private investors, research institutions, NGOs, and international finance institutions to experiment with new financial models so as to accelerate the deployment of private capital into climate change and other environmental investment opportunities. The Lab for Global Finance Innovation\(^\text{14}\) is one such endeavour (targeting developing countries). A European initiative of the European Mortgage

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\(^{13}\) Property Assessed Clean Energy financing (PACE) is a mechanism where the energy efficiency loan is tied to the property rather than the borrower. Total loan value of commercial and residential PACE loans issued since 2009 is nearly USD 3 billion.

\(^{14}\) “The Lab identifies, develops, and pilots transformative climate finance instruments. It aims to drive billions of dollars of private investment into climate change mitigation and adaptation in developing countries.” http://climatefinancelab.org/
Federation\textsuperscript{15} that brings together the banking sector and green building NGOs to create standard green mortgage products to scale energy efficiency renovations in the housing sector is another example. More initiatives directly targeting innovation in adaptation finance and risk-sharing instruments are likely to be seen and should be tracked by local government policy-makers.

6. Conclusions

In order to utilise limited public finance resources and mobilise private finance effectively, city governments will need appropriate processes and resources for sound investment planning and execution. Despite this, most cities lack the tools for performing economic assessments of damages, adaptation, and financing options.

To help policy makers make adaptation decisions more effectively and efficiently, RAMSES has developed a cost assessment framework that follows a hierarchical approach for prioritising and financing adaptation. The cost assessment framework is divided into three key iterative phases across four levels. The three phases define a procedure for [1] assessing risks and vulnerability based on damage costs, [2] identifying and assessing adaptation options based on their economic net benefits, and [3] planning and implementing city investments based on a range of financing mechanisms and funding models.

The three phases are overlapping and interrelated, requiring a flexible process of costing and decision making. For example, the process for prioritising which climate hazards a decision maker should target with adaptation efforts cannot be performed in isolation. The results in Phase 2 feed into the analysis of Phase 3/4 for costing the net economic benefits of adaptation. Similarly, the economic benefits of adaptation options (Phase 3/4) will both influence and be influenced by the finance mechanisms and city investments chosen by the city (Phase 5). Finally, both the analysis of net economic benefits of adaptation, as well as the analysis of finance mechanisms in Phase 5, will to some extent determine which hazards limited resources should be directed at.

Part of the difficulty in performing cost and benefit assessments for climate impacts and adaptation investments relates to factors including (but not restricted to) uncertainty (e.g., related to the timing and severity of the climate change/event; the assets, systems and people who will be exposed, the scale of the damage, and the prices to mitigate against the damage and to restore/rehabilitate, etc.); the cost-optimal timing of the investment; data availability, especially at the city level; and thresholds or tipping-points after which damage scales dramatically and adaptation measures are ineffective. The methodologies presented in the cost assessment framework allow decision-makers to better identify the right tools and processes to prepare cost-effective adaptation strategies given the inherent information limitations.

At the same time, policy-makers tasked with determining how to implement adaptation options deemed worthwhile from their economic benefits will be influenced by the available local government finance or likelihood of finance instruments becoming available and ability of local government to influence finance flows from other public sources; and ability for investments to be borne by private

\textsuperscript{15}The idea is to incentivise homeowners to move their properties out of the ‘brown’ zone (e.g. energy rating E-G) and into the ‘green’ zone (e.g. energy rating A-D) by way of preferential interest rates or additional funds at the time of origination of the mortgage.” http://hypo.org/ecbc/market-initiative/emf-ecbc-energy-mortgages-initiative/
actors based on the private and public co-benefits realised. Without this knowledge related to financing, a full determination of which options to prioritise cannot be completed.

The framework offers guidance to understanding finance mechanisms available at the city level and their application to adaptation projects. It examines three areas of government action that will be needed for channelling substantial investments into sustainable infrastructure: (1) raising finance (e.g. through national government transfers, international funding and bond markets), (2) steering finance (creating markets for sustainable infrastructure investments through pricing, standards and regulation) and (3) blending finance (to leverage the scale of private and institutional capital required).

Underpinning these action areas, a range of promising financing mechanisms exist including land value capture, green bonds, fiscal decentralisation and development bank investments. Combinations of financing mechanisms need to be tailored to city-specific income levels, financial maturity and government capacity.

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