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Understanding climate change impacts, vulnerability and adaptation at city scale: an introduction

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Roughly half of the world's population live in cities, and this share is increasing yearly, projected to reach 60% by 2030 (OECD 2008; Fig. 1). Moreover, most of the urban population growth in this period will occur in developing countries, projected to have urban growth rates roughly double those of developed countries in the 2005–2030 timeframe. Cities also contribute a large proportion of national GDP and can thus be expected to be the dominant hubs of economic activity for every nation. While this is true in the developed world, it is increasingly the case in the context of developing countries (Bicknell et al. 2009). For this reason, cities provide not only jobs and centers of economic activity but also important social, environmental and cultural services (Bicknell et al. 2009; OECD 2008). This concentration of population and economic activity makes cities particularly vulnerable to climate change as they are the home to valuable built infrastructure and to a large number of the world's poor, and as they account for 60–80% of world energy use (Bicknell et al. 2009; IEA 2008; Newman et al. 2009).

As a consequence, the way cities develop and how they manage energy consumption will be keys to successful climate policy both from mitigation and adaptation points of view. Moreover, the mitigation of greenhouse gas emissions at city scale will deliver not only global benefits in the form of avoided climate change, but also local

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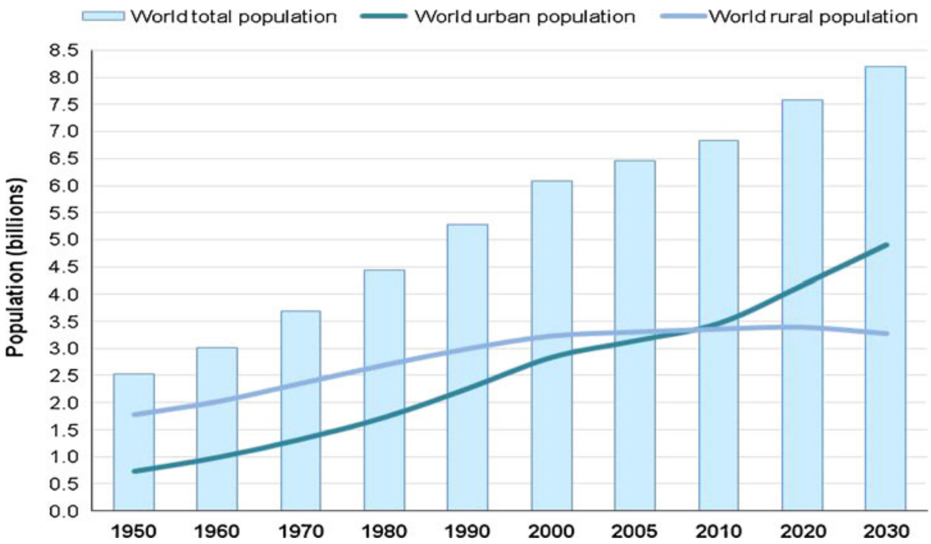

Fig. 1 World population trends—urban–rural breakdown. Source: Based on data from the United Nations (2006) as cited in OECD (2008)

co-benefits, including cleaner air, quieter and greener outdoor spaces and, in some instances, jobs in new "green" business areas such as clean energy or waste recycling and reuse (OECD 2000; Bollen et al. 2009). Urban scale adaptation can also deliver co-benefits, for example in ecosystem services or water and energy security benefits, while also limiting the direct and indirect impacts of climate change.

In response to these challenges, a growing number of cities have taken bottom-up initiatives to achieve greenhouse gas reduction as part of city policy objectives (Bintliff et al. 2007; Bulkeley and Betsill 2005; Betsill and Bulkeley 2007; Lowe et al. 2009). Cities have also begun to work together in transnational networks to strengthen greenhouse gas reduction efforts and learning, including through combining their purchasing power to achieve common goals such as improved energy performance of public buildings (e.g. C-40 2010; Betsill and Bulkeley 2004, 2007). But despite increased attention to climate change at the urban scale of governance, some issues have received far more attention than others. In general, impacts, vulnerability and adaptation to climate change have been the topic of significantly less research than mitigation at city scale.

A key adaptation challenge for local actors is to understand the nature of future climate change risks in their region and to identify the main drivers of urban vulnerability. Better understanding of drivers of climate change impacts will assist local authorities to communicate with local, other sub-national and national decision makers, to mobilize political will, to assess adaptation options and to design cost-effective and timely responses. The need for a foundation of knowledge about local vulnerability and impacts represents an opportunity for a fruitful two-way exchange between climate change scientists and impact experts on the one hand, and local and national decision-makers on the other (Cash and Moser 2000; Cash et al. 2006; NRC 2009).

There is mounting evidence of the need for adaptation planning at the local scale. In particular, many cities are likely to be hit by shifting climate patterns as well as possible increased intensity and frequency of extremes, such as flooding, heavy precipitation and cyclones, extreme temperatures and drought conditions (Baettig et al. 2007; Wilbanks et al. 2007). Three prime examples of extreme events that have primarily affected cities are the European heat wave in 2003, with dramatic consequences in many urban centres most notably in Paris (Beniston 2004; Schaer et al. 2004); the landfall of Hurricane Katrina near the city of New Orleans in 2005 (Burby 2006; Grossi and Muir-Wood 2006; Hallegatte 2008); and the Mumbai flood in July 2005 (Bhagat et al. 2006; Gupta 2007). These events demonstrate the types of extremes that could become more common with a changing climate and growing cities. Furthermore, a few cities appear to be at the forefront of adaptation planning and implementation (e.g., Chicago, London, Miami, New York, Paris, Toronto),[1] a number of umbrella groups have grown up to assist cities to learn from each other as they develop capacity and experience in this area,[2] and international organizations have started providing guides and report on how to include climate change vulnerability in urban planning (e.g., World Bank 2008, for East Asia cities; UNFCCC 2009).

In recent years, some local impact analysis has emerged to demonstrate the value of city-scale impact assessment, for example, in Alexandria, Boston, Copenhagen, London, Miami, Mumbai, New York, Singapore and Vienna.[3] These works tend to tackle different aspects of environmental risk in cities, taking climate change into account as one among many drivers of environmental change risks, such as flood risks and water system management (e.g., Rosenzweig et al. 2007), epidemiologic impact of ozone and fine particles pollution (e.g., Bell et al. 2007; Knowlton et al. 2004), and heat-related mortality (e.g., Dessai 2003).

Despite this proliferation of efforts on climate change impacts at city scale, to date the assessment of the *economic* impacts of climate change at this scale has received relatively little attention, as most analyses focus on physical vulnerability only. On the economic impacts of climate change (often referred to as damage costs), most of the literature has focused on global scale impacts (e.g. Tol 2002a, b; IPCC 2007a, b; OECD 2008; Stern 2007), and a relatively large body of literature critiques these estimates as being at best partial when used in formal economic analysis of policies (Schneider et al. 2007; Hitz and Smith 2004; OECD 2004; Hallegatte 2007). Also, the existing studies rarely include extreme events and their potential damages, even though the risk of certain events is likely to increase Schneider et al. 2007).

Given the paucity of work in this area, there is a need for bottom-up, local- and regional-scale economic assessments to inform cross-scale decision-making and to

[1]See City of Chicago (2008) and Parzen (2008), Greater London Authority (2008), Miami-Dade County Climate Change Advisory Task Force (2008), Mairie de Paris (2007), Toronto Environment Office (2008).

[2]See: Urban Leaders Adaptation Initiative [http://www.ccap.org/index.php?component=programs&id=6]; Alliance for Resilient Cities (ARC) [http://www.cleanairpartnership.org/arc.php]; and ICLEI's Climate Resilient Communities in the US and adaptation work in Europe: [http://www.iclei.org/].

[3]Kirshen et al. 2008 (Boston), Hallegatte et al., (2011b) (Copenhagen), Ranger et al., (2011) (Mumbai), LCCP 2002 (London), Ng and Mendelsohn 2005 (Singapore), OECD 2004 (Alexandria), Rosenzweig et al. 2007 (New York), Stanton and Ackerman 2007 (Miami), Compton et al. 2002 (Vienna).

provide important empirical evidence to improve global evaluations of impacts and vulnerability.

1 Aim of the special issue

This Special Issue reports on the results from a recent OECD project that explores local benefits of climate change policies in cities and the linkages between national and local climate policy responses. One of the aims of this project is to include in these local assessments the potential incidence and economic cost associated with changes in extreme events in cities.

This volume was conceived to begin to fill the gap in the literature on urban economic impact assessment, including the analysis of economic consequences and the role of extreme events as well as the need for finer grained evaluation of local and regional economic impacts of climate change. To do so, it focuses on coastal cities, which have been identified as "hot spots" for climate change (McGranahan et al. 2007). This volume draws on earlier OECD work which has been aiming to better assess benefits of adaptation and mitigation climate policies (Corfee-Morlot and Agrawala 2004). The volume consists largely of papers that were commissioned by the OECD. The focus of the papers is on economic issues, vulnerability to climate change and adaptation. Although the ultimate aim of all OECD work is to support policy-makers, the volume is also designed to add to the growing foundation of academic research on urban climate change issues.

This volume joins other OECD work that argues for the need to advance local understanding of climate change, which may be central to policymaking for a number of reasons (Corfee-Morlot et al. 2009; Kamal-Chaoui and Robert 2009; OECD 2009). These include advancing understanding of climate change vulnerability; developing political support for action; and designing and implementing timely, cost-effective and lasting policy responses (see also Corfee-Morlot et al. 2011). In short, better understanding and estimating of local vulnerability will assist decision-makers in managing vulnerability to climate change.

2 Overview of results

This volume starts with a review of existing literature on climate change impacts and adaptation at urban scale by Hunt and Watkiss (2011). They show that impact analysis at city scale is not new as they identify in-depth vulnerability, impact and adaptation studies in 36 major cities around the world. They find that a slight majority of available studies are qualitative, lacking any form of quantitative assessment. Less than one-fifth of the studies have some form of economic assessment or valuation of impacts. The studies present information on a predominantly narrow range of possible impacts, most typically including household or urban water supply (and/or quality) issues, impacts to built infrastructure, coastal zone management and energy issues. Reflecting both a historical preference for locating cities in coastal areas and the relatively advanced research area of climate change impacts associated with sea-level rise, the authors find that the majority of the cities that have detailed studies are coastal, with the assessment focusing on the risk from, and approaches to dealing with, rising sea level. A few studies also address other issues including impacts on tourism, cultural amenities or biodiversity. A small number of cities, including London and New York, have benefited from sequential impact and adaptation assessments and can draw on a series of studies to support and inform decision-making. In addition to highlighting the need to do more economic assessment at urban scale, Hunt and Watkiss underscore the need to increase the number of cities and the topics covered in such economic studies, for example to include more extensive treatment of the issues of water, energy, and non-market impacts.

From this literature, it appears that the applied methodologies (e.g., sector-scale or macro-scale analyses) and the analysis domain (e.g., with or without accounting for adaptation) are very different, making it difficult to compare results in a meaningful way across studies. To better understand the risks and cost-effective potential for adaptation to limit these, there is a need for more comprehensive impact and adaptation analysis at city scale. To do so, this project includes a concept paper, by Hallegatte et al. (2011a), which proposes a methodological roadmap to assess climate change impacts and policy benefits at city scale. Some of the components of this roadmap are already found in city analyses (e.g., change in energy consumption); others are more difficult and are rarely if ever addressed (e.g., non-market impacts, or cross-sector knock-on effects).

Another challenge is to explicitly take into account uncertainty about climate predictions, particularly at regional (sub-national) scale, as well as about socio-economic development pathways. Some of the gaps in the literature exist in part because current tools for urban climate impact assessment are lacking. The concept paper also notes that most existing analyses investigate only the physical vulnerability of cities to the direct impacts of weather and climate events. For instance, they assess future changes to the damages to buildings caused by flooding, or the health effects due to heat waves under a scenario with climate change. But it is well understood that socio-economic vulnerability is not only physical vulnerability; it depends on changes in physical parameters (e.g., building type and maintenance, elevation, etc) as well as socio-economic factors. For example, a slowly growing urban area with a large investment capacity is likely to be more resilient to a given flood event than a rapidly growing urban area without resources to cope with such a disaster (see for instance Benson and Clay 2004).

This importance of socio-economic drivers of risk associated with climate change means that adaptation strategies can aim to reduce the welfare consequences of climate change impacts, rather than at limiting the impacts per se. For instance, with sea level rise, the cost of protecting a coastal city against storm surges caused by more intense hurricanes can be too expensive to be desirable, especially considering the relative (in)frequency of these storms (Hallegatte 2006). However, it may be more efficient to cope with these coastal flood events than to avoid them. This can be done, for instance, through an early warning and evacuation system combined with a government- or internationally-supported insurance scheme. To be able to assess not only 'hard' adaptation using seawalls and water management infrastructure, but also 'soft' adaptation measures, such as using insurance and recovery and reconstruction plans, the case studies of this Special Issue include economic modelling and assess both direct and indirect losses.

Beyond the assessment of direct and indirect losses, and of adaptation policy benefits, any comprehensive assessment of the urban benefits of climate policy will require a number of other analytical steps. These include investigation of a range of mitigation scenarios, resulting in lower or higher emission pathways over time as drivers of climate change, and thus the local avoided-impact benefits of global mitigation. It will also include specific assessment of the side benefits and side costs (referred to here as co-effects) of climate policy action. These co-effects might be negative or positive. For example, implementing air conditioning in all buildings is an adaptation measure that might be taken to increase comfort levels inside buildings as local temperatures rise, but this measure may also increase urban heat island effects and thus further raise urban temperatures (Ohashi et al. 2007; Hsieh et al. 2007). Enhancing insulation, on the other hand, is an adaptation measure to cope with the same impacts but that may have positive co-effects, for example through lower energy bills. Any attempt to provide comprehensive analysis of climate policy options will need to address the full range of direct and indirect economic benefits, as well as the co-effects of policy options, to understand the full set of economic interactions (Hallegatte 2009).

An important characteristic of the studies described in this volume is that they investigate city vulnerability both at locale scales (with detailed case studies on two cities, namely Copenhagen and Mumbai) and at global scales (using a simplified methodology on all coastal cities with more than one million inhabitants in 2005). Analyses of climate change at global scale can only be done with simplified methods, but is useful as it provides information on the link between urbanization and climate change risks at the global scale. Global vulnerability is also useful information to assess how the global insurance and reinsurance system and existing international solidarity schemes will be able to cope with disaster losses in the future. A global analysis also indicates where the most vulnerable places are, and where more research (e.g., through more detailed case studies) would be most useful.

Such a global analysis has been carried out by Hanson et al. (2011). Their results demonstrate the importance of investigating flood risks in coastal cities. They found that 40 million inhabitants of coastal cities with more than one million inhabitants in 2005 are exposed to 100-year floods (i.e., floods that have a 1% chance of occurring every year). This means that this population is often dependent on coastal protection, and is at risk if that protection fails or is overtopped. In terms of assets, US$3 trillions are exposed to 100-year floods, i.e. 5% of world GDP. Taking into account future socio-economic development (population growth, increased urbanization, and economic growth), natural and artificial subsidence, and climate change (assuming a 50-cm sea level rise and a 10% increase in storm intensity), the exposed population is expected to increase three-fold by the 2070s, reaching 150 million inhabitants. One third of the increase would be due to climate change and artificial subsidence, and two thirds to socio-economic changes. Exposed assets would increase much more, reaching US$35 trillions by the 2070s, i.e. 9% of world GDP at that time. These results show both that exposed population and assets are likely to increase very significantly, potentially making urban flooding a much larger issue in the future, and that adaptation and risk management policies (e.g., land-use planning, flood defences, subsidence control) can yield very large benefits. To get into the details, and to analyze adaptation policies in practical situations, the project then turns to case studies.

Two case studies on Copenhagen (Denmark) and Mumbai (India) consider vulnerability, impacts of climate change and adaptation options at the local scale. Here vulnerability is shown to depend on many factors that vary widely, such as extreme event frequency and intensity, local elevation and topography, building types and norms, economic structure and wealth level, and cultural aspects of the population. As a consequence, estimating the vulnerability of any one city is a significant and time-consuming task, based on a large amount of local data and information. Yet carrying out case studies provides detailed insights about the complex and dynamic processes that lead to climate change impacts; such studies also help to verify that global scale analysis is reasonably robust in representing local specificities.

The first case study is carried out by Hallegatte et al. (2011b), on the city of Copenhagen, an industrialized-country low-growth coastal city, and considers the risks from storm surges caused by extra-tropical storms. Because of the high uncertainty on future sea level rise, this analysis assesses flood risks for a large range of possible sea level rises, from 25 to 125 cm. The case of Copenhagen investigates a city that can be considered to be a low-vulnerability high-adaptive-capacity location. Indeed, the city of Copenhagen is today very well protected against storm surge, both by its natural location and by its artificial flood defences. In the absence of these defences, however, total flood losses[4] would reach today EUR3.1 billion (US$3.8 billion) and about 5,000 jobs for the 120-year return period event (at 150 cm above average sea level). With 50 cm of sea level rise, and still no protection, these losses would increase by 140%, to EUR7.4 billion (US$9.0 billion) and more than 7,500 jobs. Protection levels appear adequate today but the analysis shows that even in such a well-protected city, proactive adaptation measures will be necessary in the future: without these, losses from coastal floods would soar and costly, frequent defence updates would be required. Importantly, these measures will require planning and anticipation, and institutions to design and implement them.

The second case study is carried out by Ranger et al. (2011) on the city of Mumbai, a rapidly-growing coastal city in a developing country. The analysis investigates the risks from heavy precipitation and associated urban flooding. This case is very different from the Copenhagen one: the city is considered as highly vulnerable, even under today's conditions. Moreover, the city has lower adaptive capacity, with about 50% of the population living in informal settlements and a drainage system that is insufficient to deal even with normal monsoon rainfall. There is no consensus on how precipitation will change over India in response to global warming, with half the models projecting an increase, and half predicting a decrease. The analysis carried out in this project is based on one climate model, the Precis model forced by the HadCM3 model in a SRES A2 scenario. Since this model projects a large increase in precipitation over India, the results in terms of flood risks can be considered as falling within the upper range of future possibilities. As a consequence, this study can identify the possibility of a future increase in flood risk but, alone, it is insufficient to design an adaptation strategy. Doing so would require repeating the present analysis with other climate models, to estimate the robustness of possible measures and assess their ability to cope with climate uncertainty. Another difficulty in investigating

[4]Total losses include (1) the loss of assets (e.g., buildings, production equipment, transport and energy infrastructure), referred to as the direct loss; and (2) the output loss that are due to the disaster, referred to as the indirect loss. A more detailed discussion of these categories and of the question of double-counting is provided in the concept paper of this issue (Hallegatte et al. 2011b).

developing-country cities is the scarcity in socio-economic data. This scarcity has been a problem in the Mumbai analysis, and much information had to be assessed with indirect methods, introducing a large uncertainty in all results.

Using the Precis model, flood risks are found to increase very rapidly in response to climate change; for instance the total losses (direct plus indirect) caused by the 100-year flood would more than triple, with indirect losses representing between 15% and 20% of direct losses. The paper also investigates the economic benefits of a set of adaptation options. These include an upgrade to the drainage system to reduce direct losses, and an increase in the reconstruction capacity and a generalization of insurance to reduce indirect losses. It is found that a combination of improved drainage and reduced building vulnerability could reduce mean losses below their current level, even with more extreme rainfall because of climate change. In addition, generalizing insurance coverage would reduce indirect losses by 50%. Estimates demonstrate the high potential for adaptation to significantly reduce the economic impacts of climate change. Moreover, although it was beyond the scope of this study to cost out adaptation measures, the analysis suggest that some are likely to be 'no regret,' meaning that they would be cost-effective for all possible changes in climate conditions, and even in the absence of climate change.

The final paper in this volume, by Corfee-Morlot et al. (2011), addresses governance issues, situating climate change adaptation as a problem of multilevel governance and calling for strengthening analytic-deliberative practice to facilitate decision-making at urban scales. It calls on national and sub-national governments to work closely with city authorities to ensure that there is legitimate policy space for cities to participate in the design and delivery of climate policy solutions. Given the fragmented nature of climate policy today, there is a need for basic tools to facilitate good decision-making. This includes improved analytical tools (i.e., scenario building and scientific assessment to characterise and understand uncertainty about predicted climate change and its impacts) as well as better institutional capacity to address climate change at local scales. The paper explores the possibility to use "boundary organizations", and a range of institutional models for these, to develop local scale climate impact assessment and support local science-policy dialogue as part of a local decision-making process. Drawing on a number of different examples, a key feature is identified as the aim to better develop, assess and integrate knowledge about climate change impacts into urban policy and decision-making as well as a two-way exchange between experts on the one hand, and stakeholders with local knowledge on the other. While the agenda for multi-level governance of climate change is inevitably much broader than this, an important enabling step can be taken by national governments to provide funding and technical assistance to establish boundary organizations that have the resources and the mandate to work closely with city authorities to do adaptation planning. National governments also need to work with local authorities to identify and resolve the inevitable jurisdictional overlaps, issues of mandate and a range of other barriers that limit cities from exploiting their unique proximity to local decision-makers to advance innovative local responses to climate change. If tackled today, enabling national policy frameworks could help city authorities and other local decision-makers to carry forward locally-tailored, cost-effective and timely solutions.

In summary, this project leads to a few major policy conclusions. First, the global analysis and the two case studies suggest that the risks from natural hazards are very likely to increase rapidly in coastal cities, because of a confluence of factors most notably socio-economic growth and climate change, which are likely to change at least the intensity if not the frequency of extreme weather events. In coastal zones, these drivers of vulnerability combine with human-induced land subsidence to increase exposure to rising sea levels and storm surge. Even though large uncertainties remain, a strong conclusion is that the role of climate change (and subsidence) is secondary but significant, following socio-economic development as the largest driver of change in exposure.

This project focuses on floods and coastal cities. To get a more complete picture of urban risks, and propose potential adaptation measures, the same type of analysis would be needed in other cities, including inland cities that face different threats (e.g., heat waves, water scarcity, local pollution episodes).

Second, socio-economic development can be influenced so as to reduce growing risks from climate change, for instance with risk-oriented land-use planning and urban design, or measures to reduce anthropogenic subsidence of urban areas built on susceptible soils in coastal zones. Such policies can be implemented at the city level of decision-making, however there is a need for coordination across neighboring cities and sometimes broader spatial scales (including the regional and national scales). This is because fragmentation of policies at sub-national scales is likely to lead to failure to deliver cost-effective adaptation outcomes and indeed may transfer the balance of climate risks from one location to another. Also, developing country cities face specific obstacles to the effective implementation of land-use and urbanization planning, including the important issues of rapid population increase, absence of land tenure, and informal settlements. There is a gap, therefore, between solutions suggested from risk analyses, and what can actually be implemented on the ground given institutional constraints and barriers.

Third, specific adaptation measures can be implemented to limit flood risks, for instance with sea walls and other coastal protections, improved drainage infrastructure (possibly with a change from gravity drainage to pumps), generalized insurance systems, early warning and evacuation systems, and enhanced reconstruction processes. These measures are meant to reduce either or both direct losses (i.e., destruction from natural hazards) and indirect losses (i.e., the welfare impacts of these hazards). It is likely that an optimal adaptation policy mix includes both measures aiming to reduce direct losses and measures targeting indirect losses.

Although a full economic assessment of adaptation options was not carried out, in many cases measures may be "no regret," that is they would yield benefits if implemented today, even in the absence of climate change. This is especially true in developing countries, in which basic urban infrastructure is often absent (e.g., appropriate drainage infrastructure), leaving room for actions that both increase immediate well-being and reduce vulnerability to future climate change. Adaptation actions often require anticipation to be effective, either because they require a lot of planning and design (e.g., sea walls or flood barriers) or because they are efficient only over the long term (e.g., land-use planning). For these reasons, it would be particularly beneficial to start immediately to develop careful cost-benefit assessments of such adaptation options, with local, context-specific information so as to design and implement adaptation and risk management plans in coastal cities. Such plans should integrate climate change considerations within routine urban land-use and infrastructure planning. This is especially true in developing country cities, because they are growing rapidly and they are in the process of designing and building urban infrastructure, which will determine urban form, and thus to some extent long-term vulnerabilities. Translating results from risks analyses like the ones presented in this special issue into policy-making is not trivial. This is particularly true in developing countries, which have limited resources to cope with the multiple challenges of managing rapid and often unplanned urbanization (see also Bicknell et al. 2009).

Beyond the specific case of coastal cities that is discussed in this issue, national governments and local authorities will need to work together to ensure that the potential for cost-effective anticipatory action at local level is developed and exploited to protect urban populations over time. Anticipatory decisions today can steer cities towards low-risk development which would have potentially high benefits over the coming decades to century.

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