United Nations Development Programme

Paving the Way for Climate-Resilient Infrastructure

Guidance for Practitioners and Planners

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Paving the Way for Climate-Resilient Infrastructure

Guidance for Practitioners and Planners

Official Proceedings

International Conference: Strategies for Adapting Public and Private Infrastructure to Climate Change

San Salvador, El Salvador
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DEFINITION

Climate proofing

Climate proofing refers to the explicit consideration and internalization of the risks and opportunities that alternative climate change scenarios are likely to imply for the design, operation and maintenance of infrastructure. In other words, integrating climate change risks and opportunities into the design, operation, and management of infrastructure.

Acronyms and Abbreviations

AsDB	Asian Development Bank
CAPRA	Central American Probabilistic Risk Assessment
CBA	cost-benefit analysis
CCA	climate change adaptation
CEA	cost-effectiveness analysis
CHIPS	Couple Hurricane Intensity Prediction System
CO_2	carbon dioxide
DRM	disaster risk management
DRR	disaster risk reduction
ECLAC	Economic Commission for Latin America and the Caribbean
EIA	environmental impact assessment
ETH	Swiss Federal Institute of Technology Zurich
EWS	early warning system
FRACC	Feedback-Rich Adaptation to Climate Change
GCM	global climate models
GDP	gross domestic product
GFDRR	Global Facility for Disaster Reduction and Recovery
GHG	greenhouse gas
GIS	geographic information System
HDI	Human Development Index
IDB	Inter-American Development Bank
IPCC	Intergovernmental Panel on Climate Change
ISDR	International Strategy for Disaster Reduction (see UNISDR)
JCSS	Joint Committee on Structural Safety
LECRDS	low-emission climate-resilient development strategies
LQI	Life Quality Index
MARN	Ministry of Environment and Natural Resources, El Salvador
M&E	monitoring & evaluation
MC	marginal cost
MCA	multi-criteria analysis
MNSB	marginal net social benefit
MOP	Ministry of Public Works, Transport, Housing and Urban Development, El Salvador
MSB	marginal social benefit
NGO	non-governmental organization
NSB	net social benefit
OECD	Organisation for Economic Co-operation and Development
PNG	Papua New Guinea
PDNA	Post Disaster Needs Assessment
PDF	probability density function
PIEVC	Public Infrastructure Engineering Vulnerability Committee
PRA	probabilistic risk assessment
SCCF	Special Climate Change Fund
SNET	National Service of Territorial Studies, El Salvador
SLR	sea-level rise
SVSL	societal value of a statistical life
SWTP	societal willingness to pay
TC	total cost
TSB	total social benefit
UNDAC	United Nations Disaster Assessment and Coordination
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNISDR	United Nations International Strategy for Disaster Reduction
UNOCHA	United Nations Office for the Coordination of Humanitarian Affairs
USAID	United States Agency for International Development

Foreword

Mr. Gerson Martínez

According to the Global Facility for Disaster Reduction and Recovery (GFDRR) and the United Nations Disaster Assessment and Coordination (UNDAC), El Salvador is recognized as the most vulnerable country in the world. The 2010 UNDAC report, *Assessment of the Capacity for Emergency Responses 2010*, states that almost 90 percent of the territory in El Salvador is located in an area of high risk. These areas are home to more than 95 percent of the country's population, and approximately 96 percent of the country's gross domestic product (GDP) is linked with these locations. According to studies from the Economic Commission for Latin America and the Caribbean (ECLAC), natural disasters have caused 6,500 deaths since 1972, with an economic cost of greater than 16 billon 2008 United States dollars. Of these impacts, more than 62 percent of the deaths and between 87 to 95 percent of the economic losses were related to climatic events.

These figures are alarming and give rise to considerable concern in light of the projections that El Salvador will experience an increase in frequency and severity of natural hazards as a result of climate change, particularly in relation to extreme rainfall. The country is already witnessing such extreme events, with devastating consequences including economic and human loss.

During the two first years of this administration, the country suffered extreme weather events with exceptional levels of rainfall. On 29 May 2010, during Tropical Storm Agatha, precipitation levels were recorded at 483 mm over the course of 24 hours with maximum rainfall intensity concentrated over six hours. The period of return for this level of intense rainfall is more than 300 years.

In November 2009, the combination of Hurricane Ida and a low-pressure system in the Pacific coast also presented extremely high rainfall intensity over six hours. Like Tropical Storm Agatha, the period of return for this level of intense rainfall is more than 300 years. The disaster provoked by Ida caused the death of 200 people, and directly affected another 122,816 people. The damages and material losses were estimated at $314.8 million, equivalent to 1.44 percent of GDP. The rehabilitation and reconstruction needs were estimated at close to $344 million.

These two events clearly demonstrate the country's high vulnerability to natural hazards, and the necessity to take preventive action through a combination of risk management and climate change adaptation measures. The Salvadoran government, through the Ministry of Public Works (MOP), the Ministry of Environment and Natural Resources (MARN), and the National System of Civil Protection, with the support of the United Nations Development Programme (UNDP), is currently developing a strategic framework to orient the decision-making process to protect life and ensure economic sustainability by increasing the climate resiliency of public and private infrastructure, and advancing toward climate change adaptation and strategic risk management. This framework will integrate the emergency, rehabilitation and reconstruction processes that are currently excluded from development plans. It will also help change the nature of the decision-making process from an emergency and mitigation-driven approach to a preventative and anticipative approach that takes into consideration climate change adaptation as well as natural resources and biodiversity recovery.

The objective of the framework is to incorporate guidelines into the planning, design, construction, operation and maintenance of public infrastructure; to actualize the legal framework and technical standards; to enhance State governance; to ensure financing for the sustainability of this policy and its conversion into State policy; and to promote a cultural change in this direction.

Mr. Gerson Martínez, Minister of Public Works, Transport, Housing and Urban Development of El Salvador

The international conference **Strategies for Adapting Public and Private Infrastructure to Climate Change** that took place in El Salvador in June 2010 served as the starting point to define the conceptual basis for a national and regional strategy to increase the climate resilience of infrastructure. The conference culminated in a workshop to prepare a proposal for a national climate-resilient infrastructure project that would allow the country to take concrete actions to protect against the impacts of climate change.

The climate resiliency of public and private infrastructures is a multidimensional issue that requires convergence between the need to develop the economic and social infrastructure of the country and the necessity to protect the country's ecosystems. The restoration of ecosystems and their capacity to regulate the impacts of climate change will reduce risks and slow down the deterioration of infrastructure as well as increase the possibility of new investments.

Climate change is a transboundary and global issue. A regional agenda for adaptation must include articulated strategies to integrate both the management of risks and the ability to respond to climate change. Response systems must be organized so that they can act in synergy and maintain the functionality of the region's infrastructure.

Since the 2010 Conference, the Government of El Salvador has initiated various efforts to concretize actions to improve the climate resiliency of the country's infrastructure. With the support of UNDP, a project was prepared and presented to the Climate Change Adaptation Fund to promote the development of climate change resilient infrastructure in the Metropolitan Area of San Salvador.

The Ministry of Public Works, taking unprecedented action in the region, established a special department for climate change adaptation and strategic risk management that is comprised of a group of specialists to address risk mitigation and implement the country's strategy for climate-resilient public infrastructure. This group plays a key role in advising the other departments of the ministry, its project, and other institutions to prevent and cope with risks and avoid future disaster. The creation of this unit is an important step in demonstrating the commitment of the government to risk prevention and mitigation. This department will work jointly with the Ministry of Environment and Natural Resources and the National Civil Protection System for the identification of risks in the territory. This department serves as a leading example for the region.

Through the Secretary for Economic Integration of Central America (SIECA), the Government of El Salvador is also promoting a regional strategy for risk management and climate change adaptation with emphasis on the development and climate resilience of public and private infrastructure. Regional coordination of this effort would enable coordinated and positive results in emergency response situations, risk prevention and adaptation actions. Regional coordination would benefit if participating countries adopted a shared strategy for Strategic Risk Management and Climate Change Adaptation and established a department within the Ministry of Public Works to monitor and coordinate this task. In support of this approach, a second regional conference on strategies to adapt the public and private infrastructure to climate change is being planned to generate political commitment within the region and mobilize international commitment.

Undeniably, the resiliency of public and private infrastructure safeguards important progress and investments made in the pursuit of development and avoids the loss of human life in the face of climate change. Given the risk to human life, we must devise development plans that are people-centred and incorporate climate change adaptation strategies to protect the welfare of our communities.

Acknowledgements

These Proceedings are based on presentations at the International Conference: Strategies for Adapting Public and Private Infrastructure to Climate Change, hosted by the United Nations Development Programme (UNDP) in San Salvador, El Salvador on 30 June 2010. UNDP's Adaptation Learning Mechanism (ALM), a Global Environment Facility/Strategic Priority on Adaptation-supported global knowledge-sharing platform on climate change adaptation, provided funding for this project.

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The efforts and contributions of all individuals and organizations are gratefully acknowledged.

Conference Statements

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Herman Rosa Chávez, Minister of the Environment and Natural Resources, Government of El Salvador

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Executive Summary

Executive Summary

Yannick Glemarec

Countries across the globe are experiencing extreme weather events that are resulting in catastrophic impacts to humans and infrastructure, both of which are extremely susceptible to climate variability. The primary cause of these tragedies is undoubtedly related to global climate change. In November 2009, the country of El Salvador experienced extreme rainfall over the course of two days, 7-8 November, which caused severe flooding and landslides in seven of the country's 14 departments, including San Salvador. The heavy rains killed about 200 people and left thousands of households without homes. Damage to infrastructure was also high, with 43 bridges destroyed and another 161 damaged. Many communities were left without access to transport, communications, electricity and basic services. The damage from the rainfall was so significant that it prompted decision makers to take immediate action, and seek international policy capacity building assistance.

"Infrastructure plays an important role in the development of countries. In many developing countries, evolving infrastructure can be particularly climate-sensitive and therefore highly vulnerable to the destruction that occurs due to natural disasters."

In the same year, El Salvador's Ministry of Public Works (MOP) and Ministry of Environment and Natural Resources (MARN) requested support from the United Nations Development Programme (UNDP) to develop of a strategic framework for decision-making processes to increase the climate resiliency of infrastructure. The framework would incorporate long-term climate change adaptation (CCA) and immediate disaster risk management (DRM) into policies for the planning, design, construction (including retrofitting and reconstruction), operation and maintenance of public infrastructure. As part of UNDP's support to El Salvador, an international conference on strategies for adapting public and private infrastructure to climate change was organized in San Salvador on 30 June 2010.

The conference highlighted many of the issues related to increasing the climate resilience of infrastructure, including the reality that most long-lived infrastructure decisions — including decisions regarding water management, transport, energy and urban planning — are climate sensitive and require a significant amount of lead time to implement. This means that action must begin today, before climate risks materialize, to protect critical socio-economic infrastructure, and to manage the risks associated with the impacts of climate change expected to occur by the middle of this century. There is a need to grow investments in infrastructure in the coming years to proactively prepare for the future.

Infrastructure plays an important role in the development of countries. In many developing countries, evolving infrastructure can be particularly climate-sensitive and therefore highly vulnerable to the destruction that occurs due to natural disasters. Because these events cut across socio-economic sectors and administrative jurisdictions, they can jeopardize development objectives in distant places. Public infrastructure tends to be multifunctional in nature and serves a range of diverse stakeholders spread over a wide geographic area. It directly or indirectly provides critical services to the area it covers. Interruptions in services can cause negative economic impacts over a large territory. The lack of reliable services impedes a country's ability to pursue development goals. For this reason, it is important to incorporate efforts to increase the climate resilience of infrastructure into development strategies, by taking into consideration the risks of climate change, such as the UNDP Green, Low-Emission and Climate-Resilient Development (Green LECRD) strategy.

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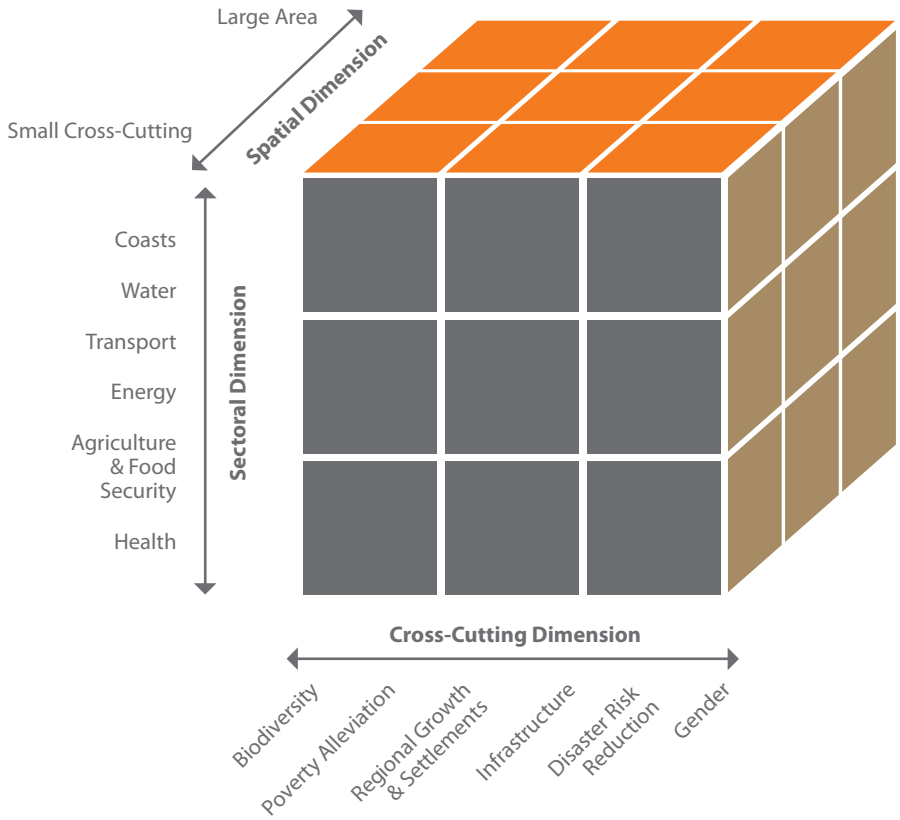
Adapting infrastructure to the risks of climate change within a broader Green LECRD strategy not only helps to reduce the loss of lives, physical damages and interruptions in critical socio-economic services, but it also yields additional benefits from reduced poverty mitigation, more balanced regional development, greater energy security, reduction of greenhouse gas (GHG) emissions and biodiversity conservation. These benefits are achieved because many of the initiatives required to protect public infrastructure against the impacts of climate change are also necessary in order to realize the other critical infrastructure-based development benefits.

Figure 1.1, discussed by Robert Kay in Chapter 5, illustrates the co-benefits of integrating the concept of climate-resilient infrastructure into Green LECRDS, and merging both with infrastructure planning. By systematically considering the three different dimensions of infrastructure decision-making (spatial, sectoral and cross-cutting dimensions) climate-resilient infrastructure can promote cross-sectoral and jurisdictional synergies as well as 'win-win' options. For example, planners could design a new transport network that would facilitate flood-water drainage while reducing commuting, enabling wildlife movements and fostering balanced regional development.

"Adapting infrastructure to the risks of climate change within a broader Green LECRD strategy not only helps to reduce the loss of lives, physical damages and interruptions in critical socio-economic services, but it also yields additional benefits from reduced poverty mitigation, more balanced regional development, greater energy security, reduction of greenhouse gas (GHG) emissions and biodiversity conservation."

Figure 1.1: Conceptualization of spatial, sectoral and cross-cutting dimensions of climate change



Source: Robert Kay, this report, Chapter 5.

The roadmap for climate-resilient infrastructure as part of a Green LECRD strategy will vary depending on circumstances; many possible roadmaps exist. All climate-resilient processes require the following steps:

1. **Mapping of present and future climate variability and change risks.** Infrastructure decision makers will need to identify the possible risks that various kinds of infrastructures will face over the next 50 to 100 years as a consequence of climate variability and change.

2. **Mapping of critical socio-economic infrastructure.** These are the primary physical structures, technical facilities and systems that are socially, economically or operationally essential to the functioning of a society or community, both in routine and extreme emergency circumstances. They include transport systems, air and seaports, electricity, water and communications systems, hospitals and health clinics, and centres for fire, police and public administration services.[1]

3. **Defining acceptable risk levels.** Usually, it is neither feasible nor advisable to reduce climate-based risks to zero. Integrating climate change risks and opportunities into the design of infrastructure should aim to reduce infrastructure risks to a quantifiable level, accepted by the society or economy. In practice, it might mean identifying the types and duration of service interruptions that can or cannot be accepted.

4. **Selecting non-structural and structural risk mitigation measures.** In many cases, a wide variety of non-structural and structural options exist to reduce risks to agreed acceptable levels. **Non-structural measures** are any measures not involving physical construction such as building codes, land-use planning laws and their enforcement, research and assessment, information resources, and public awareness programmes. **Structural measures** are any physical construction to reduce or avoid possible impacts of hazards, such as flood levees, ocean wave barriers, earthquake-resistant construction and evacuation shelters. The potential to generate additional development benefits will be critical in the weighting regional options.

DEFINITION

Non-structural measures

Any measures not involving physical construction such as building codes, land-use planning laws and their enforcement, research and assessment, information resources, and public awareness programmes.

Structural measures

Any physical construction to reduce or avoid possible impacts of hazards, such as flood levees, ocean wave barriers, earthquake-resistant construction and evacuation shelters. The potential to generate additional development benefits will be critical in the weighting regional options.

The context for the conference is provided through the summary of the statements delivered by the El Salvador Ministers, Gerson Martínez and Herman Rosa Chávez, as well as UNDP Resident Representative, Richard Barath. The statements outline El Salvador's vulnerability to and the general threat of climate change, and within this context, the need to increase the climate resilience of infrastructure. These statements highlight El Salvador's continuous efforts to create an integrated strategic framework for developing public and private infrastructure that is resilient and resistant to the stresses of climate change.

As El Salvador's capacity in this area increases, the country seeks to move towards a preventive, ongoing and sustainable risk management approach, in which long-term strategic design complements immediate response. To accomplish this, the country aims to develop a regional agenda to converge complementary infrastructure strategies; create a culture, strategy and operation for climate change adaptation; and establish an integrated system, supported by specialized commissions and units. Underscoring the motivation for the conference, the national speakers emphasized the need for inter-sectoral dialogue to form a strategy for adapting public and private infrastructure to climate change.

[1] United Nations International Strategy for Disaster Reduction (2009). Terminology on Disaster Risk Reduction. Geneva. Available from www.unisdr.org/eng/terminology/terminology-2009-eng.html (in English and Spanish).

Pradeep Kurukulasuriya, UNDP/GEF, builds on what the Ministers and UNDP Resident Representative said, and **provides an overview of UNDP's Environment and Energy Group's (EEG) approach to supporting countries to enhance their adaptive capacity by managing climate change risks.** Given that current and future climate-related experiences are unprecedented and characterized by more uncertainty than past weather patterns, long-term, deliberative and forward-thinking adaptation approaches must accompany business-as-usual reactive responses. Kurukulasuriya emphasizes that climate-risk management should take into consideration climate change scenarios, vulnerability, cost-effectiveness, adaptive systems, as well as institutional capacity and partnerships.

The background paper, *'No-Regrets' Risk-Based Approach to Climate Proofing Public Infrastructure: Improved National and Subnational Planning for Resilience and Sustainable Growth,* prepared by **Paul B. Siegel outlines the serious threats to infrastructure posed by the predicted increase in frequency and severity of geophysical and hydro-meteorological hazards.** He argues that despite incremental costs at the project level, incorporating climate change risks into development programming can result in positive externalities from improved planning processes and implementation; long-term economic, social and environmental social benefits; and 'win-win' scenarios based on 'no regrets' investments. At the root of this development method is a blend of climate change adaptation and disaster risk reduction (DRR) strategies, plans, and actions that ensure the reduction of risks to acceptable levels and that strengthen decision-making processes with the incorporation of climate risk management into programmes and projects. Siegel's paper concludes the introductory section — **Part I** — of this guidance document, followed by a thorough accounting in **Part II** of the six technical presentations given in El Salvador. These papers elaborate on the proposed UNDP multi-step process to integrate climate change risks and opportunities into the design of infrastructure and key principles for making infrastructure more climate resilient.

In the first technical presentation, **Robert Kay presents key principles and actions necessary for countries to address climate change related risks to infrastructure.** Kay stresses that in order to map climate variability and change risks, as well as socio-economic infrastructure, countries need to think about the multiple, interconnected dimensions of climate change: infrastructure elements and systems; adaptive potential of infrastructure elements and systems based on life cycle phases; and take a people-centred view of infrastructure. He stresses that selection of risk-mitigation measures requires analysis of adaptation options using participatory process and criteria, as well as development of implementation pathways with consideration of barriers and opportunities. Taking into account growing scientific and experiential knowledge as it becomes available is essential, but should not lead to postponed adaptation action.

Expanding on Kay's message, **Roberto Sanchez-Rodriguez's presentation (Technical Presentation 2) focuses on internalizing climate risks in the context of planning and urban development, particularly in low- and middle-income countries.** Sanchez-Rodriguez presents a case study of Mexico City's flooding and water supply risks to illustrate the challenges that El Salvador is likely to face. The case study highlights the importance of a multisectoral perspective in defining climate change risks, as well as an integrated, holistic approach to addressing these threats. He underscores the need for new or updated national and local institutions to address the complexity of climate change; strong leadership in the coordination of policies and actions among national, departmental and local levels; and balance between structure (top-down actions) and agency (bottom-up actions).

"Given that current and future climate-related experiences are unprecedented and characterized by more uncertainty than past weather patterns, long-term, deliberative and forward-thinking adaptation approaches must accompany business-as-usual reactive responses."

Michael Faber (Technical Presentation 3) presents a framework for risk assessment and risk-informed decision-making for infrastructure development. Faber emphasizes that climate-related decisions should be based on risks rather than observations, robust with regard to assumptions, and adaptable to future realities. Using risk management frameworks founded on Bayesian probabilistic decision theory, Faber highlights the potential for risk-based systems modeling. He explains how the application of modeling for individually and jointly acting hazards can be utilized to optimize robustness and resilience of structures, infrastructure systems, procedures and organizations.

Building on Faber's risk management framework, **Travis Franck's review (Technical Presentation 4) of approaches for probabilistic risk modeling focuses on core principles and applications of incorporating probability and uncertainty into risk management and modeling.** Franck provides an overview of probabilistic risk assessment (PRA) methods, including a concrete example of modeling for coastal impacts of climate change; considers the strengths and limitations of PRA methods; and discusses alternative ways to communicate PRAs to facilitate dialogue on future risks for a structured approach to decision-making for cost-effective choices. Emphasizing the uncertainty of the factors that contribute to climate change risk, Franck presents PRA as a systematic and comprehensive methodology to evaluate risks associated with a complex problem that incorporates uncertainty into development planning. Franck explains how PRA provides a tool for developing infrastructure in a way that is more resilient and robust, that offers value under a wide range of climatic conditions, and that increases social benefits while decreasing social and financial losses.

Matthew J. Kotchen (Technical Presentation 5) discusses an economic framework for evaluating the climate proofing of investments in infrastructure. The framework's emphasis on economic valuation focuses on consideration of the costs and benefits of climate proofing, evaluated through market and nonmarket valuation techniques. He explains how this framework can be modified to incorporate climate-proofing externalities, geographic scope, considerations of proofing vs. prioritizing infrastructure projects, and discounting. Kotchen stresses that building capacity for efficient climate change adaptation requires the following tasks:

- Identification of potential infrastructural adaptations
- Expansion of knowledge of nonmarket valuation
- Strengthening of institutions for greater international and regional coordination of efforts
- Building human capital for institutional support

Finally, **Stephen Gold's presentation (Technical Presentation 6) outlines UNDP's vision for supporting El Salvador to reduce infrastructure risks within a green, climate-resilient and low-emission development framework.** He synthesizes technical discussions from the conference into a practical strategy for adapting public and private infrastructure to climate change. The UNDP framework is outlined as a five-step process for preparing a Green LECRDS designed to attract and direct public and private investment toward catalysing and supporting sustainable economic growth. The steps are summarized as:

STEP 1

Develop a Multi-Stakeholder Planning Process

STEP 2

Prepare Climate Change Profiles and Vulnerability Scenarios

STEP 3

Identify Strategic Options Leading to Green, Low-Emission Climate-Resilient Development Trajectories

STEP 4

Identify Policies and Financing Options to Implement Priority Climate Change Actions

STEP 5

Prepare a Green, Low-Emission Climate-Resilient Development Roadmap

These proceedings are offered as a guidance document to practitioners and planners seeking to increase the climate resilience of public and private infrastructure. The content of this report provides a foundation from which to change course and adapt infrastructure to the impacts of climate change, and head off severe economic and human loss.

"The UNDP framework is outlined as a five-step process for preparing a Green LECRDS designed to attract and direct public and private investment toward catalysing and supporting sustainable economic growth."

PART I: OVERVIEW

Introduction

1

On 7-8 November 2009, El Salvador experienced extreme rainfall that caused severe flooding and landslides in seven of the country's 14 departments, including San Salvador. The heavy rains killed about 200 people and left thousands of households without homes. Damage to infrastructure was also high, with 43 bridges destroyed and another 161 damaged. Many communities were left without access to transport, communications, electricity and basic services.

The country is projected to face an increase in such severe weather events and risks related to climate variability and change. In response, El Salvador sought assistance from the United Nations Development Programme (UNDP) to develop preventative measures to avoid catastrophic injuries to people and damage to infrastructure. This assistance, requested by El Salvador's Ministry of Public Works (MOP) and Ministry of Environment and Natural Resources (MARN), came in the form of policy capacity building. UNDP was asked to develop a strategic framework for decision-making processes for climate-resilient infrastructure that would incorporate long-term climate change adaptation (CCA) as well as more immediate disaster risk management (DRM) into policies for the planning, design, construction (including retrofitting and reconstruction), operation and maintenance of public infrastructure.

To further support El Salvador and meet its request for aid in this area, UNDP organized an international conference on strategies for adapting public and private infrastructure to climate change in San Salvador on 30 June 2010. This report presents the proceedings from the conference. The proceedings are a compilation of the statements and technical papers presented at the conference, as well as background information and available strategies for increasing the climate resilience of infrastructure.

Purpose

This Report summarizes the proceedings of the El Salvador conference. It also outlines the multiple development benefits of climate proofing infrastructure and the importance of conducting such an exercise within a broader territorial approach. While these Proceedings address the specific context of El Salvador, the methodologies outlined can be applied to a wide range of situations. The proceedings are meant to serve as a guidance document for practitioners working to protect public and private infrastructure from the devastating impacts of climate change in order to avoid human and economic loss.

Target audience

Public development practitioners at the national and subnational levels are the primary audience for these proceedings, as well as domestic and international experts assisting government authorities in planning infrastructure investments.

Structure of the Proceedings

The proceedings are divided into two parts, with an executive summary to provide readers with a comprehensive overview of the report. **Part I** provides the context for the conference and for the report, and circulates the background paper prepared for the conference by Paul Siegel that highlights the similarities and differences between hazard-proofing and climate proofing. The background paper includes a review of the different tools available to identify and map climate change related hazards. **Part II** includes thorough accounts of the six technical presentations given at the conference. These papers discuss the key considerations addressed when developing a strategy for increasing the climate resilience of infrastructure.

Workshop Context

2

Richard Barathe, Gerson Martínez, Herman Rosa Chávez

The threat of climate change

Climate change is a scientifically proven fact and a reality that the international community must face. United Nations Secretary-General Ban Ki-moon refers to climate change as the greatest challenge of the 21st Century, one that the international community must immediately proactively address. This means adopting radical measures to adapt to and mitigate climate change's effects.

The impacts of climate change are upon us, and there is nothing that can be done to avoid the impacts of past greenhouse gas (GHG) emissions. We are on a course that shows average global temperature increasing at least by 0.5˚C to 1˚C in the next 20 years. Now, and going forward, actions are available and feasible to stabilize GHG concentrations in the atmosphere at a level that would prevent catastrophic climate change. In order to achieve safe levels, the world needs to reduce emissions by 50 percent — a daunting but necessary task. Developed countries must make the greatest contribution to this goal. However, developing countries also play an important role in pursuing a path of green, low-emission and climate-resilient development, and in breaking the paradigm of economic growth based on increased emissions. El Salvador can act as a leader on this path.

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El Salvador's vulnerability

Central America's geographic location makes the region particularly vulnerable to the effects of climate change. As a tropical isthmus between two oceans, El Salvador and surrounding countries are highly susceptible to severe tropical storms and extreme natural events. Historical records and maps reiterate the threats of escalated hydro-meteorological phenomena such as storms, hurricanes, floods, landslides and drought. El Salvador faced record rainfall in 2010. The increased frequency of climate anomalies suggests a 'new normal' to which El Salvador and the region must adapt.

The effects of climate change exacerbate existing vulnerabilities in developing countries, and El Salvador is no exception. Recent studies show that nearly 89 percent of El Salvador's territory and 96 percent of the population are at risk, including 2 million people in precarious urban settlements. In addition, 96 percent of the country's gross domestic product (GDP) is linked to these risk areas. The high social and economic costs of recent tropical storms such as Ida and Alex illustrate this vulnerability. Ida affected more than 120,000 people, and recent rains left 200 dead. The economic costs of Ida and Alex reached over $180 million and $150 million, respectively. This represents 2 percent of El Salvador's GDP and the approximate size of the 2010 budget for the Ministries of Health and Education.

Summary of statements by Richard Barathe, Resident Representative of UNDP, El Salvador; Gerson Martínez, Minister of Public Works and Housing Development; and Herman Rosa Chávez, Minister of the Environment and Natural Resources.

Focus on infrastructure

Climate change threatens both physical and natural infrastructure. A significant proportion of the economic costs of Ida and Alex are attributed to impacts on public and private infrastructure, including public works, schools, hospitals, homes, neighbourhoods, bridges, roads and dams. Just as physical infrastructure is fundamental to the functioning of society, natural infrastructure plays a key role in protecting populated areas from inundation by flooding and mudslides. In recent decades, degradation of ecosystems has exceeded damage to physical infrastructure in El Salvador with grave consequences. Heavy floods and landslides in areas of San Salvador, for example, have resulted in casualties.

El Salvador's lack of nature and land use laws has further increased the vulnerability of its infrastructure. For example, housing developments are built on unsuitable soils in certain areas of San Salvador. Construction, including public works, has breached basic standards and even common sense. The cumulative impact of interventions warrants assessment and redesign of urban and infrastructure development.

> "The challenge is to create entrepreneurship and integration for the region of Central America, its countries and its people. El Salvador proposes to develop a regional agenda in which each country pursues converging, complementary strategies that can be articulated in a policy of integrated climate change risk management."

Knowledge and action needs for El Salvador

El Salvador is working to create an integrated strategic framework for developing public and private infrastructure that is resilient and resistant to the stresses of climate change. By enhancing knowledge and planning, El Salvador can take immediate steps to strengthen the capacity of both the public and private sector in this endeavour.

Climate change knows no political borders or territorial divisions. Through extensive and intensive monitoring of climate phenomena, El Salvador aims to learn more about where it is most at risk. The Ministry of the Environment (MARN) is currently rehabilitating its monitoring processes and strengthening analytical capabilities to provide necessary information for developing expeditious solutions. The completion of a comprehensive threat map is an important next step for the country to enhance knowledge of its strengths, weaknesses, vulnerabilities and potential.

With increased knowledge, El Salvador seeks to modify its risk management approach. El Salvador's traditional response to extreme events has been recovery — collecting the debris, the wounded and the dead. However, reacting to disasters out of urgency will not suffice. Given effective monitoring and planning, the impacts of disasters can be reduced in some cases. Long-term strategic design needs to complement immediate response.

The challenge is to create entrepreneurship and integration for the region of Central America, its countries and its people. El Salvador proposes to develop a regional agenda in which each country pursues converging, complementary strategies that can be articulated in a policy of integrated climate change risk management.

As part of this approach, public policies must be redesigned for preventive, ongoing and sustainable strategic risk management. Key priorities also include climate change mitigation; adaptation of systems, institutions, organizational models and technical standards; and update of concepts, designs, technologies, materials and logistics. The lack of precedent for the current and future climate situation necessitates new criteria for infrastructure design and implementation.

Function of the workshop

Meeting these challenges requires a roundtable of five key pillars:

1. Central government;
2. State governments at the subnational level (governance outside of political party officers);
3. Municipal governments;
4. Private enterprises, including leadership of the construction industry, supported by the Ministry of Public Works (MOP); and
5. Communities of citizens within a new harmonized system.

Through the joint contribution of these players, El Salvador can develop a culture, strategy and operation for climate change adaptation. The objective is not just to produce an abstract agenda, but also to create an integrated system supported by specialized commissions and units.

The UNDP workshop in San Salvador provides a platform for this intersectoral dialogue and marks the beginning of a process to lay the foundations of a strategy for adapting public and private infrastructure to climate change. In order for mitigation and adaptation actions to be effective and sustainable, involvement and commitment is necessary at all decision-making levels, particularly from regional, national and local authorities, and from public and private sectors. Importantly, the forum affords the opportunity for MOP and MARN to collaborate on these efforts. MOP has taken leadership on developing El Salvador's National Climate Change Plan, while MARN has set an example of prioritizing risk reduction, as the definition of environmental policy. The focus on interdisciplinary cooperation among government and private actors is key to the approach of both ministries.

This activity is the first phase of a process to seriously incorporate the dimension of climate change adaptation into the protection of public works and private projects. El Salvador cannot afford further tragedy of lost investments or lives. The need for action is driven by a sense not only of duty to current populations, but also of global justice and intergenerational responsibility.

"In order for mitigation and adaptation actions to be effective and sustainable, involvement and commitment is necessary at all decision-making levels, particularly from regional, national and local authorities, and from public and private sectors."

Workshop Objective and Scope

3

Pradeep Kurukulasuriya

Climate change and its impacts on infrastructure comprise a complex problem without a single all-encompassing solution. Tackling this issue is beyond the capacity of one institution. Given the tremendous commitment to this topic in El Salvador, it is possible to collectively develop a response strategy that will help address this issue as the challenge of climate change intensifies over time.

Motivation

As a country classified as high risk, El Salvador is extremely vulnerable to hydro-meteorological and geological hazards. A series of recent climate-related incidences — including Hurricane Ida, whose impacts of severe flooding and landslides resulted in $239 million in damages and losses (including 200 human lives and $100 million of damages to infrastructure) — are indicators of what will become a much greater problem. Climate change is establishing a new norm of increased frequency and severity of these extreme events, as well as of long-term changes. Given the serious impacts that these threats have on infrastructure, El Salvador needs to internalize climate change risks into infrastructure.

“Climate change is establishing a new norm of increased frequency and severity of these extreme events, as well as of long-term changes. Given the serious impacts that these threats have on infrastructure, El Salvador needs to internalize climate change risks into infrastructure.”

Objectives

At the request of the Government of El Salvador, UNDP is ready to work with experts in the country and the region to address the issue of climate change and infrastructure through the following objectives:

1. **To understand the additional risks posed by long-term climate change on infrastructure:** Rather than long-standing climate variance or weather-related issues, considerations about additional risks posed by long-term climate change on infrastructure concern significant changes that will manifest gradually, and sometimes very rapidly. Significant uncertainty about both the science and the responses contributes to challenges in synthesizing this understanding.

2. **To formulate a strategic approach to managing long-term risks recognizing a variety of priorities:** Developing a strategic approach for El Salvador to manage this issue will require a recursive and iterative process demanding continuous reconsideration of assumptions and updated thinking. A holistic, systems approach to the problem, including both hard and soft measures, is necessary.

3. **To mobilize financial and technical resources as well as internal and external partnerships:** Interventions to change infrastructure cost money, but access to funds from different sources around the world (e.g. trust funds and bilateral resources) are increasingly being made available to developing countries to put these resources into place.

4. **To support implementation and share results:** UNDP will offer ongoing support throughout El Salvador's intervention efforts. The discussions taking place at this meeting represent the beginning of a long partnership between UNDP and El Salvador and other partners to start addressing this issue.

Pradeep Kurukulasuriya is Senior Technical Adviser on Climate Change Adaptation at UNDP/GEF

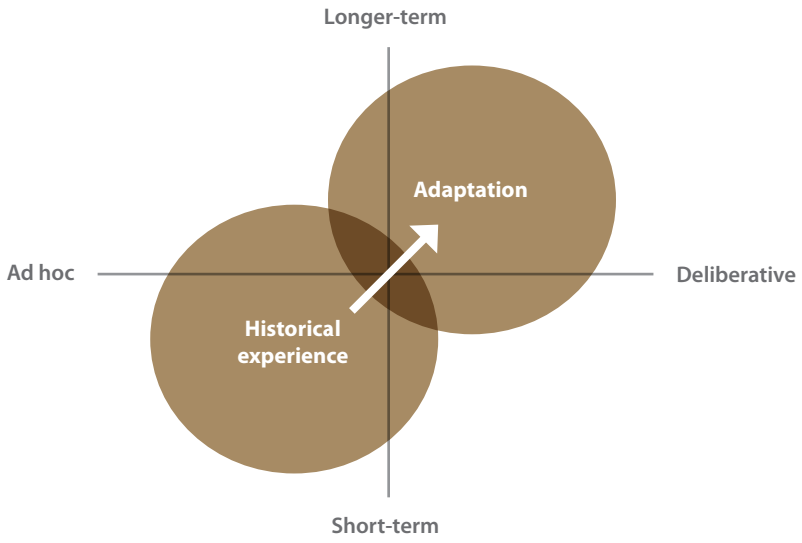
Key issues

The need for longer-term deliberative adaptation actions

Historically, responses to weather-induced events has generally been dealt with in a very ad hoc, short-term way. Based on previous experiences, assumptions that similar events will happen in the future have informed measures to address them. The problem with this approach in the context of climate change is that history is not the appropriate indicator of what is expected to happen in the future. Likely scenarios of future climate-related experiences are unprecedented and characterized by uncertainty. Therefore, society's actions must be much more deliberative and forward thinking. This has significant implications for when and where to invest, the type of investment that is necessary, as well as addressing intergenerational issues that go beyond political life cycles. These considerations have to be made in a much more systematic way in order to effectively manage climate change risks and opportunities.

"Given that infrastructure investments can have 30-year economic life expectancies, it is necessary to adapt to today's and tomorrow's hazards and climate conditions."

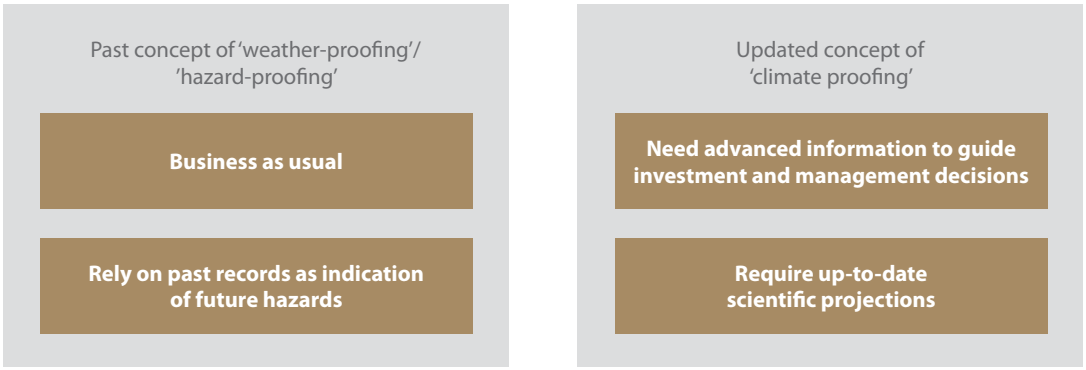
Figure 3.1: Moving from short-term and ad hoc adaptation toward longer-term and deliberative adaptation



The need for a framework for climate-resilient infrastructure

In the context of long-term climate change, previous concepts of 'weather-proofing' or 'hazard-proofing' of infrastructure investments that rely on past records as an indication of future hazards are no longer sufficient. Given that infrastructure investments can have 30-year economic life expectancies, it is necessary to adapt to today's and tomorrow's hazards and climate conditions. The actions that countries do or do not take will affect future impacts, but what these impacts will look like specifically is uncertain. Societies must be sure that investments of scarce resources are resilient to the **range of possibilities** that will manifest. An updated concept for increasing the climate resiliency of infrastructure must therefore include the right type of advanced information for guiding the decision-making processes (see Figure 3.2). This has not happened yet in many places.

Figure 3.2: Moving towards an updated concept for climate-resilient infrastructure



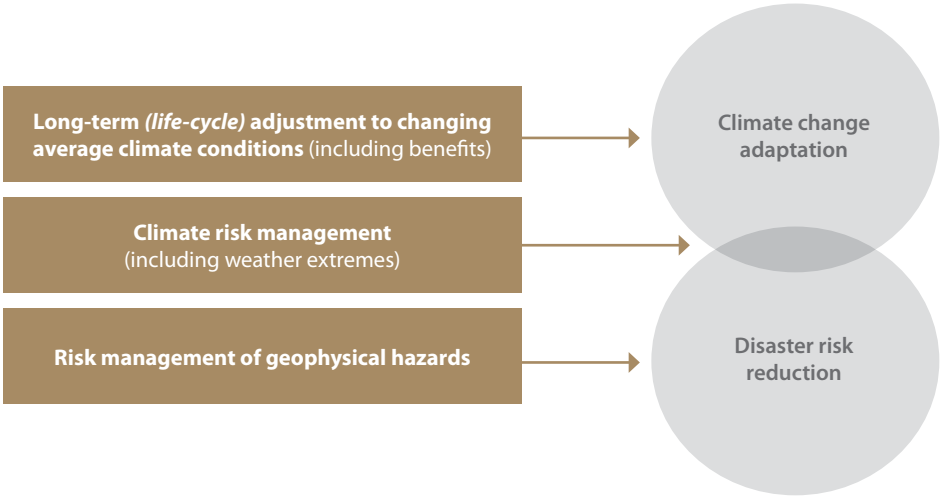
> "Climate risk management encapsulates this integration of DRR with climate change adaptation."

The need for linking disaster risk reduction and climate change adaptation

A common school of thought defines response to climate change as disaster risk reduction (DRR). However, while disaster risk management strategies, policies and measures are necessary and a good starting point for adaptation, DRR is only one important part of the solution. Adaptation is not only about better risk reduction or coping with a stochastic climate. The emergence of new types of hazards (i.e. risks that have not yet been considered), as well as changes in risk factors (i.e. the probability of consequences), will also contribute to changing average climate conditions. Vulnerability to climate change is a function of these changing risks, as well as the levels of exposure, sensitivity, and adaptive capacity to new and emerging hazards.

Therefore, a forward-looking strategic approach that takes into consideration these factors for long-term adjustments to climate changes is also part of the solution. Climate risk management encapsulates the integration of DRR with climate change adaptation (see Figure 3.3).

Figure 3.3: Linking climate change adaptation and disaster risk management



DEFINITIONS

Disaster risk reduction

The concept and practice of reducing disaster risks through systematic efforts to analyse and manage the causal factors of disasters, including through reduced exposure to hazards, lessened vulnerability of people and property, wise management of land and the environment, and improve preparedness for adverse events.

Source: UNISDR (2009a)

Climate proofing

Climate proofing refers to the explicit consideration and internalization of the risks and opportunities that alternative climate change scenarios are likely to imply for the design, operation and maintenance of infrastructure. In other words, integrating climate change risks and opportunities into the design, operation, and management of infrastructure.

Doing development differently

These new concepts for addressing impacts of climate change on infrastructure suggest the need to do development differently. Climate change will have profound implications on how countries develop. In order to secure development benefits that might otherwise be undermined by climate change, there is a need to undertake the following actions:

- Systematically internalize and incorporate climate change scenario information into development planning.
- Address vulnerability to today's climate and future climate.
- **Implement cost-effective adaptation responses:** Resources for addressing climate change are marginal given the magnitude of problem. Therefore, it is necessary to allocate these resources in a way that maximizes benefits in the context of an uncertain future. This will require, among other things, an understanding of the economics of adaptation.
- **Create adaptive systems for managing evolving risks:** Systems for making continuous decisions (rather than developing discreet solutions) about this issue must be in place at national, subnational and community levels.
- **Strengthen institutional capacity and cross-agency relationships and partnerships:** El Salvador has a very solid foundation of institutions and existing partnerships from which to build. In this regard, El Salvador can serve as a model case for other countries not only in the region, but also around the world.

DEFINITION

Disaster risk

The probability of an event with harmful consequences. The potential disaster losses — in lives, health status, livelihoods, assets and services — which could occur in a particular community or society over some specified future time period.

Source: UNISDR (2009a)

Figure 3.4: UNDP's approach to supporting countries on climate change

VISION:
Foster human development in a changing climate

STRATEGY:
Develop the capacity of countries to prepare, finance, implement and report on green, low-emission and climate-resilient development strategies

PRIMARY SERVICES:

MAINSTREAMING:
Assist countries to develop green, low-emission and climate-resilient strategies including strategies to maintain economic growth and resilience

ENVIRONMENTAL FINANCE:
Identify, access and combine sources of environmental finance to attract and drive much larger private sector invesment flows toward green, low-emission, climate-resilient and ecosystem-friendly development

UNDP's strategy for supporting countries in climate change adaptation comprises two primary services:

1. Mainstreaming climate risk management into governance and development processes at national and subnational levels by improving strategies and capacities to sustain economic growth and development in a changing climate.

2. Helping countries to attract and direct public and private investment towards catalysing and supporting green climate strategies for development.

Box 3.1: Key content and organization of the conference

The strategies discussed in the conference will support a risk-based 'no-regrets' approach to increasing the climate resiliency of infrastructure. This approach consists of three key principles:

1. Disaster-risk and climate change adaptation strategies, plans and actions ensure that risks are reduced to an acceptable level.
2. Decision-making processes are strengthened and incorporate plans and actions to manage future and present climate risks.
3. Climate proofing development projects and related initiatives support sustainable development.

The conference covers the following components of internalizing climate change risks into infrastructure through this no-regrets approach:

- Production of relevant, sophisticated information to guide decision makers;
- Application of probabilistic risk assessments;
- Incorporation of 'soft' solutions (capacity building and institutional arrangements) in conjunction with commonly considered 'hard' solutions;
- Integration of the strengths of many disciplines to address this multisectoral issue through a multidisciplinary approach; and
- Emphasis on country-driven, localized responses that are adapted to local strengths and needs.

Conference presentations and discussions on the first day of the workshop focused on the following key topics critical to highlighting local priorities for action:

- Climate change risks and urban planning and development;
- Framework for risk assessment and decision-making for development infrastructure;
- Probabilistic risk modeling: basic principles and applications, potential and limitations;
- Economics of climate proofing: risk analysis and assessment of costs;
- Reducing infrastructure risks within an integrated climate-resilient framework for development; and
- Identification of key issues for action by expert panel from El Salvador.

The following action points describe the objectives of a smaller group that met on the second day of the conference:

- Further develop key issues for action broached on the first day;
- Formulate a project concept for fundraising and implementation; and
- Engage in in-depth follow-up discussions on underlying causes, solutions and barriers that need to be overcome.

UNDP, in partnership with the Government of El Salvador, will mobilize funding from alternative sources (options discussed include the Global Environment Facility [GEF], Special Climate Change Fund [SCCF] and Adaptation Fund).

A 'No-Regrets' Risk-Based Approach to Climate Proofing Public Infrastructure: Improved National and Subnational Planning for Resilience and Sustainable Growth

4

Paul B. Siegel

Motivation, objective, approach

Motivation

The heavy rains and flooding in El Salvador in November 2009 destroyed lives, homes and infrastructure. According to a post-disaster needs assessment, Hurricane Ida inflicted $239 million in damages and losses, equivalent to about 1.1 percent of the gross domestic product (GDP) (See UNOCHA, 2010). This figure reflects around $135 million in damages to assets and almost $104 million of losses due to reductions in economic activity, including production losses and higher service costs. Damage to public infrastructure was estimated at over $100 million.

Independent consultant, Dr. Paul B. Siegel prepared this report for the UNDP Environment and Energy Group Environmental Finance Discussion Paper Series, UNDP Climate Change Strategy: Climate Change and Infrastructure Development, 17 May 2010.

Hurricane Ida demonstrated El Salvador's high vulnerability to natural hazards. El Salvador is one of the highest ranked countries in the world in terms of population and GDP at risk from natural hazards (Dilley et al., 2005). It is exposed to a wide range of hazards, including hydro-meteorological hazards such as hurricanes, droughts and floods, and geological hazards including earthquakes, volcanoes and landslides.[1] Some of the worse damages and losses occur when hydro-meteorological and geological hazards interact (e.g. landslides caused by heavy rains). According to the *2009 Global Assessment on Disaster Risk Reduction* (UNISDR, 2009), El Salvador is classified as a 'High Risk Class' country from multiple hazards. Concerns about natural disasters in El Salvador are further exacerbated by forecasts of greater frequency and severity of different natural hazards, and increased vulnerability associated with climate change.

There is scientific consensus that the world is experiencing climate change and an increase in the frequency and severity of natural disasters (Stern, 2008; UNDP, 2008; UNISDR, 2009d; World Bank, 2009). Latin America, in particular, is expected to suffer from climate change and increasing natural disasters (UNDP, 2008; De la Torre et al., 2009; EU, 2009; World Bank, 2009b). While specific climate scenarios and impacts are uncertain, experts agree that climate change implies more frequent and severe weather-related events for El Salvador (SNET, 2008; World Bank, 2008; Mansilla, 2009). Even small changes in climate patterns and weather extremes can result in significant damages to existing infrastructure and should influence the design of new infrastructure (Feethem, 2010). Many Salvadorans face even greater risks related to natural disasters and infrastructure in the present, and the near and more distant future.

[1] Hydro-meteorological hazards include tropical cyclones (also known as hurricanes and typhoons), thunderstorms, hailstorms, tornados, blizzards, heavy snowfall, avalanches, coastal storm surges, floods including flash floods, drought, heat waves and cold spells. Geological hazards include internal earth processes, such as earthquakes, volcanic activity and emissions, and related geophysical processes such as mass movements, landslides, rockslides, surface collapses, and debris or mud flows. Hydro-meteorological conditions also can be a factor in geological hazards such as landslides, rockslides, surface collapses, and debris and mud flows (UNISDR, 2009).

Objective

The Ministry of Public Works (MOP) and Ministry of Environment and Natural Resources (MARN) realize that El Salvador faces many risks related to climate variability and change and extreme weather events, as well as possible volcanic eruptions. Public infrastructure including roads, bridges, ports and airports, energy generation and delivery systems, drainage systems, water collection, storage, delivery and waste systems, schools, hospitals and public buildings are at risk from natural disasters and climate change. MOP and MARN requested support from UNDP to provide a strategic framework for decision-making processes for climate proofing infrastructure. The strategic framework should incorporate long-term climate change adaptation (CCA) as well as more immediate disaster risk management (DRM) into policies for the planning, design, construction (including retrofitting and reconstruction), operation and maintenance of public infrastructure.

The objective of this background paper is to highlight for planners and policy makers the key issues involved with climate proofing public infrastructure. 'Climate proofing' refers to actions that make infrastructure more resilient and resistant to anticipated scenarios of long-term climate change, as well as the risks associated with geological hazards and climate variability and extremes. This paper outlines critical concepts and decision-making processes for planning new investments in public infrastructure. Similar concepts and decision-making processes apply for retrofitting existing infrastructure and reconstruction of damaged infrastructure.

DEFINITION

Climate change adaptation

The adjustment in natural or human systems in response to actual or expected climate stimuli or their effects, which moderates harm or exploits beneficial opportunities.

Source: UNISDR (2009a)

Approach

Climate proofing investments in public infrastructure should be considered within the broader context of territorial development that mainstreams and integrates CCA and DRM. Natural disasters often are characterized as local problems, but their impacts and costs can cross jurisdictions, and can become problems at municipal, state or national levels. Conversely, hazards and vulnerabilities in distant places can have an important impact on local hazards and vulnerabilities.

The focus on planning and planning processes for climate proofing public infrastructure is relevant because all investments in public infrastructure are subject to planning processes at the community, local, subnational and national levels.[2] The most critical decisions on the potential uses and beneficiaries of infrastructure and the precise siting of public infrastructure require a broad perspective and involve many stakeholders. A wide range of development agencies is increasingly advocating a holistic multisectoral, multi-institutional national and subnational approach to CCA and DRM for climate proofing.[3]

Although a local approach to climate proofing is key, there is an important leadership role for national institutions, especially in the acquisition and harmonization of hazard data, and setting and enforcing codes and standards. The guidance and expertise of national institutions must be integrated into local activities to become effective. For instance, even when excellent hazard maps exist, they are seldom used by agencies other than the national disaster management agency. Even when these maps are used in land zoning policy, or if advanced meteorological or seismic information is used to create better building codes and standards, enforcement is often a problem (van Aalst and Burton, 2004; Benson and Twigg, 2007).

[2] See for example, Mora and Kepi, 2006; Benson and Twigg 2007; Center for Science in the Earth System, 2007; Genivar, 2007; USAID, 2007; Bitting and Kloss, 2008; Center for Science in the Earth System, 2008; GFDRR, 2008; IILEI, 2008; USDOT, 2008; Ribeiro et al., 2009; Singh, 2009; GFDRR, 2009; UNDP, 2009b; UNDP, 2009c; UNISDR, 2009c; World Bank, 2009a; GFDRR, 2010a; GFDRR, 2010b.

[3] According to findings from a recent World Bank study tour (World Bank, 2007), national and municipal approaches to disaster risk reduction and prevention should be multisectoral and holistic, using a balanced mix of hardware (e.g. retrofitting of schools and bridges, resettlement of high-risk informal settlements) and software. Software includes risk assessment tools (e.g. microzonation, structural survey of schools and other life-line infrastructures); risk financing tools (e.g. risk insurance); socioeconomic programmes (resettlement of persons from high risk areas); infrastructure works (canalization, drainage pipes, terracing, retrofitting of infrastructure such as schools and hospitals); and urban planning (e.g. land-use planning). In addition, due to the broad scope and resources gap in implementing such a comprehensive risk reduction and prevention programme, the government at the national and local level should involve many players across civil society, including the private sector, NGOs, academia and citizens in general.

Incorporating climate proofing into projects may be viewed as a cost, but there are potential benefits from improving planning processes and implementation of plans including monitoring and evaluation (M&E) systems (e.g. greater accountability and less corruption, improved maintenance). 'Win-win' scenarios are possible through climate proofing. This is particularly true because many of the costs associated with climate proofing public infrastructure are actually no-regrets investments (AsDB, 2005). On the other hand, there might be tangible incremental costs associated with improving resilience to natural disasters and climate change, especially for retrofitting.[4]

The no-regrets investments in climate proofing, including planning processes and capacity building, can generate positive economic, social and environmental social benefits regardless of whether climate change and natural disasters occur (Mani et al., 2008; Heltberg et al., 2009). The no-regrets approach is consistent with the UNDP's 'climate risk management' approach (UNDP, 2009a) and the United Nations Framework Convention on Climate Change (UNFCCC) 'precautionary principle' approach (UNFCCC, 1992). The underlying approach for decision-making for climate proofing is to deal with present and future climate risks, and avoid high-risk investments that might lead to catastrophic losses. The actions associated with climate proofing include investments in materials and equipment, reforms in policies and institutions (including building codes and standards), and improvements in capacity to manage hazards and potential risks associated with climate change and natural disasters, including early warning systems (EWS) and emergency response (UNISDR, 2008, 2009a; UNOCHA, 2009).

In many ways, climate proofing infrastructure is not a new concept. Engineers have historically taken into account information on various hazards and potential impacts for in the design, construction, use, and maintenance of public infrastructure. However, given climatic uncertainties (particularly at a local scale),[5] current design codes and standards might not be applicable in the future. This has implications for both new and existing infrastructure. Increased awareness about natural disasters and climate change, and including potential economic, social and environmental losses, provides a new vantage point to review and improve the processes and technologies used for climate proofing.

According to UNISDR (2008), CCA and DRM must be "made a formal part of development processes and budgets and programmed into relevant sector projects, for example in the design of settlements, infrastructure, coastal zone development, forest use, etc., in order to achieve sustainable land management, avoid hazardous areas, and to ensure the security of critical infrastructure such as hospitals, schools and communications facilities." There are lessons to be learned from Latin America and other parts of the world (e.g. Vergara, 2005; Red Cross International, 2006; Benson and Twigg, 2007; Leslie, 2008; Mansilla, 2008; Christopolos et al., 2009; World Bank, 2009c; GFDRR, 2009a, 2009b, 2010a, 2010b; UNISDR, 2010).

DEFINITION

Disaster risk management

The systematic process of using administrative directives, organizations, and operational skills and capacities to implement strategies, policies and improved coping capacities in order to lessen the adverse impacts of hazards and the possibility of disaster.

In this paper, disaster risk management (DRM) refers to both DRM and disaster risk reduction.

Source: UNISDR (2009a)

[4] Retrofitting is the reinforcement or upgrading of existing structures to become more resistant and resilient to the damaging effects of hazards. Retrofitting requires consideration of the design and function of the structure, the stresses that the structure may be subject to from particular hazards or hazard scenarios, and the practicality and costs of different retrofitting options. Examples include adding bracing to stiffen walls, reinforcing pillars, adding steel ties between walls and roofs, installing shutters on windows, and improving the protection of important facilities and equipment (ISDR, 2009a).

[5] A major problem is the lack of downscalable climate data for local hazard modeling.

DEFINITIONS

Vulnerability

The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard.

Disaster Risk=Natural Hazard x Vulnerability-Capacity

Source: UNISDR (2009a)

Natural hazard

A natural process or phenomenon that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.

Source: UNISDR (2009a)

Conceptual framework for climate proofing infrastructure

Risk-vulnerability chain

Losses from natural disasters and climate change are not just related to hazard events, but to the underlying economic, social and environmental conditions in a specific location. The availability of local capacity (including institutions, building codes and standards, and enforcement capacities) is key to manage disaster risks. The risk-vulnerability chain conceptualizes the relationship between hazards, vulnerability, risk management arrangements and risk-related losses. The risk-vulnerability chain can be summarized as:[6]

Disaster Risk = (Natural Hazard x Vulnerability) – DRM and CCA Capacity

This paper applies the above equation and UNISDR terminology (see UNISDR, 2009a) to provide a consistent set of terms. Thus, disaster risk (the probability of losses) is a function of a *hazard* (probability of an adverse event), *vulnerability* (the exposure and susceptibility of assets and livelihoods to hazards), and *capacity* (the formal and informal institutional, legal, political, social and cultural networks that can help lessen the negative impacts of [*hazard x vulnerability*]).[7]

The characteristics of a specific hazard in terms of severity and the exposure and sensitivity of assets and livelihoods to the hazard determine expected losses. Households, communities and governments (local, state, national) utilize risk management strategies that are either ex ante (prevention, reduction, compensatory arrangements such as savings or insurance), or ex post (coping) actions that may be ad hoc or planned responses.[8] Risk, the probability of a loss of well-being, depends on the hazards, exposure and sensitivity, expected impacts and losses, and ex ante and ex post risk management strategies that attempt to reduce vulnerability, increase capacity, and lessen the negative impacts from damages/losses to assets and livelihoods. Probabilistic risk models attempt to quantify probabilities for the various components of the risk-vulnerability chain, and are used as a decision-making tool for climate proofing infrastructure.

Risk Assessment = Hazard Assessment + Vulnerability Assessment + Capacity Assessment[9]

Risk Assessment: This is a method to determine the nature and extent of risk by analysing potential hazards and evaluating existing conditions of vulnerability that could pose a potential threat or harm to people, property, livelihoods and the environment. Risk assessments (and associated hazard and vulnerability assessments) include a review of the technical characteristics of hazards such as their location, intensity, frequency and probability; the analysis of exposure and vulnerability including the physical, social, health, economic and environmental dimensions; and the evaluation of the effectiveness of prevailing and alternative coping capacities in respect to likely risk scenarios. It is also important to take CCA and DRM capacity to manage risks into account.

Hazard Assessment: This involves evaluating and ranking potential hazard events by forecasting their frequency and intensity, and determining a range of possible scenarios over time. One of the most challenging aspects of hazard assessments under climate change is the divergence of predictions by different models, and the lack of local data (from downscaled climate models) that can be used for modeling the future. In most cases, hazards are exogenous in that they are external events not easily influenced by decision-making.

[6] There are different definitions of vulnerability in the literature (Alwang et al., 2001; Adger, 2006). Vulnerability = f (risks, exposure and sensitivity, capacity) is another way to express vulnerability and risks. Not surprisingly, there is a good deal of confusion about use of these terms. The differences are more semantic than real and both approaches try to understand the causes of vulnerability and how to reduce it. It is important to identify the complementarities to facilitate better communication and cooperation between practitioners working on natural disasters, climate change, and social protection.

[7] Sometimes capacity is omitted from the equation and may be considered a dimension of vulnerability.

[8] In most cases, it is difficult to prevent natural hazards; however, with climate change, there are actions like CO2 emissions related to human economic activities that can influence concentrations of GHGs and thereby increase or decrease some hazards.

[9] See Benson and Twigg (2007) for an excellent overview of all the steps. Many of the references include examples of probabilistic risk modeling (e.g. ADB, 2005; CAPRA Workshop, 2008; Larsen and Goldsmith, 2007; Larsen, et al., 2007; IDB, 2008; Canadian Council of Professional Engineers, 2009; Fleischhauer, 2009; Gill, et al., 2009; Yamin, et al., 2009; Lapp, 2010; White, 2010)

Vulnerability Assessment: There are many aspects of vulnerability, arising from various physical, social, economic, and environmental factors. Examples may include poor design and construction of buildings, inadequate protection of assets, lack of public information and awareness, limited official recognition of risks and preparedness measures, and disregard for wise environmental management. Vulnerability varies significantly within a community and over time. Vulnerability broadly includes exposure and sensitivity of assets and livelihoods, which can be changed by policy makers and planners.

Capacity Assessment: Policies and institutional structure and context are major factors for increasing resilience. Clearly, capacity can be influenced by policy makers and planners, and by other investments. Capacity includes technical competence of individuals and the functioning of institutions individually and in tandem, and it also includes inter-institutional dynamics, functioning of markets (including different financial and insurance products). This includes persons and institutions directly and indirectly involved with CCA and DRM.

Figures 4.1 and 4.2 provide a schematic presentation of the risk-vulnerability chain in the context of probabilistic risk modeling (see Annex 4 for details about the Central American Probabilistic Risk Assessment (CAPRA) as an example of probabilistic risk modeling). In Figure 4.1, capacity is not a separate component, but is included in vulnerability. In fact, there is considerable overlap between vulnerability and capacity, and in many cases the risk vulnerability chain is based on ***Risk = Hazard x Vulnerability***. However, because of the importance of capacity, and the fact that it can be conceptually and analytically separated from vulnerability, it is best to disaggregate vulnerability and capacity.

Climate change models forecast more intense hurricanes and flooding in some parts of El Salvador and greater droughts in other parts. Four aspects of storms are particularly important for infrastructure: rainfall, winds, coastal storm surges and floodwaters. Stronger storms have longer periods of rain, higher wind speeds, higher coastal storm surges and greater flooding. Infrastructure designers, planners and operators should use probabilistic models and revise codes and standards, instead of relying on the deterministic models used in the past and existing codes and standards. The uncertainty associated with projecting impacts over 20- or 50- to 100-year time horizons makes probabilistic models an important method for incorporating climate change into decision-making processes. The key is to model and understand the implications of long-term climate change and determine an optimal combination of no-regrets, low-cost/co-benefit, high-cost priority actions.

Climate change adaptation and DRM comprise a wide range of strategies and actions at the household, community, local, national (and possibly international) levels, aiming to prevent hazards from occurring and/or reducing their negative impacts. There is a menu of formal and informal instruments, and no single instrument offers complete protection. The key is identifying instruments that are appropriate for given hazards and vulnerabilities in the context of immediate risks. Capacities in a specific location should be developed or strengthened in the context of long-term climate change to address vulnerabilities and boost resilience. Climate change adaptation and DRM strategies include a broad range of interventions to increase resilience (e.g. engineering design and construction, building codes and standards, insurance, ecosystem management, emergency response), embedded within a holistic suite of capacity and institutional-strengthening efforts that can protect and strengthen assets and livelihoods. These strategies and measures eventually help society to manage impending risks.

"There is a menu of formal and informal instruments, and no single instrument offers complete protection. The key is identifying instruments that are appropriate for given hazards and vulnerabilities in the context of immediate risks."

There are major data and methodological challenges for applying rigorous modeling techniques to decision-making for climate proofing infrastructure. It is very difficult (perhaps impossible) to obtain climate data that can be used to forecast future climate patterns and extreme weather events in a given locality. With changing climate patterns and extreme weather events, it is difficult to estimate specific climate impacts on different types of infrastructure and tailor improvement in design, operation and maintenance accordingly.

Considering the challenges of making infrastructure more resilient, it is important that contingency plans include well-organized and coordinated courses of action with clearly identified institutional roles and resources, information, processes, and operational arrangements for specific actors at times of need. Based on scenarios of possible future conditions (including those which reflect impacts that are likely to occur rapidly as well as those that are likely to manifest gradually), the right type of information can allow key actors to envision, anticipate and manage problems that are likely to emerge. Contingency planning is an important part of overall preparedness and can include different financial and insurance mechanisms to ensure that critical facilities do not stop functioning (Benson and Twigg, 2007; Pollner et al., 2008).

DEFINITION

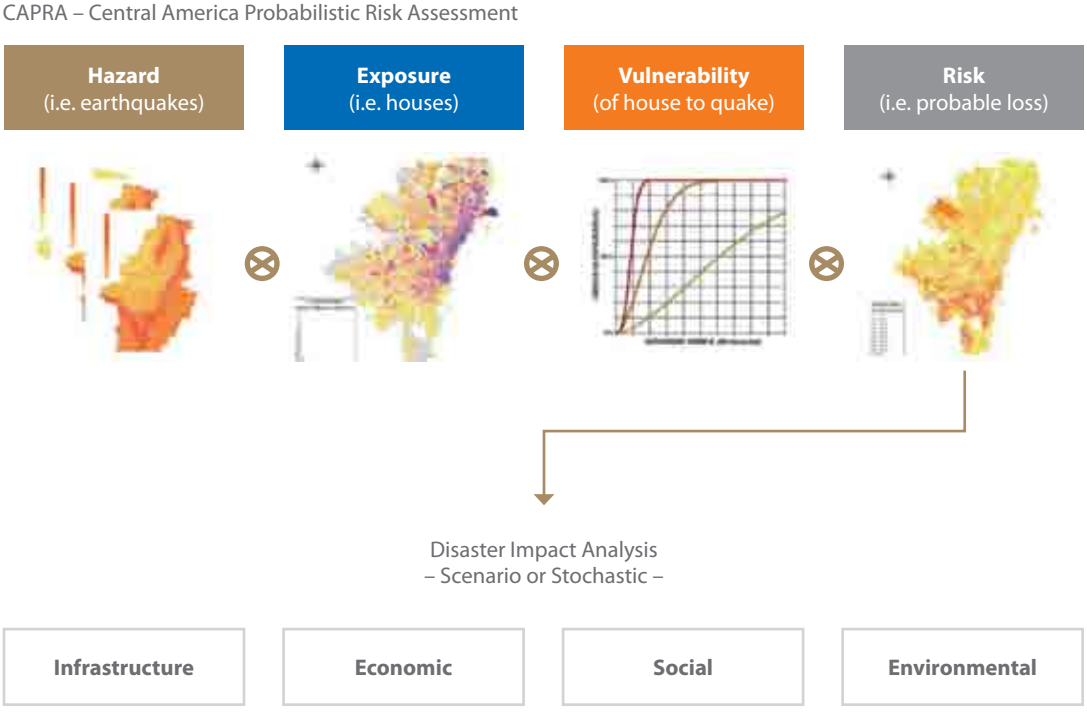
Resilience

The ability of a system, community or society exposed to hazards to resist, absorb, accommodate and recover from the effects of hazards in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions.

Source: UNISDR (2009a)

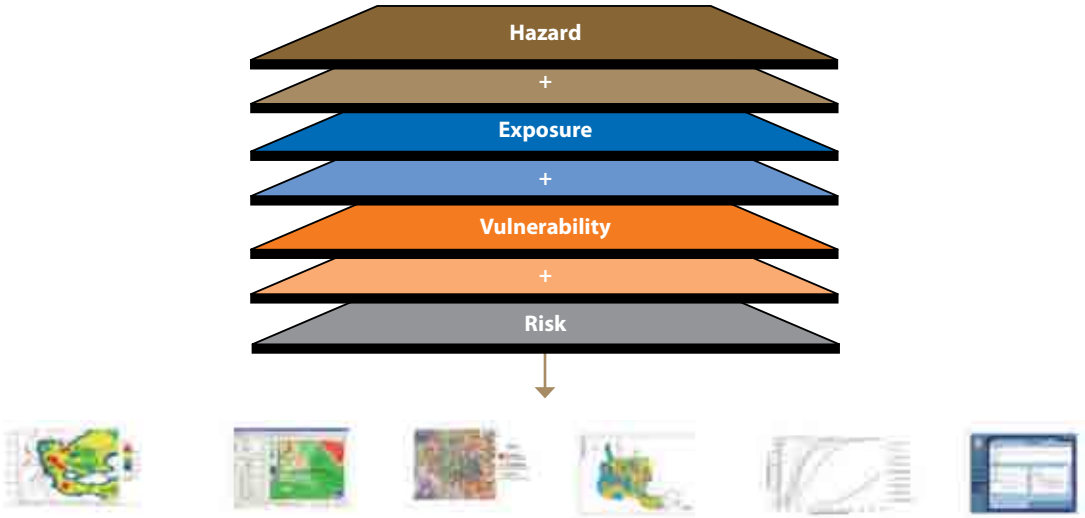
"Considering the challenges of making infrastructure more resilient, it is important that contingency plans include well-organized and coordinated courses of action with clearly identified institutional roles and resources, information, processes, and operational arrangements for specific actors at times of need."

Figure 4.1: Probabilistic risk modeling (a)



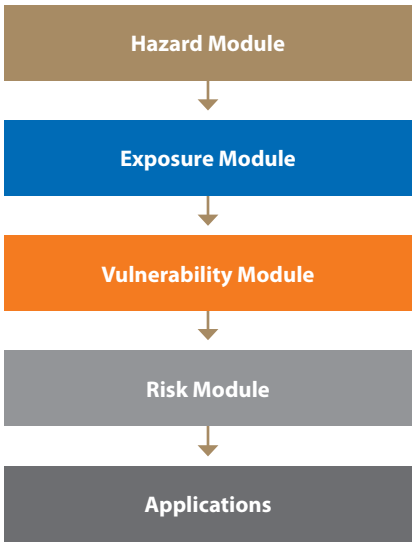
Source: CAPRA: www.ecapra.org.

Figure 4.2: Probabilistic risk modeling (b)



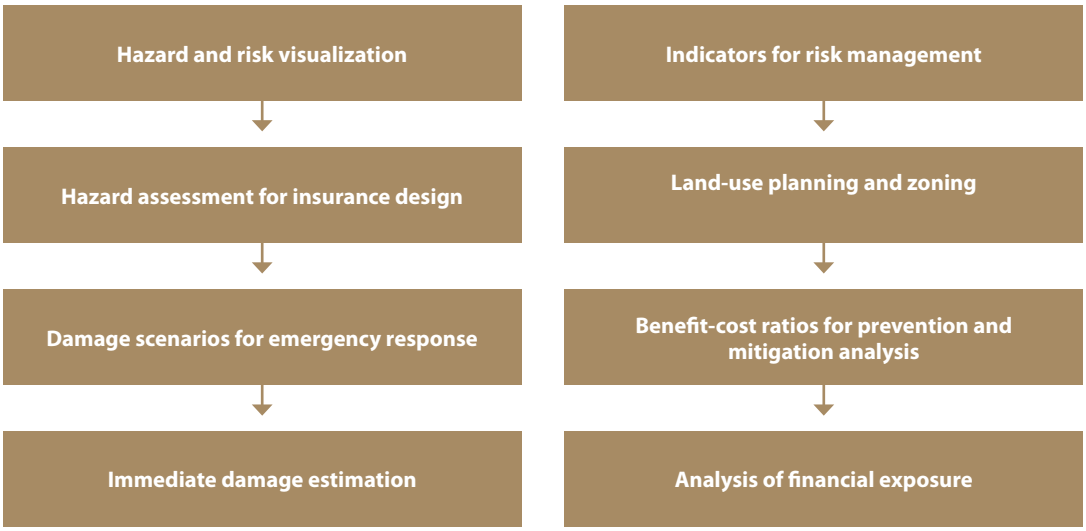
Source: CAPRA: www.ecapra.org.

Figure 4.3: Probabilistic risk modeling (c)



Source: Yamin et al. (2008).

Figure 4.4: Components of probabilistic risk modeling (d)



Source: Yamin et al. (2008).

Climate proofing infrastructure: A new concept?

Climate proofing infrastructure against risks related to climate variability and climate change may sound like a new concept, but engineers customarily take historical climatic conditions into account when designing, constructing, using and maintaining infrastructure. In the past this was called 'weather-proofing' or 'hazard-proofing.'

DEFINITION

Capacity

The combination of all the strengths, attributes and resources available within a community, society or organization that can be used to achieve agreed goals.

Source: UNISDR (2009a)

Decision makers should be aware of a range of emerging infrastructure concerns in the context of long-term climate change. Investments in transport networks, electricity and water infrastructure usually have an economic life expectancy of several decades. In these scenarios, operators must anticipate the need to adapt not only to today's hazards but also to tomorrow's likely hazards and climatic conditions. Relying on past records as an indication of the future is no longer a viable option. A sophisticated array of information is necessary to inform and guide decisions concerning investment on infrastructure and management. Future infrastructure investments must incorporate up-to-date scientific projections of how precipitation, temperature and wind patterns might change, as this will influence the location and operations of infrastructure such as hydro-power plants, motorways, bridges and so on.

There are several definitions of climate proofing. In general, climate proofing is a shorthand term for identifying risks that a development project faces from climate variability and change, and ensuring that those risks are reduced to acceptable levels through long-lasting and environmentally sound, economically viable, and socially acceptable changes implemented at one or more of the following stages in the project cycle: planning, design, construction, operation, and decommissioning (AsDB, 2005).

Box 4.1: Definitions of climate proofing

In his *Roadmap to Climate proofing for Cities,* Fleischhauer (2009) presents several definitions of climate proofing:

- "Climate proofing does not mean reducing climate-based risks to zero…The idea is to use hard infrastructure to reduce risks to a quantified level, accepted by the society or economy. This risk can be further combated by 'softer' measures, such as insurance schemes or, as a last resort, evacuation plans…" Source: Kabat et al. (2005)
- "From an engineering perspective, climate proofing is the capacity of a system to continue to function well as the climate changes. It is a measure of the range within which the system, such as an ecosystem, a socio-economic system or a technological system, continues to function 'normally'…." Source: Netherlands National Research Program: "Climate Changes Spatial Planning" (2007)
- "Ensuring the sustainability of investments over their entire lifetime taking explicit account of a changing climate is often referred to as 'climate proofing'." Source: European Union Green Paper "Adapting to climate change in Europe – options for EU action" (2007)
- Source: Climate proofing in the Impact Assessment of the EU White Paper "Adapting to climate change: Towards a European framework for action" (2009).
  - **EU policies and programmes:** Mainstreaming of climate change into cooperation and development strategies and programmes (climate proofing) is imperative.
  - **Land use planning:** Decisions taken on land use planning need to incorporate as soon as possible climate proofing considerations and long term considerations in the land use planning and spatial planning.
  - **Integrated planning:** Develop guidelines for climate proofing spatial planning integrated with land and water management and nature conservation, addressed to local and subnational authorities.

Several additional definitions and concepts are important for decision-making processes related to climate proofing:

Acceptable risk: The level of potential losses that a society or community considers acceptable given existing social, economic, political, cultural, technical and environmental conditions. In engineering terms, acceptable risk is also used to assess and define the structural and non-structural measures that are needed to reduce possible harm to people, property, services and systems to a chosen tolerated level, according to codes or 'accepted practice' which are based on known probabilities of hazards and other factors. The concept of acceptable risk needs to be linked to that of critical facilities (UNISDR, 2009a).

Critical facilities: These are the primary physical structures, technical facilities and systems that are socially, economically or operationally essential to the functioning of a society or community, both in routine circumstances and in the extreme circumstances of an emergency. Critical facilities are elements of the infrastructure that support essential services in a society. They include such things as transport systems, air and seaports, electricity, water and communications systems, hospitals and health clinics, and centres for fire, police and public administration services (UNISDR, 2009a). There is a need to identify essential infrastructure vulnerable to climate change. CCA priorities should focus on critical facilities and places where potential negative impacts are significant and considered in a broader planning context (VTrans, 2008).

Residual risk: The risk that remains in an unmanaged form, even when effective DRM and CCA strategies, plans and actions are in place. Early warning systems and emergency response and recovery capacities must exist for these risks. The presence of residual risk implies a continuing need to develop and support effective capacities for EWS, emergency services, preparedness, response and recovery; together with risk transfer mechanisms and socio-economic policies such as safety nets (UNISDR, 2009a).

Socio-natural hazard: The increased occurrence of certain geophysical and hydro-meteorological hazards, such as landslides, flooding, land subsidence and drought, that arise from the interaction of natural hazards with overexploited or degraded land and environmental resources. This term is used for the circumstances where human activity is increasing the occurrence of certain hazards beyond their natural probabilities (i.e. climate change). Evidence points to a growing disaster risk from combined geophysical and hydro-meteorological hazards in El Salvador. Socio-natural hazards can be reduced and avoided through good management of land and environmental resources, which use increased capacity to lower vulnerability (Highland and Bobrowsky, 2008; UNISDR, 2009a).

Structural and non-structural measures: Structural measures are any physical construction to reduce or avoid possible impacts of hazards, or application of engineering techniques to achieve hazard resistance and resilience in structures or systems. Non-structural measures are any measure not involving physical construction that uses knowledge, practice or agreement to reduce risks and impacts, in particular through policies and laws, public awareness raising, training and education. Common structural measures for disaster risk reduction include dams, flood levies, ocean wave barriers, earthquake-resistant construction, and evacuation shelters. Common non-structural measures include building codes, land use planning laws and their enforcement, research and assessment, information resources, and public awareness programmes. Note that in civil and structural engineering, the term 'structural' is used in a more restricted sense to mean just the load-bearing structure, with other parts such as wall cladding and interior fittings termed non-structural (ISDR, 2009a).

Climate change adaptation versus environmental impact assessment (EIA): In the past, environmental impact assessments (EIAs) were done before, during, and after projects to better understand how project activities might impact the environment. Questions about how environmental impacts might affect the project were not explicitly addressed because the causality was assumed to be unidirectional. With climate proofing, an EIA or an EIA-like exercise is a critical input into the CCA decision-making process. Issues to assess include environmental impacts (including those directly and indirectly related to climate variability and change) on the conditions underlying the project; how environmental projects can increase capacity and lower vulnerability (and possibly lessen the probability of a severe hazard event); and how do project activities and environmental impacts interact over time and space. Many methods of analysis associated with hazard assessments and EIAs (and the information generated) are useful for climate proofing. However, CCA and climate proofing require a broader application of existing methods, modifications and extensions to existing methods, and possibly new methods.[10]

[10] According to Fleischhauer (2009) there has been an important paradigm shift with respect to the relationship between climate risk management and assessments of environmental impacts.

Several key concepts for decision-making for climate proofing can be drawn from the risk-vulnerability chain and the above definitions:

a) Climate risks are associated with both climate variability and change in the present and future, and therefore related to both CCA and DRM. This is 'climate risk management.'

b) Natural hazards drive the need for climate proofing, but vulnerability and capacity are major determinants of actual losses from a given hazard event.

c) Vulnerability and capacity can be changed by policies/regulations (software) and investments (hardware). A combination of improved codes and standards and improved construction techniques are needed.

d) Mainstreaming and integration of CCA and DRM in the context of a multisectoral territorial planning (that includes land-use plans and natural resource management plans) can result in options for no-regrets actions.

e) There are acceptable levels of risk that should be determined by a wide range of stakeholders.

f) Key aspects of 'acceptable risk' include the sustainability of critical facilities in the short term (in response to a hazard event), and the long term (in response to changes in climate over time).

g) There is a need for multidimensionality: economic, social, environmental, and cultural dimensions should be considered.

h) The entire project cycle should be considered: planning, design, construction, operation and maintenance.

Climate proofing infrastructure: A risk-based no-regrets approach[11]

Public infrastructure tends to be multifunctional and serve a wide range of diverse stakeholders spread over a wide geographic area (beyond where the infrastructure is physically located). By its very nature, public infrastructure provides many critical services directly and indirectly, and interruptions in services can cause negative economic impacts to many households over wide geographic areas. The negative economic impacts, although local, can have important macroeconomic impacts (Freeman et al., 2002). The vulnerability of a given point in space to meteorological or geo-physical hazards can depend on the CCA and DRM capacity over a wide area, especially for storms, floods, landslides and mudslides. It is critical to identify the appropriate accounting stance for decision-making about climate proofing (e.g. community, municipality, district, watershed) to apply the risk-based approach based on components in Figures 4.1 and 4.2.

Public infrastructure projects have life expectancies that require consideration of present and future climate conditions. Climate change, manifested through changes in atmospheric and oceanic conditions, will impose both increased and new risks on many natural and human systems, especially as a result of changes in climate variability and changes in the frequency and magnitude of extreme climatic events. The objective of a risk-based approach to CCA is to manage both the current and future risks associated with the full spectrum of hydro-meteorological and geological hazards. This is best undertaken in a holistic manner as an integral part of sustainable development planning.

"The objective of a risk-based approach to CCA is to manage both the current and future risks associated with the full spectrum of hydro-meteorological and geological hazards. This is best undertaken in a holistic manner as an integral part of sustainable development planning."

[11] Drawn from: Asian Development Bank (ADB, 2005b) *Climate-Proofing: A Risk-based Approach to Adaptation.* Pacific Studies Series. http://www.adb.org/Documents/Reports/Climate-Proofing/main-report.asp

National, local and sector development should be based on harmonized DRM and CCA strategies, plans and actions that ensure risks are reduced to acceptable levels. These actions, and the related strategies and plans, will help strengthen all decision-making processes by requiring that specific programmes and projects include plans and actions to manage risks associated with future, as well as present, climate variability and extreme weather events. Such actions will result in the climate proofing of development projects and related initiatives in support of the wider process of sustainable development. This is a risk-based no-regrets approach.

"Mainstreaming aims to enhance the effectiveness, efficiency, and longevity of initiatives by reducing climate-related risks, while at the same time contributing to sustainable development and improved quality of life."

It is important to assess the risks arising from current climate variability and extremes as well as from future changes in those risks that might result from longer-term changes in climate. Likewise, it is important to assess CCA strategies and other measures that can be used to reduce unacceptable risks, including analyses of their benefits and costs. These analyses should determine, in a rigorous and quantitative manner, the incremental costs of adaptation to climate change. In some cases, if these costs are clearly identified and quantified by a developing country, they might be compensated, at least in part, by the international community (e.g. bilateral and multilateral aid providers, and funding mechanisms such as the Special Climate Change Fund or the Adaptation Fund).

It is critical to mainstream climate change considerations into national strategic development plans, and climate proofing infrastructure and community development projects is part and parcel of this process. In the context of addressing climate and related risks, the term 'mainstreaming' is used to describe the integration of CCA adaptation into ongoing and new development policies, plans, and strategies, including laws and regulations (e.g. EIA requirements). Mainstreaming aims to enhance the effectiveness, efficiency, and longevity of initiatives by reducing climate-related risks, while at the same time contributing to sustainable development and improved quality of life.

It is important to consider the different levels at which adaptation takes place, and the linkages between them. Adaptation takes place at the project level, through regulation and compliance, through short- and mid-term policy-making and planning at subnational level, and through national strategic development planning. It is also important to strengthen the enabling environment for CCA to increase the likelihood of successful adaptation at project and community levels.

The process undertaken by public authorities to identify, evaluate and decide on different options for the use of land, including consideration of long-term economic, social and environmental objectives and the implications for different communities and interest groups, and the subsequent formulation and promulgation of plans that describe the permitted or acceptable uses, is critical. Land-use planning is an important contributor to sustainable development. It involves studies and mapping; analysis of economic, environmental and hazard data; formulation of alternative land-use decisions; and design of long-range plans for different geographical and administrative scales. Land-use planning can help to mitigate disasters and reduce risks by discouraging settlements and construction of key installations in hazard-prone areas, including consideration of service routes for transport, power, water, sewage and other critical facilities (ISDR, 2009a).

Key steps for the process of decision-making on climate proofing infrastructure

- **Identify the area and time frame of analysis:** A description of the area where planning new public infrastructure or where carrying out an inventory of existing (or damaged) infrastructure is necessary. Use information on past hazards to understand the major hazards and spatial distribution of hazards given the vulnerabilities and capacities.
- **Identify stakeholders and potential uses of infrastructure, acceptable risks and critical facilities:** Given the area and time frame, identify the relevant stakeholders from different areas, sectors, socio-economic classes, public and private sectors, community, local, subnational and national government agencies. Begin a participatory process to identify multiple potential uses of infrastructure, and key issues such as acceptable risk and critical facilities.
- **Assess building codes and standards and enforcement:** Define the ordinances or regulations and associated codes and standards intended to control aspects of the design, construction, materials, use and maintenance of infrastructure that are necessary to ensure human safety and welfare, including resistance to natural hazards and climate change. Building codes can include both technical and functional standards. They should incorporate the lessons of international experience and should be tailored to national and local circumstances. A systematic regime of enforcement is a critical supporting requirement for effective implementation of building codes (ISDR, 2009a). This information is useful for vulnerability and capacity assessments.
- **Objectives for climate-proofing exercise:** Along with the previous three steps, it is critical to focus on the objectives of the climate-proofing exercise. CCA/DRM objectives should be balanced against the and overall economic, social, environmental, cultural objectives of the stakeholders.
- **Overview of major hazards and recent experience with hazards disasters:** This is a data-intensive exercise using a wide range of sources and analytical techniques. A major challenge is predicting future climates. It is best to start with an inventory of past data and experiences with different hazards, using geographic information systems (GIS) to organize and present data in maps.
- **Vulnerability assessment:** There should be an assessment of a wide range of socio-economic, environmental, and cultural data from quantitative (e.g. census data, household surveys) and qualitative sources (rapid participatory assessments). The vulnerability assessment might be the most important and most difficult to carry out, although the capacity assessment is also challenging. It is especially difficult to match up the mixed quantitative/qualitative data on vulnerability (and capacity) with the extremely quantitative data used for hazard assessments. Issues like demographic forecasts are complicated, as are forecasts of land use and natural resource management.
- **DRM/CCA capacity assessment:** There are many policies and institutions that directly and indirectly contribute to the DRM/CCA capacity of a given area. National and regional policies and institutions are import, and in some cases, international policies and institutions.

- **Probabilistic risk modeling:** Risk modeling should be methodically conducted along with scenario testing since it brings together hazard, vulnerability and capacity assessments, which involve different types of data in different units of analysis. Reasonable alternatives should be assessed and prioritized.
- **Climate-proofing assessment:** Together with the risk analysis, there should be an assessment the economics of different climate-proofing options. There is a need for integrated economic, engineering and environmental analyses to assess the benefits and costs of alternative climate-proofing options under varying assumptions about hazards, vulnerabilities and capacities. In many cases traditional cost-benefit analyses are replaced by more eclectic analytical methods and/or application of cost-effectiveness methods. Choosing an appropriate discount rate is important. The discount rate should be based on the market rate, but also include allowance for uncertainty and catastrophic loss. In this manner, the discount rate is not zero, but can be sufficiently low to allow for greater intergenerational equity and justifications of long time horizons.[12]
- **Territory-based climate-proofing plans:** Combining stakeholders' objectives of the climate-proofing exercise and the results of the probabilistic risk modeling, it is possible to bring the CCA/DRM plans into the planning context at the appropriate level(s). This will include decisions about climate-proofing actions, including hardware and software. Also, this would include plans for financing the infrastructure and institutions, EWS and emergency response, and alternative finance and insurance mechanisms to lessen losses after a hazard event occurs.
- **Establish EWS:** There is a need to generate and disseminate timely and meaningful warning information to enable individuals, communities and local governments threatened by a hazard to prepare and act appropriately with sufficient time to reduce the possibility of harm or loss. EWS include four basic components: knowledge of the risks; monitoring, analysis and forecasting of the hazards; communication or dissemination of alerts and warnings; and local capabilities to respond to the warnings received. The expression 'end-to-end EWS' emphasizes that warning systems needed to span all steps, from hazard detection to community response.
- **M&E:** This is a critical part of the process and should be linked to the EWS. Based on the analyses for climate-proofing decisions, there is a constant need to update data and assess how climate proofing is performing in reality. Does climate proofing provide no-regrets benefits or is it an unwelcome cost burden? Are residents in the area less or more exposed to hazards? Are there sufficient risk management instruments available to residents?
- **Reflections and feedback mechanisms:** It is important to document and discuss major successes and key challenges and difficulties involved with making infrastructure climate proof. Stakeholders should consider this information as well as lessons learned.

[12] Weisbach and Sunstein (2008) claim that resource allocation decisions should be used using the market discount rate (adjusted for uncertainty) and refer to Weitzman (2007), who claims that the discount rate also must be adjusted for uncertainty and possible catastrophic risk from climate change. This means they are advocating discounting at the market rate (properly adjusted for uncertainty and catastrophic risks). Thus Weisbach and Sunstein (2007), Weitzman (2007), and Nordhaus (2007) provide economic arguments that strongly support a no-regrets approach, in which they propose that the discount rate should be used to identify forward-looking high-return to efficiently and equitably manage the potential direct and indirect impacts of climate change, with a focus on the poorest and most vulnerable households and communities.

Concluding comments

Key principles concerning climate proofing of infrastructure

There have been a number of initiatives aimed at understanding the implications of climate proofing infrastructure. These are described in Annex 1 to this report. Key findings are outlined below.

1. In the context of long-term climate change and infrastructure, decision makers should be cognizant of a range of emerging concerns. Relying on past records as an indication of the future is not a viable option. A sophisticated array of information will be necessary to inform and guide decisions concerning investment on infrastructure as well as decisions on management.
2. Integrating climate change risks into infrastructure investments requires a probabilistic risk-based approach. Planners and decision makers are already familiar with risk management, since risk assessment and management are common to many sectors, including health care, finance, transport, agriculture, energy and water resources. It is, therefore, a sensible entry point for facilitating the mainstreaming of risk-based adaptation to infrastructure.
3. Soft solutions (the capacity to make informed decisions, the institutional setting to facilitate and support risk management, and so on) are sometimes as important, if not more, than hardware solutions.
4. A multidisciplinary approach is required to address what is a multisectoral, cross-cutting issue. Engineers need to work with municipal planners and infrastructure asset managers to determine appropriate levels of services that anticipate climate change impacts.
5. Country-driven, localized efforts to internalize climate change risk considerations are essential. Top-down approaches are not successful.
6. The resources, imagination and mobilizing power of the private sector are critical to support innovative and widespread risk management in a world of changing climate.
7. The role of government should be to facilitate market interventions to promote innovations in climate risk management.
8. Engineering vulnerability/risk assessment forms the bridge to ensure climate change is considered in engineering design, operations and maintenance of civil infrastructure.
9. Climate change models do not provide the granularity required for the site-specific scales used in engineering design of individual infrastructures. Engineering vulnerability/risk assessment provides a recognized methodology that handles the uncertainties that are inherent in climate change projections.
10. The performance response of infrastructure components that require estimation of climate change impacts include structural integrity, serviceability, functionality, operations and maintenance, emergency response risk, insurance considerations, policies and procedures, economics, public health and safety, and environmental effects.
11. Qualitative vulnerability/risk assessment based primarily on professional judgment from a multidisciplinary team of engineers, identifies those components that are not at risk as well as those that are clearly at risk.
12. A risk-based approach can be linked to sustainable development by identifying risks to future generations that present generations would find unacceptable.
13. There are a number of tools that decision makers can rely on to internalize climate change risks into infrastructure. The CAPRA initiative is a tool that enables decision makers to manage risk at local, national and regional levels using a GIS-based platform of information on natural hazard risk, for disaster risk analysis and communication. Such platforms can be used to make decisions on risk management in the context of climate change impacts on infrastructure.

Annex 1: Further Reading: Lessons Learned on Climate Proofing Infrastructure

Stockholm Policy Forum on Climate Smart Disaster Risk Management Summary Report. October 26, 2009, Stockholm, Sweden (See GFDRR, 2009b)[13]

Key findings

The parties agreed that in addition to infrastructure and technical hardware solutions, greater emphasis on software issues and existing capacities to cope and adapt is needed.

The working group on local dimensions called for bottom-up approaches and the use of existing social networks to integrate adaptation and risk reduction into ongoing development efforts. Climate change adaptation and DRM are additional priorities on a long list of existing developmental issues. The group agreed that international organizations cannot ground policy at the local level. Policy must be owned by local civil society. Practice should influence policy and the trust and confidence gap must be overcome by adopting bottom-up approaches.

Given the enormous financing needs for CCA, the private sector will be a key player in supporting investment. Participants in a working group explored ideas for harnessing the resources, imagination and mobilizing power of the private sector to support innovative and widespread risk management in a world witnessing increased natural disasters and changing climate. Participants expressed a need for governments to facilitate platforms to bring the private sector into the discussion on adaptation and disaster risk management by creating a neutral ground for stakeholder dialogue at the highest level. One suggestion was to promote research to identify opportunities for the private sector in the field of climate risk management.

Government could facilitate market interventions to promote innovations in climate risk management, focusing on diversity of actors (small and medium size companies) and diversity of sectors (not just one single aspect of CCA). There was a consensus that innovation should not only be technologically driven but also institutional, and that governments should offer the right incentive structure to build long-term sustainable thinking and promote risk reduction in an environmentally sound manner.

Key messages

Several recurring themes emerged across all three working groups, including the need for a coherent, integrated approach to CCA and DRM. There is a clear need to reach out across disciplines for enhanced coordination and learning. All three working groups called for the promotion of bottom-up approaches and engagement civil society and grassroots groups in decisions-making processes. In addition, the groups strongly emphasized the need to make better use of existing networks and mechanisms, including mobilizing social networks for adaptation goals, strengthening the capacities of existing regional institutions for improved coordination, and promoting more South-South cooperation among public and private sector actors. Finally, each working group strongly emphasized promoting ecosystems and sound environmental management approaches to CCA and DRM.

[13] http://www.sida.se/PageFiles/18125/Stockholm%20Policy%20Forum%20summry%20final.pdf

Engineers Canada, Infrastructure Climate Risk Assessment Backgrounder, January 2010, Public Infrastructure Engineering Vulnerability Committee (PIEVC)[14]

Emerging good practices and lessons learned

"It is fundamentally clear that climate change represents a profound risk to the safety of engineered systems and to public safety in Canada and around the world. As such, professional engineers must address climate change adaptation as part of our primary mandate – protection of the public interest, which includes life, health, property, economic interest and the environment. Climate change results in significant changes in statistical weather patterns resulting in a shifting foundation of fundamental design data. Physical infrastructure systems designed using this inadequate data are vulnerable to failure, compromising public safety."

Engineering vulnerability/risk assessment forms the bridge to ensure climate change is considered in engineering design, operations and maintenance of civil infrastructure. Identifying the highly vulnerable components of the infrastructure to climate change impacts enables cost-effective engineering/operations solutions to be developed. It is a structured, formalized and documented process for engineers, planners and decision makers to recommend measures to address the vulnerabilities and risks to changes in particular climate design parameters and other environmental factors from extreme climatic events. The assessments help justify design, operations and maintenance recommendations and provide documented results that fulfil due diligence requirements for insurance and liability purposes.

Currently, climate change models do not provide the granularity required for the site-specific scales used in engineering design of individual infrastructures. Engineering vulnerability/risk assessment provides a recognized methodology that handles the uncertainties that are inherent in climate change projections. It enables the identification of key vulnerabilities and risks in a form that enables engineers to exercise their professional judgment for infrastructure design, operations and maintenance recommendations.

The following are recommended good engineering practices that have so far emerged from this work as well as lessons learned for future engineering vulnerability assessments.

To precisely define the engineering vulnerabilities of a particular infrastructure, it is necessary to define the individual components of the infrastructure 'system.'

- The performance response of infrastructure components that require estimation of climate change impacts include structural integrity, serviceability, functionality, operations and maintenance, emergency response risk, insurance considerations, policies and procedures, economics, public health and safety and environmental effects.
- It is most important to calibrate vulnerability/risk assessments of existing infrastructures with on-site managers, operators and maintainers, who serve as the reality check for assumed impacts and consequences of future climate changes and events. This input is best achieved through a workshop to develop consensus on the risks and impacts/consequences. This achieves 'buy-in' from the people who will be involved in implementing adaptive solutions to address the vulnerabilities and risks.

[14] www.pievc.ca

- Qualitative vulnerability/risk assessment based primarily on professional judgment from a multidisciplinary team of engineers identifies those components that are not at risk and those that clearly are. Quantitative risk assessment is often required to resolve the level and nature of the engineering vulnerability for those components that cannot be estimated by qualitative assessment. These analyses will also help determine the most appropriate engineering or operations solutions
- Two levels of infrastructure vulnerability based on professional judgment (engineering and operational) have been identified. High vulnerability means a high risk of reduced or limited performance and perhaps even failure of the component due to the indicated climatic factor. These require remedial action in the short to medium term. Medium vulnerability means there is a moderate risk of significant impact or failure of the component and remedial action is required in the medium to longer term
- Engineers need to work with municipal planners and infrastructure asset managers to determine appropriate levels of services that anticipate climate change impacts.

Climate Proofing: Lessons Learned and Barriers to Successful Application. Asian Development Bank (AsDB, 2005a) *Climate Proofing: A Risk-based Approach to Adaptation: Summary for Policy Makers.* Pacific Studies Series[15]

Summary comments

The Asian Development Bank (AsDB) may continue to demonstrate and advocate a risk-based approach to adaptation, both within the region and internationally, since it combines both the likelihood and consequence components of climate-related impacts, and assesses risks for both current and anticipated conditions, with the option of examining either specific events or an integration of those events over time. Other reasons for advocating a risk-based approach include the familiarity of planners and decision makers with risk management, since risk assessment and management are common to many sectors, including health care, finance, transport, agriculture, energy, and water resources, thus facilitating the mainstreaming of risk-based adaptation. The approach also facilitates an objective and more quantitative approach, including cost-benefit analyses that result in evaluation of the incremental costs and benefits of adaptation and assist in prioritizing adaptation options. The risk-based approach involves many players, but provides a framework that facilitates coordination and cooperation, including the sharing of information that might otherwise be retained by information 'gate keepers.'

Significantly, a risk-based approach can be linked to sustainable development by identifying those risks to future generations that present generations would find unacceptable. Advocacy of the risk-based approach to adaptation could extend to encouraging international agencies, such as the Intergovernmental Panel on Climate Change (IPCC), to formally endorse and encourage a risk-based approach to adaptation, including provision of documentation and training opportunities to build the needed cadre of in-country expertise. AsDB will also give consideration to developing and disseminating additional case studies. The preparation of generalized findings and lessons is needed based on new and existing case studies that demonstrate a risk-based approach to adaptation.

[15] http://www.adb.org/Documents/Reports/Climate-Proofing/climate-proofing-summary.pdf

AsDB will identify, maximize, and take advantage of the many synergies between its sustainable development initiatives and climate change adaptation initiatives. AsDB will consider

- adjusting its procedures to ensure that the design and funding implications associated with climate proofing its infrastructure, community and other development projects are addressed early in the project cycle;
- undertaking further work to develop methods to identify, early in the project cycle, the incremental costs of this climate proofing, allowing these costs to be met from sources other than loans, etc., to the developing country;
- strengthening the Environmental Impact Assessments so that they give adequate recognition to climate-related risks and in turn, how environmental impacts affect climate-related risks; and
- ensuring that the terms of reference for technical assistance include the requirement that climate risks be reflected in both pre-design work and the actual project design.

The case studies highlight the following conclusions:

- It is possible to enhance the sustainability of projects at risk to climate change by climate proofing at the design stage, noting that this will normally require an investment that is small relative to the additional maintenance and repair costs incurred over the lifetime of the project.
- Many CCA options qualify as no-regrets adaptation initiatives, including being cost-effective.
- Retroactive climate proofing is likely to be considerably more expensive than that undertaken at the design stage of a project.
- Governments should reflect these findings by ensuring that all projects are climate proofed at the design stage, making this part of good professional practice.
- Developing country governments should determine the incremental costs and benefits of all major development projects and request that aid providers and other agencies fund these incremental costs.
- National- and subnational-level regulations should be climate proofed, as this will allow enforcement of policies and plans that should themselves be climate proofed.

If a risk-based approach to CCA is to gain full acceptance, further attention needs to be given to methods that support

- formal specification of risk-based targets that define future levels of acceptable risk;
- determination of the damage costs from flooding due to heavy rainfall and sea surges, in combination;
- specification of relationships between the likelihood and consequence of risk events of relevance, and especially the refinement of stage-damage curves;
- quantifying the social, environmental, and wider economic costs of climate variability and change, including extreme events;
- creation of 'rules' that specify future social, economic, and wider environmental changes; and
- selection of appropriate discount rates to be applied to future costs and benefits.

Construction Design, Building Standards and Site Selection. Guidance Note #12: Benson, C. and J. Twigg (2007) *Tools for Mainstreaming Disaster Risk Reduction: Guidance Notes for Development Organizations*. PROVENTION Consortium[16]

Construction design, building standards and site selection

In past development initiatives involving the construction of infrastructure, the option of designing and building to reduce the vulnerability of infrastructure to natural hazards has often been ignored due to the perceived higher costs and lack of appropriate expertise. Furthermore, the selection of the location for services or critical facilities has often been based on land cost and availability rather than safety from potential natural hazards.

Typically, development organizations rely on best local practices in hiring contractors to undertake construction work. Problems arise when best local practice does not incorporate the use of any building codes for hazard resistance or uses building codes that inadequately account for local hazards. The latter type of code typically exists in countries where infrequent natural hazards occur or where there is an incomplete historical record of past natural disasters. This results in hazard or zoning maps that do not adequately represent the frequency of occurrence or potential magnitude of natural hazards. Even when appropriate building codes exist, their correct application requires skilled engineers, architects and builders and effective enforcement and inspection procedures. Poor governance and corruption, leading to, for example, abuse of land use controls and building permits and codes, and illegal expansion of buildings, often exacerbate damage caused by disasters. In addition, most developing countries lack certification and licensing processes for professionals and enforcement procedures are non-existent. Enforcement procedures have, however, also been found to be ineffective in developed countries, and developing countries.

The adoption of best local practice and of opportunity-based land use can lead to a promotion of existing weaknesses in buildings and infrastructure. Funding and development organizations alike need to ensure that experienced hazard specialists and engineers coordinate or implement construction projects, either employing them directly or ensuring that such people will lead the contracted work. This specialist (or team of experts, depending on the number of hazards and scale of the project) should set a framework for the design and construction, which may then be executed by other engineers, builders and workers.

Contrary to common perception, the implementation of hazard-proof measures in building can be relatively inexpensive in terms of construction costs. What can be expensive is the provision of an effective framework for the take-up of these measures (e.g. the provision of skills training, appropriate hazard studies, research into low-cost strengthening solutions). However, if an effective mechanism exists for the enforcement of quality control and codes of practice, these costs will be covered by the construction industry. In many cases, building codes and enforcement are weak, which puts the onus on the agencies that commission and fund development projects to provide the necessary training, education, and research and development. The development and enforcement of appropriate building codes and standards does not make development costs prohibitive. An investment in disaster mitigation can result in a manifold saving in disaster relief and development setbacks. Where development agencies have invested in the promotion of hazard-resistant construction, many of the projects are well thought out and show large benefit.

[16] http://www.proventionconsortium.org/themes/default/pdfs/tools_for_mainstreaming_DRR.pdf

An integrated and comprehensive approach is necessary to improve the safety of buildings from natural hazards. This includes investing in strengthening existing structures and promoting safer building in development projects and post-disaster reconstruction projects. In hazard-prone countries, it is essential that both funding and development organizations ensure that engineers specialized in hazard-resistant construction are consulted in the initial stages of construction projects.

In order to set the design criteria for a risk reduction project, the hazards, current risk, and socially acceptable level of risk must be identified. A multi-hazard appraisal should be carried out at an early stage to identify the types of hazards, their likely severity and recurrence. An evaluation of the current risk includes identifying locations most likely to become unsafe in the event of a natural hazard (e.g. areas prone to flooding, landslides or earthquake-induced liquefaction) and assessing their land use, as well as assessing the ability of local construction to resist the identified hazards. A survey of existing buildings and infrastructure can identify significant vulnerabilities prior to the occurrence of a hazardous event. In a post-disaster scenario, lessons can be learned from the behaviour of different construction types during the event. Post-disaster diagnostic surveys should be integrated into disaster reconstruction programmes. In order to determine the socially acceptable risk level, local and national building codes, international legislation and good practice should be examined to obtain an idea of current accepted levels of risk for different hazards and infrastructure. For example, in the case of most earthquake engineering codes, structures of normal importance are designed to withstand an earthquake with a 10 percent probability of being exceeded in 50 years (i.e. an event with a return period of 475 years). The local government and community should then be consulted and a level of risk determined for the design. It is important to note that the level of socially acceptable risk will vary according to the use and importance of the facility and the desired post-natural hazard event performance. Finally, if the level of current risk is greater than that which is socially acceptable, then the need for hazard-proofing (and/or re-siting) is established, and the socially acceptable risk and identified hazards become the design criteria for the new construction or strengthening works.

Throughout project design and implementation, it is essential that local stakeholders are actively involved. Local stakeholders include the direct beneficiaries, the wider affected community, local authorities, government, and local academic and building experts. This will aid in the development of a truly sustainable technical solution (for infrastructure strengthening or reconstruction) and will increase acceptance of the project. A sustainable and successful project goes beyond site selection, the choice of a sustainable solution and training of local builders, to also involve issues of land tenure, finance, education for risk awareness and future maintenance.

Global Facility for Disaster Reduction and Recovery (GFDRR, 2010a) "Safer Homes, Stronger Communities" A Handbook for Reconstructing after Natural Disasters. by A.K. Johan with others[17]

Guiding principles

1. **A good reconstruction policy helps reactivate communities and empowers people to rebuild their housing, their lives, and their livelihoods.** A reconstruction policy should be inclusive, equity-based, and focused on the vulnerable. Housing reconstruction is key to disaster recovery, but it depends on the recovery of markets, livelihoods, institutions and the environment. Diverse groups need diverse solutions, but biases will creep in, so a system to redress grievances is a must.
2. **Reconstruction begins the day of the disaster.** If traditional construction methods need to change to improve building safety, governments must be prepared to act quickly to establish norms and provide training. Otherwise, reconstructed housing will be no less vulnerable to future disasters than what was there before. Adequate transitional shelter solutions can reduce time pressure and should be considered in a reconstruction policy. Owners are almost always the best managers of their own housing reconstruction; they know how they live and what they need. But not all those affected are owners and not all are capable of managing reconstruction; so the reconstruction policy must be designed with all groups in mind: owners, tenants, and landlords, and those with both formal and informal tenancy.
3. **Community members should be partners in policy making and leaders of local implementation.** People affected by a disaster are not victims: they are the first responders during an emergency and the most critical partners in reconstruction. Organizing communities is hard work, but empowering communities to carry out reconstruction allows their members to realize their aspirations and contribute their knowledge and skills. It also assists with psychosocial recovery, helps re-establish community cohesion, and increases the likelihood of satisfaction with the results. This requires maintaining two-way communication throughout the reconstruction process and may entail the facilitation of community efforts. A real commitment by policy makers and project managers is needed to sustain effective involvement of affected communities in reconstruction policy-making and in all aspects of recovery, from assessment to monitoring.
4. **Reconstruction policy and plans should be financially realistic, but ambitious with respect to disaster risk reduction.** People's expectations may be unrealistic and funding will be limited. Policy makers should plan conservatively to ensure that funds are sufficient to complete reconstruction and that time frames are reasonable. Rebuilding that reduces the vulnerability of housing and communities must be the goal, but this requires both political will and technical support. Housing and community reconstruction should be integrated and closely coordinated with other reconstruction activities, especially the rehabilitation and reconstruction of infrastructure and the restoration of livelihoods.
5. **Institutions matter and coordination among them improves outcomes.** Best practice is to have defined a reconstruction policy and designed an institutional response in advance of a disaster. In some cases, this will entail a new agency. Even so, line ministries should be involved in the reconstruction effort and existing sector policies should apply, whenever possible. The lead agency should coordinate housing policy decisions and ensure that those decisions are communicated to the public. It should also establish mechanisms for coordinating the actions and funding of local, national, and international organizations and for ensuring that information is shared and that projects conform to standards. Funding of all agencies must be allocated equitably and stay within agreed-upon limits. Using a range of anticorruption mechanisms and careful tracking of all funding sources minimizes fraud.

[17] http://www.housingreconstruction.org/housing/

6. **Reconstruction is an opportunity to plan for the future and to conserve the past.** What has been built over centuries cannot be replaced in a few months. Planning and stakeholder input help to establish local economic and social development goals and to identify cultural assets for conservation. Even a modest amount of time spent designing or updating physical plans can improve the overall result of reconstruction. Reconstruction guidelines help ensure that what is valued is preserved, while encouraging more sustainable post-disaster settlements. Improving land administration systems and updating development regulations reduces vulnerability and improves tenure security.
7. **Resettlement disrupts lives and should be minimized.** Resettlement of affected communities should be avoided unless it is the only feasible approach to disaster risk management. If resettlement is unavoidable, it should be kept to a minimum, affected communities should be involved in site selection, and sufficient budget support should be provided over a sufficient period of time to mitigate all social and economic impacts.
8. **Civil society and the private sector are important parts of the solution.** The contributions of NGOs, civil society organizations (CSOs), and the private sector to reconstruction are critical. Besides managing core programmes, these entities provide technical assistance, advocacy, and financial resources of enormous value. Governments should encourage these initiatives; invite NGO, CSO, and private entity involvement in reconstruction planning; and partner in their efforts. Government should also require accountability and make sure that these interventions are consistent with reconstruction policy and goals.
9. **Assessment and monitoring can improve reconstruction outcomes.** Assessment and monitoring improve current (and future) reconstruction efforts. Unnecessary assessments can be minimized if there are policies that require institutions to share assessment data and results. Local communities should participate in conducting assessments, setting objectives, and monitoring projects. Using reliable national data to establish monitoring baselines after the disaster increases the relevance of evaluations. Monitor both the use of funds and immediate physical results on the ground and evaluate the impact of reconstruction over time.
10. **To contribute to long-term development, reconstruction must be sustainable.** Sustainability has many facets. Environmental sustainability requires addressing the impact of the disaster and the reconstruction process itself on the local environment. The desire for speed should not override environmental law or short-circuit coordination when addressing environmental issues. Economic sustainability requires that reconstruction is equitable and that livelihoods are restored. Livelihood opportunities in reconstruction should be maximized. Institutional sustainability means ensuring that local institutions emerge from reconstruction with the capability to maintain the reconstructed infrastructure and to pursue long-term disaster risk reduction. A reliable flow of resources is essential and institutional strengthening may be required.
11. **Every reconstruction project is unique.** The nature and magnitude of the disaster, the country and institutional context, the level of urbanization, and the culture's values all influence decisions about how to manage reconstruction. Whether a government uses special or normal procurement procedures, how it weighs the concerns of speed versus quality, and what it considers the proper institutional set up and division of labour will also vary. History and best practices are simply evidence to be weighed in arriving at the best local approach.

Global Facility for Disaster Reduction and Recovery (GFDRR, 2008) *Climate-Resilient Cities: A Primer on reducing Vulnerabilities to Climate Change Impacts and Strengthening Disaster Risk Management in East Asian Cities*[18]

Best practices: Infrastructure sector

In this list of planned actions, it is clear that there are important hardware and software investments and policies that are needed to reduce vulnerability and increase capacity.

Nam Dinh Province, Viet Nam. A range of DRM measures have been identified for Nam Dinh according to the draft Second National Strategy and Action Plan. Although many have yet to be implemented and/or enforced, it is instructive to know what has been planned:

- Afforest and protect existing upstream forest watersheds to reduce downstream floods;
- Build large- and medium-scale reservoirs upstream on big rivers to retain flood water;
- Strengthen dike systems to resist flood levels;
- Build flood diversion structures;
- Clear floodways to rapidly release flood water;
- Strengthen dike management and protection works to ensure safety of the dike systems;
- Construct emergency spillways along the dikes for selective filling of flood retention basin; and
- Designate and use flood basins to decrease the quantity of floodwater flow.

Other non-structural measures that have been identified include:

- River flood forecasting models must be developed to give prompt warnings and quickly carry out effective response measures;
- The national disaster committee and organizations for flood and storm control from central to local levels of government must be strengthened to mobilize the work of flood and storm mitigation and management at all levels;
- Legal documents such as the Regulation on Flood and Storm Warning, Ordinance on Flood and Storm Prevention; Ordinance on Dikes; and Government regulations on construction of dikes, flood release, flash flood prevention, disaster relief, activities of standing offices for flood and storm prevention, damage measurement and assessment, and others have been prepared and should be continuously reviewed and strengthened;
- Community disaster awareness should be enhanced through education, training, workshops, and the circulation of disaster bulletins;
- Plans in accordance with all probable situations that include disaster-specific measures should be prepared so that disaster damage can be mitigated;
- Shifting the cultivation season should be studied as a measure to mitigate damage to agriculture production; and
- Master plans should be developed that will mitigate hazards, familiarize local populations, and prepare for evacuating people in specific localities where there is no capability for limiting the impact of frequent disasters. For each disaster occurrence, lessons learned and experience should be collected for future application.

[18] http://siteresources.worldbank.org/EASTASIAPACIFICEXT/Resources/climatecities_fullreport.pdf

Hazard Risk Management and Vulnerability Reduction Study Tour, 19-27 June 2007, Final Report

Lessons from Colombia

Hazard-risk reduction, with a particular focus on landslides, is achieved by providing regular on-site maintenance to disaster prevention works (i.e. terraces, drainage systems, canals, slope-reinforcements); monitoring disaster prevention works to ensure that they are functioning properly; and ensuring on-site waste management.

At the national level, Colombia has implemented a successful disaster risk management and vulnerability reduction strategy. Its success is arguably the result of its decentralization, where each municipality is responsible for devising hazard risk reduction coping strategies that fit the local context. Another key factor in its success is its comprehensive nature, which cuts across sectors and approaches including urban planning, municipal infrastructure, disaster risk financing, community-driven development and private-public partnerships.

While hazard risk reduction is primarily a municipal responsibility, regional and central governments are ready to provide support if the hazard overwhelms municipal capacity and resources, either in the case of a disaster or in vulnerability reduction and prevention. As evidenced by the regional contribution to this programme, which finances 50 percent and is provided by CORPOCALDAS, the regional government does indeed prioritize hazard risk prevention programmes. Across the Colombian government — including the municipal, regional and central levels — there is strong awareness that prevention and planning for potential disasters is the most cost-effective way to manage hazard risk and is the main contributor to vulnerability reduction.

The programme is economically viable and provided municipalities with cost savings of 44 percent in maintenance of hazard risk reduction works during its first year of implementation, 2004. In 2004, programme costs totalled $195,000, almost half the maintenance costs of the same works during the previous year ($347,000). This does not include the cost-savings in both economic terms and in potential lives saved in Manizales due to the successful implementation of landslide risk strategies and overall vulnerability reduction, which is by far the most important economic return and impact of the programme.

United Nations International Strategy for Disaster Reduction (UNISDR, 2009d) "Applying Disaster Risk Reduction for Climate Change Adaptation: Country Practices and Lessons." Briefing Note 02[19]

- Measures to reduce vulnerability and disaster risk are proven and are already applied to adaptation. Tools, capacities and supporting mechanisms for disaster risk reduction have been tested around the world and are available for wider use in climate change adaptation.
- Disaster risk reduction offers a triple win. Implementing disaster risk reduction policies and programmes can limit the impacts of climate-related hazards, directly support adaptation to climate change, and help alleviate poverty.

[19] http://unisdr.org/preventionweb/files/11775_UNISDRBriefingAdaptationtoClimateCh.pdf

- Reducing disaster risk requires — and provides opportunities for — political leadership. Political commitment at the highest level is essential to drive action across all sectors and to build institutional linkages between climate change adaptation and disaster risk reduction fields.
- Multistakeholder participation is a key to durable results. Disasters and climate change affect all of society, and therefore disaster risk reduction and adaptation solutions must involve all sectors and civil society, including the private sector, and incorporate community engagement.

Kovacs, P., and H. Kunreuther (2001). "Managing Catastrophic Risk: Lessons from Canada." Paper presented at the ICLR/IBC Earthquake Conference. 23 March 2001, Simon Fraser University, Vancouver, Canada.

An essential element of preventing future disaster losses involves reducing vulnerability to hazards by building community resiliency. A strategy to build resiliency must begin with an assessment of the current vulnerability of the region. This requires information on the design of residential, commercial and public sector structures and infrastructure and their locations in relation to various hazards.

The use of GIS to incorporate natural conditions (e.g. geological data) and structural information for a region has enabled scientists and engineers to estimate potential damage and losses from different scenarios. With respect to loss reduction activities, one should evaluate the costs and the expected benefits over time of adopting specific mitigation measures. The quality of this essential planning information varies considerably from country to country, and from community to community. Frequently CCA and DRM efforts for developing and emerging economies suffer from the absence of foundational data.

Detailed hazard assessments are a requirement for catastrophic risk management models. Once a community's vulnerability has been assessed, what can be done to increase its resiliency to the consequences of natural disasters? Strategies for reducing losses and providing financial protection include well-enforced building codes, the use of warnings and evacuation plans to reduce loss of lives and damage at the onset of an event, and recovery strategies such as insurance and financial assistance following a disaster. These policy tools complement each other: well-enforced building codes reduce the need for financial assistance after a disaster and warning and evacuation procedures reduce the need for emergency hospital care in the affected region.

The full range of activities can be clustered into three critical elements of an effective emergency preparedness strategy — prevention, response and recovery.

Disaster prevention

Adaptation involves investments before disaster strikes, actions designed to strengthen society's ability to resist the impact of future perils. An adaptation or mitigation strategy for disaster prevention include the following key elements:

- **Public awareness.** Informed families that are part of a culture of preparedness are best able to manage natural hazards.
- **Land use planning.** Resilient communities keep people and structures away from areas where the hazard risk has been identified.

- **Well-enforced building codes.** Cost-effective mitigation measures should be incorporated in design standards for existing and new structures, including schools, hospitals and offices.
- **Structural measures.** Dams, levees, seawalls and other engineered structures can be effective mechanisms to protect communities.
- **Non-structural measures.** Plantings can reduce beach erosion, healthy marshes help manage flood risk and other natural elements can reduce disaster damage.

Emergency response

Response programmes bring timely and comprehensive assistance to disaster victims. Effective emergency response is essential to reduce disaster losses and establish the basis for more rapid recovery. It includes the following elements:

- **Hazard assessment.** Community-based hazard assessment is essential if local officials are to effectively formalize their disaster planning efforts.
- **Disaster planning.** Each community needs to establish a comprehensive disaster plan and develop the capacity of responsible officials to implement the plan.
- **Warning systems.** Doppler radar, hurricane tracking, seismic monitoring and other warning and information systems strengthen both prevention and response.
- **Resource planning.** Access to critical resources, including food, power and communications, should be clarified before a hazard strikes.
- **Interjurisdictional issues.** Emergency response requires coordination of police, ambulance, fire, local, regional, national and perhaps international agencies.

Community recovery

A principal objective of catastrophic risk management is for a community to re-establish itself after disaster strikes, restoring functionality and a sense of normality for community members. Disaster recovery takes time, funds and effective management including the following elements:

- **Charities.** The Red Cross has a long history of helping people in times of need.
- **Disaster relief.** All levels of government finance and help manage aspects of disaster recovery, including public building, infrastructure and uninsured risks.
- **Private insurance.** Insurance is the primary mechanism most homeowners and businesses use to secure funds to recover following most hazards.
- **Public insurance.** Some countries have established public insurance schemes, such as the National Flood Insurance Program in the United States.
- **International aid.** Developing and emerging nations finance their disaster recovery efforts primarily through international aid.

Determining the appropriate mix of these measures to balance equity and fairness concerns with efficient allocation of resources is a key challenge for policy and decision makers.

Annex 2: Recommended Readings

A list of references and Web sites is provided in Annex 3. Below is a short list of recommended readings.

Asian Development Bank (AsDB, 2005a). *Climate Proofing: A Risk-based Approach to Adaptation: Summary for Policy and Decision Makers*. Pacific Studies Series. http://www.adb.org/Documents/Reports/Climate-Proofing/climate-proofing-summary.pdf.

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Annex 4: The Central American Probabilistic Risk Assessment (CAPRA) Initiative[20]

The Central American Probabilistic Risk Assessment (CAPRA) initiative seeks to enhance disaster risk understanding in the Central American region. It provides a GIS-based platform of information on natural hazard risk for disaster risk analysis and communication. CAPRA is a tool that enables decision makers to manage risk at local, national and regional levels.

The primary CAPRA product is a series of risk maps. The CAPRA methodology determines risk in a probabilistic manner, i.e. the intensity and frequency of occurrence of hazards over a period of time is considered. These risk maps present specific quantitative information on the potential losses a country, region, or particular city could face if struck by single or multiple hazards.

These visual representations of risk enable decision makers to adopt a comprehensive approach toward disaster risk management: with the information CAPRA provides, decisions can be made a priori about prevention, mitigation and response to natural hazards.

Led by the Central American Coordination Centre for Disaster Prevention, in partnership with Central American governments, the CAPRA initiative is supported by the United Nations International Strategy for Disaster Reduction Secretariat (UNISDR), the Inter-American Development Bank (IDB), and the World Bank.

Probabilistic risk assessment

CAPRA applies probabilistic risk techniques to determine the intensity (severity) and the likelihood (probability) of occurrence of hazards such as hurricanes, earthquakes, landslides, volcanoes or rainfall.

Probabilistic techniques employ the statistical analysis of historical datasets to assess potential hazard intensity, duration and frequency across a country's territory. This multi-hazard information is combined with data on exposure and vulnerability of assets or population to determine a spatial estimate of risk, or potential losses. Risk is expressed in terms of human impact, damage to assets, and economic and financial losses, and it is measured with probability of exceedance or frequency of occurrence parameters. The CAPRA software therefore quantifies risk according to a rigorous methodology, providing the disaster risk community with a common language for measuring, comparing or aggregating expected losses. Using probabilistic techniques, as opposed to deterministic analysis, ensures that the inherent uncertainties associated with intensity and frequency in model estimates are incorporated, providing more accurate information necessary to manage future disaster risk.

Why use CAPRA?

CAPRA responds to a demand for increased disaster risk understanding in Central America. It is a communication tool that visually represents risk in order to facilitate decision-making at various levels and sectors. Through the application of probabilistic modeling, CAPRA provides accurate risk information, and quantifies risk in useful metrics. Building on the work of generations of disaster experts, CAPRA makes use of existing initiatives and provides a common language for analysis and comparison of risk.

CAPRA goes beyond focusing on one sector: it can be applied at various levels, ranging from health and education to investment and development planning. CAPRA also offers various applications (discussed below), and moves away from black box models with 'vendor lock-in.' The software architecture is open and accessible to the community.

At the core of CAPRA is the commitment to an open and transparent information platform. At the data level, CAPRA uses standard data formats established under the Open Geospatial Consortium to build the

[20] CAPRA: http://www.eird.org/eng/revista/no-16-2009/art21.html

catalogue of risk information, allowing for maximum inter-operability with existing systems. At the software level it allows users to build their own applications — using all or part of CAPRA— enhancing the functionality of the software.

The CAPRA initiative is embracing Web 2.0 technologies and the underlying premise of collaboration offering new ways to communicate and work together. All CAPRA hazard and risk reports are available online in a wiki form (a collaborative Web site set up to allow user editing and adding of content), providing a space for users to debate and pose questions about the CAPRA methodology through an online discussion forum (www.ecapra.org/wiki).

In recent years, GIS have allowed the public to display and manipulate geo-referenced data through tools such as Google Earth/Maps, Virtual Earth and WorldWind Java. CAPRA is using these 3-D models to communicate ideas and collect data in new ways. To overcome the critical challenge of data collection in Central America, CAPRA is exploring new technologies, such as high-resolution aerial photography, satellite imagery and 'crowd sourcing.' An example of the use of crowd-sourcing to collect exposure data can be viewed on the wiki, in a risk assessment made for Bluefields, Nicaragua.

CAPRA applications

Once risk is determined, decision makers can use the various CAPRA applications to address the situation and engage in a comprehensive disaster risk management approach. CAPRA applications include:

- a hazard assessment report for territorial planning;
- a cost-benefit application for analysis of retrofitting projects;
- a calculator of technical premiums for insurance.

The CAPRA platform has the potential to assess the impact of climate change by using hazard models derived from climate, rather than historical data. For example, CAPRA could provide a risk evaluation of a climate change impact scenario using a model and future scenario projection from the IPCC.

The CAPRA community

CAPRA users range from technical experts, academics, government institutions, and emergency response organizations, to risk management consultants and decision makers, a wide and far-reaching community.

The CAPRA initiative is engaging universities to work with CAPRA software and collect data. Scholarships are offered to post graduate students to explore the potential of the CAPRA tools within the academic sector and especially to support graduate student projects. The CAPRA initiative recognizes the importance of educating the current generation of professionals in the fields related to disaster risk and therefore welcomes students' contributions and initiatives to expand and improve its tools and applications

CAPRA, moving away from the standard single hazard analysis approach, provides a multi-hazard risk assessment based on probabilistic modeling, and taking into account vulnerability, exposure and damage. This risk information can be applied at various levels and in different sectors including health, education, housing and planning. With the CAPRA applications, decisions can be made to prevent, mitigate or respond to disaster risk. CAPRA thus provides a holistic risk management approach and creates a broad disaster risk management community.

Conclusion

CAPRA is part of an ongoing effort to promote a proactive disaster risk management strategy in the Central American region. Ultimately CAPRA hopes to contribute to Central America's sustainable development by supporting a regional strategy that advances disaster risk evaluation and risk management decision-making across all sectors.

PART II:
TECHNICAL PRESENTATIONS

5 Technical Presentation 1: What a Country Should Think About and Then Do to Address Climate Change and Infrastructure Risks

Robert Kay

Key Messages

- Infrastructure includes both **hardware** (construction) and **software** (goods and services that infrastructure provides, as well as human inputs into infrastructure).
- Countries should think about the multiple, inter-connected **dimensions** of climate change; infrastructure **elements and systems**, including **cascading elements**; **adaptive potential** of infrastructure elements and systems based on life cycle phases.
- Taking a **people-centred view** of infrastructure is important; think about 'entry points' for adaptation within systems.
- **Focus questions** provide a useful tool for shaping the conceptual thinking and action on practical issues facing nations with respect to climate change and infrastructure.
- In taking action, countries should **assess sensitivity, vulnerability and risk** (the UNDP Policy Framework can provide guidance); **analyse adaptation options** (based on infrastructure life cycle stages) using participatory process and criteria, and considering barriers and opportunities; and **develop implementation pathways** (considering among other resourcing, building networks and adaptive implementation processes).
- Countries should **take control** and be the focus for adaptive action. This first requires thought about how to conceptualize climate change and adaptation issues, followed by the development of a plan that will meet national development objectives.
- **Designing an adaptive process** is crucial. Climate change is a multigenerational issue, so countries need to develop shared adaptation options that develop and change over time, as new science and lessons learned from adaptation experiences become available.
- In order to fast-track effective adaptation for infrastructure, countries need to **effectively engage** both professional communities within countries and infrastructure users. Countries can learn from users about internalizing existing climate variability into infrastructure planning/maintenance and about opportunities for addressing challenges that climate change will bring in the future.

Dr. Robert Kay, Director and Principal Consultant, Coastal Zone Management Pty. Ltd.

Full Presentation

This video presentation discusses what a country needs to conceptualize and then do to address issues around the impacts of climate change on infrastructure. The discussion is structured into three sections: (1) a brief introduction; (2) the issues that countries need to think about (conceptual issues); and (3) actions that countries need to take (action-oriented considerations).

Introduction: Defining and adapting infrastructure

Definitions of infrastructure include both hardware (i.e. construction, such as roads, bridges, airports, and buildings) and software, including inputs, components of what goes into the development of infrastructure (i.e. people involved in designing, building and retrofitting infrastructure), and outputs, components of what infrastructure provides the community. According to the Organisation for Economic Co-operation and Development (OECD), infrastructure is not an end in itself but a means for providing goods and services to society for achieving development goals (i.e. Millennium Development Goals, general economic prosperity and social well-being) (2007). These 'soft' elements of infrastructure are based on a people-oriented view of infrastructure and climate change risk.

Adapting infrastructure to climate change impacts is imperative. The Intergovernmetal Panel on Climate Change's Fourth Assessment Report and more recent scientific work clearly show the inevitable consequences of climate change due to past and present greenhouse gas (GHG) emissions. However, climate change does not affect the basic principles of infrastructure provision for development, economic growth and environmental sustainability. Climate change is only one of many development challenges. Thus, thinking about climate change impacts on infrastructure, requires consideration of the overall development context (national, local and community development objectives).

There are various conceptual challenges and practical difficulties in adaptation with respect to infrastructure. Firstly, countries need a clear conceptual understanding of climate change and adaptation, specifically in terms of infrastructure. Secondly, countries must address the practical challenges of implementing adaptation as it relates to infrastructure, including significant uncertainties and methodological challenges related to risk assessment, adaptation options, implementation and measures of effectiveness. However, these challenges should not be a constraint to pursuing adaptation action.

What countries should consider

In order to better conceptualize climate change and infrastructure risks, countries should consider the following concepts:

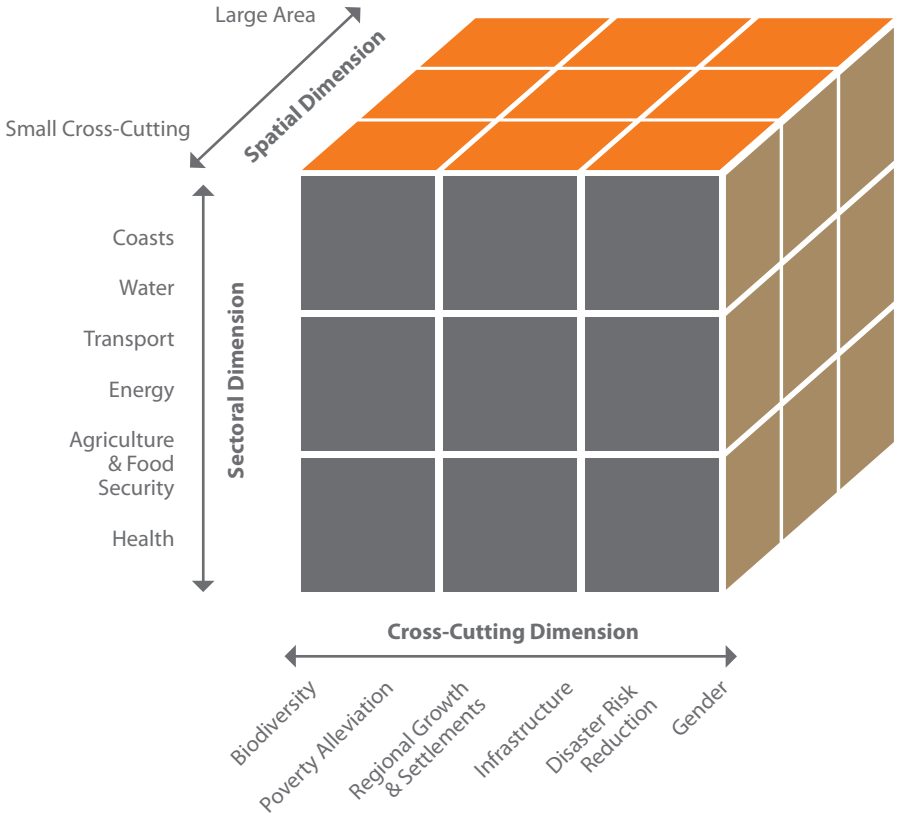
1. Cross-cutting climate change dimensions;
2. Infrastructure elements and systems;
3. Adaptive potential of infrastructure elements and systems; and
4. People-centered view (consider who is developing and using infrastructure).

Applying a series of focus questions helps guide thinking about these four different components. Eleven focus questions are provided in the Resource Guide supporting the presentation.

Dimensions

Climate change adaptation can be conceptualized across three different dimensions: spatial, sectoral and cross-cutting issues. A Rubik's Cube™ helps to illustrate the intersection of these dimensions (see Figure 5.1).

Figure 5.1: Conceptualization of spatial, sectoral and cross-cutting dimensions of climate change



Spatial dimensions consider the geographic extent of adaptation action, ranging from local to international. Spatial dimensions interact differently across a range of sectors, including coasts, water, transportation, energy, agriculture and food security and health. Finally, a series of cross-cutting issues — biodiversity, poverty alleviation, regional growth and settlements, infrastructure, disaster risk reduction and gender — make up the third conceptual dimension.

Considering one slice from this conceptual cube — the infrastructure slice — indicates how it relates to other issues within the adaptation cube. In other words, using the cube as a model allows countries to conceptualize what infrastructure means in terms of water resource planning, health planning, managing biodiversity impacts, gender issues, development issues, etc. This model also suggests the need to think about how other issues and opportunities affect and can be leveraged around infrastructure adaptation. This illustrates the need for a holistic view of adaptation issues, including understanding how infrastructure impacts and adaptation issues fit into a country's broader development paradigm.

Elements and systems

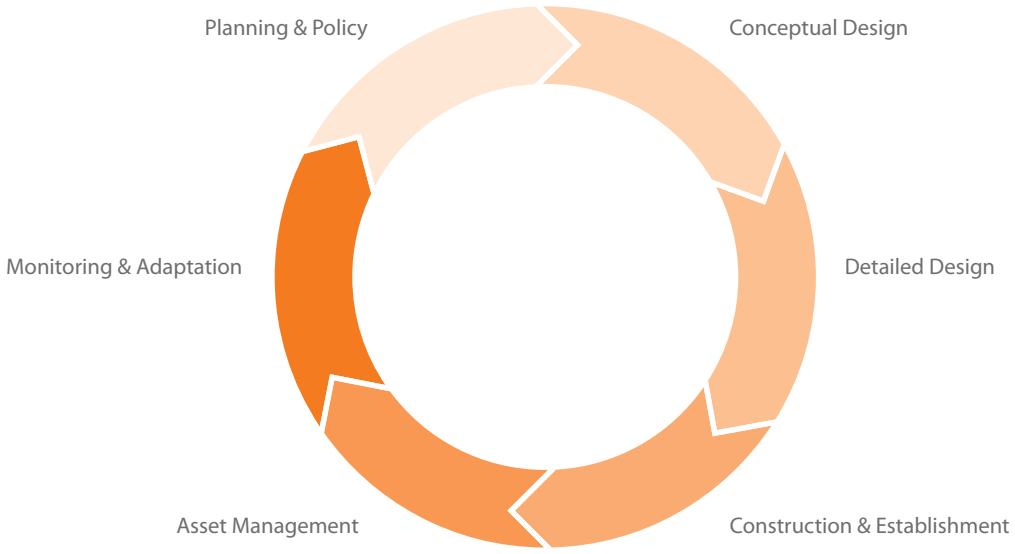
Infrastructure is comprised of both elements and systems. Countries should consider the interaction of the following infrastructure components:

- **Individual infrastructure elements** (e.g. a road bridge): Plan, design, build and retrofit of individual infrastructure elements, such as a single road, bridge, airport runway or building.
- **Whole infrastructure networks** (e.g. a road network): Entire system or network around particular infrastructure sectors of which individual elements are a component.
- **Cascading elements and networks** (e.g. road bridge failure or road network impact, cascading to ports or airports): The influence of individual infrastructure components' vulnerability to climate change impacts on other infrastructure elements and systems (indicates the inter-connectedness of the different components of climate change).
- **Influence to other vulnerabilities** (e.g. road to a vulnerable location): Relationship between infrastructure and other components of the adaptation picture (for example, concern that an excellently designed climate-proofed road does not funnel a developing community into an area vulnerable to climate change impacts).

Adaptive potential in infrastructure life cycle

Figure 5.2 illustrates the various components of the infrastructure life cycle, starting from planning and policy for infrastructure, to conceptual design of infrastructure elements, detailed design work, building of infrastructure, asset management and, finally, monitoring and possibly adapting and retrofitting. Understanding this life cycle allows countries to identify the best place to intercept and act on climate proofing infrastructure, dependent on individual context. Each stage of the infrastructure life cycle implies different potential for adaptation or climate proofing.

Figure 5.2: Adaptive potential in infrastructure life cycle



Source: Adapted from Engineers Australia: Australian Runoff Quality, 2006. http://www.engineersaustralia.org.au/committees-panels/water-engineering/publications/publications_home.cfm

People-centred view

The last conceptual element to consider is people. People with technical skills plan, design and build infrastructure. While perhaps an underrated component of the infrastructure and climate change picture, the collaborative engagement of professionals required for decision-making is a key ingredient to the adaptation process.

Furthermore, infrastructure provides significant benefits to people. Countries need to engage stakeholders who benefit from using infrastructure to assist in ensuring sustainable climate proofing. Considering how best to engage these individuals or target groups via the best 'entry points' for adaptive intervention is important.

Focus questions

The Australian National Adaptation Research Plan (NARP) for Settlements and Infrastructure provides a series of focus questions that target what a country needs to conceptualize regarding climate change, infrastructure and settlements.

These 11 focus questions[1] (grouped around conceptual thinking; governance, institutions, standards and codes for planning; spatial variance; information and knowledge sharing; and strategic engagement and synergy building) provide a useful tool for shaping the thinking around conceptual and practical issues facing nations with respect to climate proofing infrastructure.

The following is a list of the focus questions:

1. How can national **climate change governance arrangements** be improved to facilitate infrastructure planning processes and outcomes that incorporate adaptation to climate change?
2. What are the particular infrastructure **sectoral needs** in a changing climate and how can these be effectively harmonized across and between sectors?
3. What sectors of society are most **vulnerable** and least able to adapt to climate change and what role does infrastructure play in this respect? What is the nature of those vulnerabilities and the barriers to adaptation? How can physical, social, economic and institutional factors reduce vulnerability and increase adaptive capacity?
4. To what extent can **local and traditional knowledge** be best applied to enhance infrastructure resilience to climate change?
5. What is the **vulnerability of infrastructure** (individual and interlinked critical sectors) to existing and predicted climate change conditions at various spatial scales, considering average and extreme weather conditions (i.e. disasters)? How can climate-induced service or structural failure thresholds for infrastructure and services be integrated effectively into decision-making, in light of the inherent uncertainty in climate projections?
6. What **impacts on key infrastructure** could have downstream or cascading impacts during climate disasters, and how might these impacts be avoided?
7. What **infrastructure design** standards and planning periods for the various infrastructure components should be adopted for particular locations and over what time frames?
8. How can information, knowledge diffusion and engagement with **civil society and the private sector** be optimized for both adaptation implementation in those sectors and to **support adaptation actions** by government with respect to infrastructure?
9. What are the other cross-cutting adaptation issues that infrastructure will affect? For example, **gender** or consideration of **vulnerable people and places**?

[1] Adapted from Thom B, Cane J, Cox R, Farrell C, Hayes P, Kay R, Kearns A, Low Choy D, McAneney J, McDonald J, Nolan M, Norman B, Nott J, Smith T, (2010) National Climate Change Adaptation Research Plan for Settlements and Infrastructure, National Climate Change Adaptation Research Facility, Gold Coast, 60pp. (Australia) http://www.nccarf.edu.au/national-adaptation-research-plan-settlements-and-infrastructure

10. How can beneficial **synergies** be achieved, such as those between adaptation, disaster risk reduction and mitigation?
11. What further scientific work (such as refinement of climate change scenarios) and vulnerability assessments are needed to help answer these questions?

What countries need to do

Based on a thorough understanding of climate change and infrastructure issues, countries must take specific actions for adaptation and risk reduction. Necessary actions include assessment of sensitivity, vulnerability and risk; analysis of adaptation options; and development of implementation pathways.

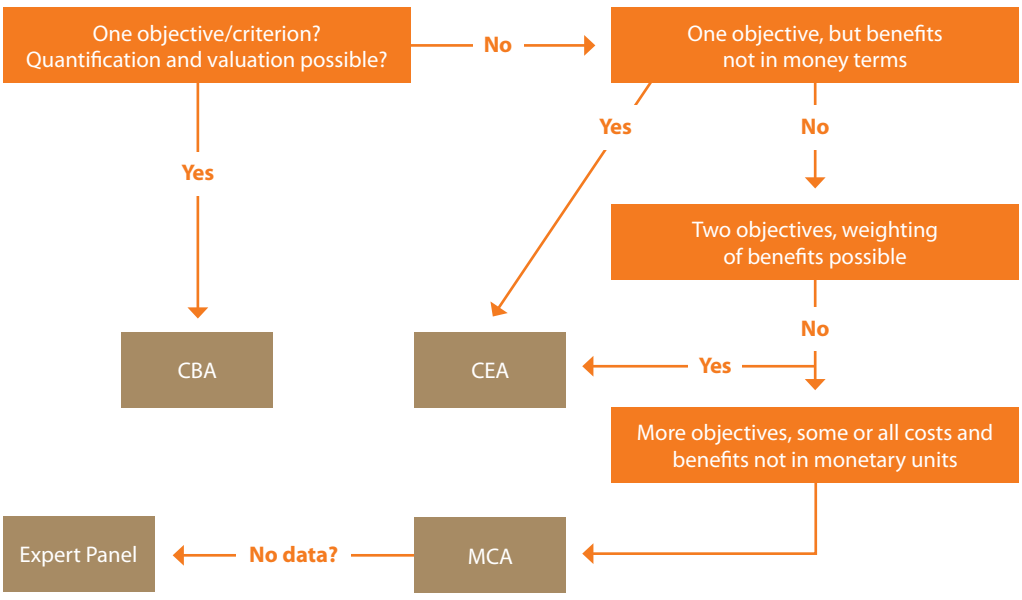
While the three action steps seem linear, the flexible application of these steps can be most effective. For example, strategic-level risk assessments leading to adaptation planning and implementation could stimulate more detailed work in particular areas, including further assessments. Postponing adaptation planning in light of incomplete knowledge often results in many lost opportunities.

The success of adaptation action requires a participatory engagement process that makes use of the aforementioned entry points. These entry points determine where in the infrastructure life cycle adaptation decisions should be made.

Assessment: UNDP's Adaptation Policy Framework

UNDP's Adaptation Policy Framework (see Figure 5.3) provides a tool for aligning available information with an appropriate type of assessment or analysis for adaptation planning.

Figure 5.3: UNDP Adaptation Policy Framework



Source: Lim, B and E. Spanger-Siegfried (eds.) (2004), in *Adaptation Policy Frameworks for Climate Change: Developing Strategies, Policies and Measures.*

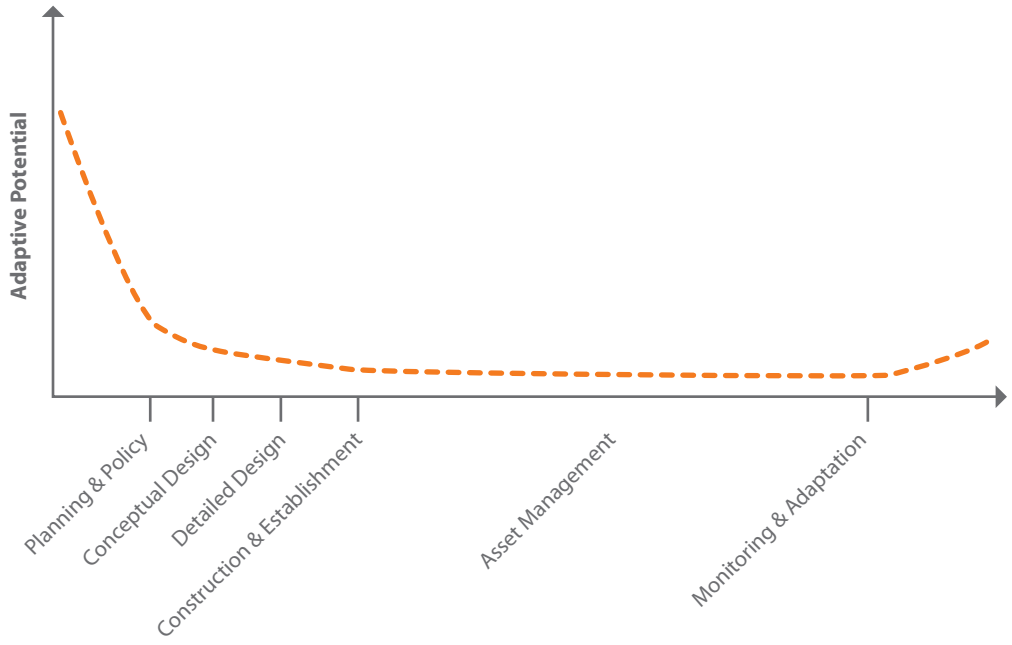
Decision makers can use this diagram in two ways. Starting from the top right corner, the flow chart can recommend, based on information available, whether decision-making processes should use cost-benefit analysis (CBA), cost-effectiveness analysis (CEA), multi-criteria analysis (MCA) or expert panel (including people with technical expertise or local knowledge or experience using particular infrastructure elements). Alternatively, use of the flow chart can begin at the bottom left corner (use of expert panel) for starting the decision-making process. This approach can stimulate the collection of additional information to eventually allow for the use of advanced decision-making tools, such as probabilistic risk assessment and CBA, for more elaborate and fine-grained adaptation decisions regarding particular infrastructure elements.

Analysis of adaptation options

Analysing adaptation options requires a participatory process engaging key stakeholders (e.g. sectors, regions and development partners). Analysis can also make use of criteria for prioritizing adaptation options (i.e. simple multi-criteria including cost-benefit, time, tolerability and thresholds). This exercise, however, tends to exclude funding and capacity constraints, which are significant parameters. A thorough analysis must consider these practical implementation barriers, as well as opportunities.

Based on the adaptation potential in infrastructure life cycles, the graph in Figure 5.4 shows the potential for adaptation during different stages of the infrastructure life cycle.

Figure 5.4: Adaptive potential by life cycle phase



As the graph indicates, in the beginning of the infrastructure life cycle, specifically in the planning and policy stage, opportunity to adapt is relatively high. This adaptation potential decreases quickly in the conceptual design and detailed design phase, reinforcing that adaptation is comparatively difficult during the construction and lifetime of a particular infrastructure element. The potential to adapt increases again at the end of the infrastructure life cycle with the possible retrofitting, adapting, redesigning and replanning of infrastructure.

For each life cycle stage, adaptive decision points for building resilience and enhancing climate proofing differ. Table 5.1 outlines these decision-making options for each phase of the infrastructure life cycle.

Table 5.1: Adaptive decision points for each life cycle phase

Life cycle phase	Example adaptive decision points
Policy and planning	Location of asset Capacity of asset Design life of asset Funding mechanisms and risk sharing Design codes and construction standards
Conceptual design	Conceptual design parameters Conceptual modeling Investment plans
Detailed design	Detailed design parameters Modeling Environmental impact assessment Financial evaluation Cost-benefit analysis
Construction and establishment	Construction methods/materials
Asset management	Maintenance program
Monitoring and adaptation	Retrofitting

In the policy and planning stage, for example, resource-saving adaptation options include moving the project to another location or creatively using funding and insurance mechanisms. As an asset progresses through the conceptual design process, adaptation opportunities include development of standards that integrate climate change vulnerability and risks into particular design parameters.

Development of implementation pathways

Implementation of adaptive action should consider resourcing (i.e. sources of funding); assigning responsibility; building networks; and adaptive implementation processes (including time frames for adaptation thresholds that could be passed during the design life of an asset). This last consideration highlights the importance of maximizing cost-effectiveness and risk-benefit of infrastructure over time.

Lastly, implementation pathways should incorporate monitoring and review of the project's effectiveness in adapting infrastructure to climate change. Because climate change is a long-term issue, adaptive responses in developing implementation pathways also need to be long-term. This approach generates new challenges that need to be integrated into existing frameworks and monitored for change over time.

Countries also need to consider the barriers to, and opportunities for, implementing effective infrastructure adaptation actions. Table 5.2 presents an example of different criteria for sequencing and prioritizing adaptation options by barriers to implementation.

As the first consideration, the concept of 'no regrets' concerns the long-term sustainability of adaptation benefits. Other barriers for prioritizing adaptation options include the need for changes in laws or statutes, community acceptance, environmental impacts, cost, resource security and adaptive capacity.

Table 5.2: Prioritization of adaptation options by barriers

Adaptation option	No regrets	Statutory requirements	Community acceptance	Environmental impact	Budget	Cost benefit	Resource security	Adaptive capacity
Option 1								
Option 2								
Option 3								

Closing Remarks

Three final recommendations for countries are noted below.

1. Countries need to take control of their own agenda and develop a clear plan. This requires extensive thinking about how to conceptualize climate change and adaptation issues, and the development of a plan that will meet national development objectives.
2. Because climate change is a multi-generational issue, countries need to develop shared adaptation options that develop and change over time, as new science and lessons learned from adaptation experiences become available. Designing an adaptive process is crucial.
3. In order to fast-track effective adaptation for infrastructure, countries need to effectively engage both professional communities within countries (i.e. through professional associations, institutions, academic communities, private sector organizations, and NGOs) and infrastructure users. Countries can learn from users about the strengths, weaknesses, successes and failures of overlaying existing climate and climate variability onto infrastructure, as well as opportunities for addressing challenges that climate change will bring in the future.

A video of this presentation, as well as a supplementary resource guide, are available in English, Spanish and French from the Adaptation Learning Mechanism (ALM) website.[2]

[2] Availble from http://www.adaptationlearning.net/training-materials/training-materials-climate-proofing-infrastructure-conceptual-considerations-and-

6 Technical Presentation 2: Internalization of Climate Risks in the Context of Planning and Urban Development

Roberto Sanchez-Rodriquez

Key Messages

- Changes in climate bring about physical effects and disaster, as well as social and economic impacts. Climate change should therefore be viewed as a development issue, and adaptation should be integrated into the development process.
- Adaptation to climate change is a learning process. Scientific knowledge should be coupled with knowledge from the public, private and civic sectors to provide multidimensional perspectives on the issue. A multisectoral view provides alternative ways of defining problems and possible solutions.
- Institutions play a crucial role in the design, implementation, monitoring and evaluation of climate change adaptation. New or updated national and local institutions need to be created to address the complexity of climate change.
- Coordination of policies and actions is necessary at a high political level with strong leadership.
- Policies need to include reactive solutions to solve short-term disasters, as well as proactive strategies to reduce vulnerability to these events via risk management and vulnerability analysis. Approaches to managing risk and vulnerability should be complementary.
- Given formal and informal urban growth, a balance between structure (top-down actions) and agency (bottom-up actions) is necessary to address climate change problems. Coordination among national, departmental and local levels is fundamental.
- Given the long life span of infrastructure, new infrastructure design and investments need to prepare for new climate conditions.
- Different components of infrastructure can be distinctive but interconnected. In the case of Mexico City, for example, flooding and water supply, while separate issues, are related. Climate change impacts also affect and are affected by other environmental and development issues. An integrated, holistic approach to addressing these problems is therefore necessary.

Dr. Roberto Sanchez-Rodriguez, Department of Urban and Environmental Studies, El Colegio de la Frontera Norte, Mexico

Full presentation

The following discussion on internalization of climate risks in the context of planning and urban development focuses on adaptation to climate change in the context of development in low- and middle-income countries, and provides insights on an adaptation plan for El Salvador. Mexico City's problems with flooding and water supply are instructive for those of El Salvador.

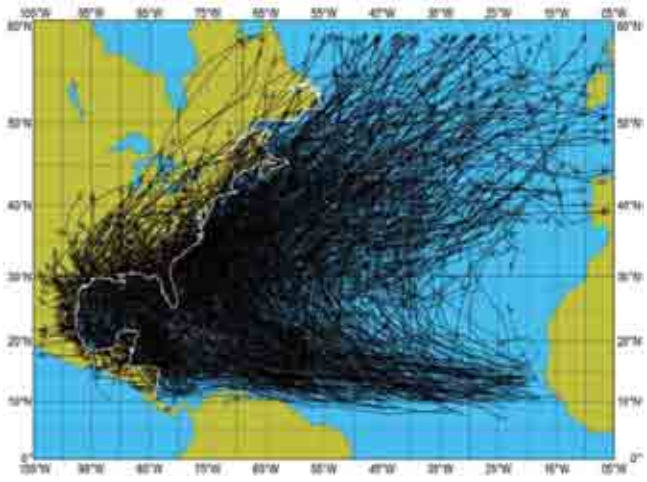
Background and motivation

Physical effects of climate change

The Intergovernmental Panel on Climate Change's (IPCC) Fourth Assessment Report highlights the threat of climate-induced disaster: increased frequency and intensity of extreme events such as tropical cyclones and hurricanes, as well as an increase in sea-level rise between 0.18 and 0.54 metres. Accompanying effects include precipitation increases in high latitudes and decreases in the sub-tropics; global temperature increase of 0.4°C by 2020, warming of at least 0.3 and 0.9°C, even with stabilized concentrations of greenhouse gas emissions (GHGs) to 2000 levels by 2100; and possible global temperature increase of 1.8°C to 4°C by 2100, depending on the emissions scenario.

During the past 35 years there have been changes in the frequency and intensity of extreme events, including hurricanes in the Gulf of Mexico and along the Atlantic coast (see Figure 6.1). While Category 1 hurricanes have reduced slightly and those in categories 2 and 3 have stabilized, Category 4 and 5 hurricanes have increased significantly. Though there is not complete scientific consensus on the relationship between climate change and extreme events, there is concern that the frequency of these severe storms increases with higher ocean temperatures.

Figure 6.1: Changes in the number and intensity of hurricanes in a warmer climate

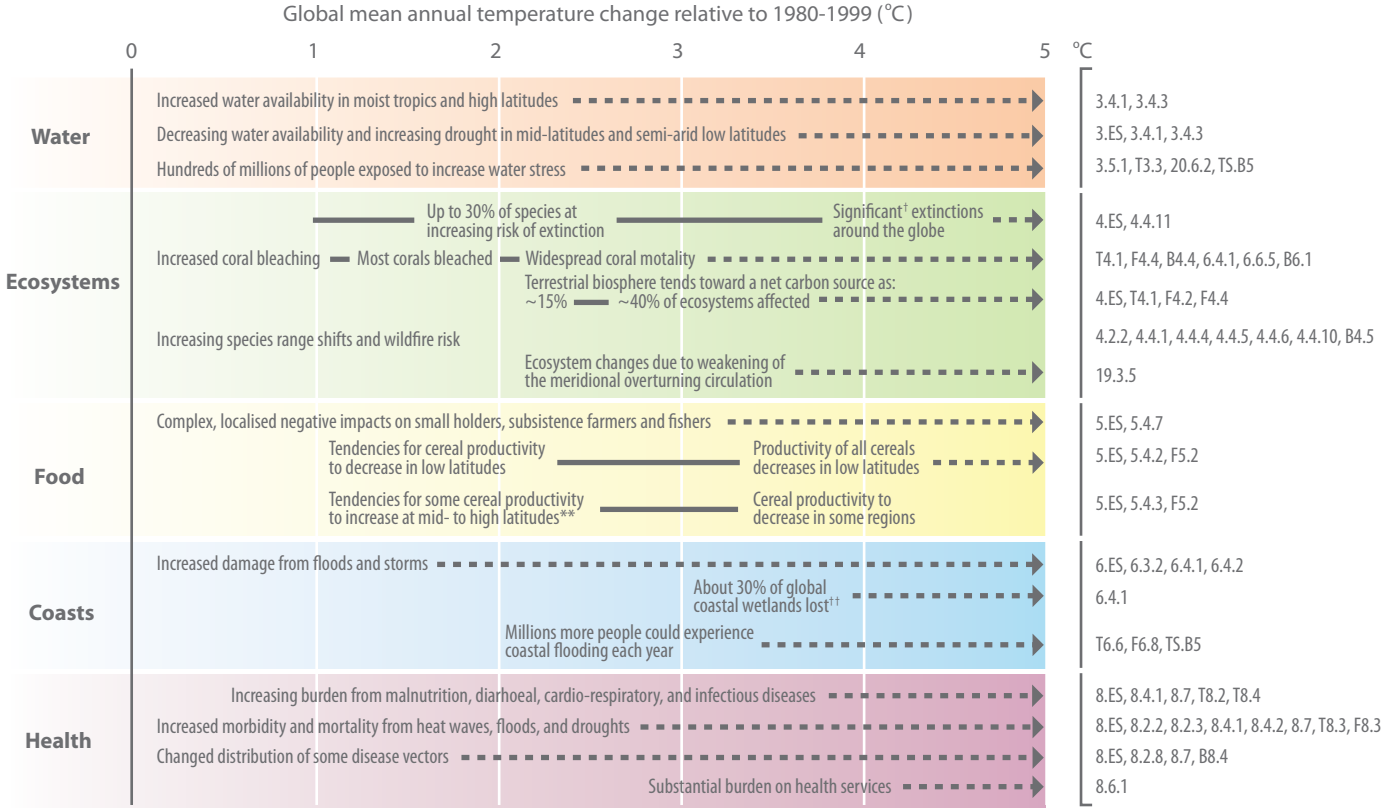


Source: Webster, P. (2005); image provided by the NOAA.

Further impacts of climate change on society

Changes in climate not only bring about disaster, they also affect how society pursues social and economic development. Throughout time, the relationship between society and climate has been symbiotic. Development, like agriculture, is inherently linked to climate. Small temperature changes translate into significant changes in the viability of certain crops, economic activities and health situations. For example, a 0.5-1°C increase in temperature change can significantly affect coffee production as well as tourism. Figure 6.2 presents several other climate change impacts that affect development. While these impacts may not seem catastrophic, they can have significant effects on the economy. Thus, preparing for long-term climate change is as essential as adapting to extreme events.

Figure 6.2: Examples of future impacts of climate change associated with changes in global average temperature

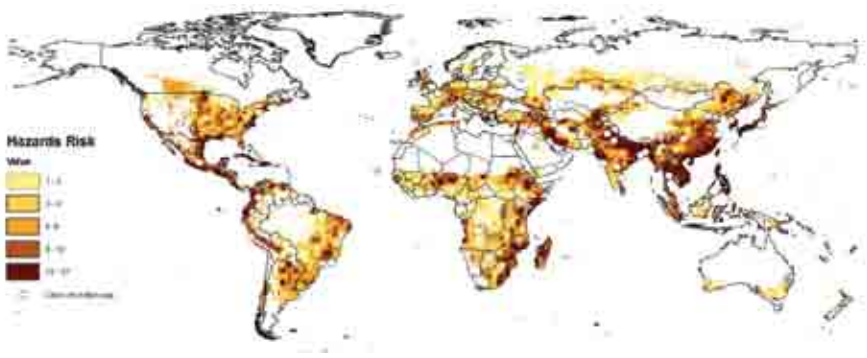


† Significant is defined here as more than 40%.
†† Based on average rate of sea level rise of 4.2 mm/year from 2000 to 2080.

Source: Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007.

Low-income countries are the most vulnerable to climate change impacts. Figure 6.3 illustrates the hazard risk level associated with climate change in cities of more than 5 million inhabitants. The map indicates that medium- and low-developed countries in Latin America, Asia and Africa are most at risk. This presents a critical challenge to these countries and underscores the need to think on a macro level about the relationship between society and climate.

Figure 6.3: Climate risks in large cities



Source: de Sherbinin et al. (2007).

Costs of climate variability and climate change

Damages caused by tropical storms and hurricanes during the last decade in the Central American region have raised attention to the close relationship between climate change adaptation and development. Data from national studies and international organizations reveal a high social and urban vulnerability to climate related hazards. Historical data from the Center for the Epidemiology of Natural Hazards in Louvain, Belgium (CRED, 2009) and the United Nations Economic Commission for Latin America and the Caribbean (ECLAC, 2009) shows that natural hazards have caused 6,500 casualties between 1972 and 2009 in El Salvador. The economic cost of those hazards was close to $16 billion dollars during this period. Eighty-seven percent of the natural hazards, 68 percent of all economic losses, and 62 percent of all fatalities were caused by climatic events. However, events occurring during the last decade represent 53 percent of all natural hazards of the last 100 years in El Salvador, and 76 percent of them are climate related hazards.

The combination of a tropical depression and Hurricane IDA in November 2009 illustrates the very high exposure of El Salvador to climatic events. Extreme precipitation reached a peak of 355 mm in five hours on 8 November. This event caused severe flooding and landslides in several parts of the country, including the capital city of San Salvador. Historical records show that the higher number of casualties associated with climatic events occurs every 10 to 30 years. The Post Disaster Needs Assessment (PDNA) estimated that Hurricane IDA affected 122,000 people and caused over $239 million dollars of damages and losses in El Salvador. Damages in San Salvador were estimated at $54.6 million, directly affecting 6,200 households, and indirectly affecting 24,000 people in the metropolitan area (particularly the municipalities of San Martin and Ilopango)(Direccion de Proteccion Civil, 2010).

In May and June 2010, tropical storms Agatha and Alex hit the country. Agatha caused flooding and landslides in the metropolitan area of San Salvador, resulting in the evacuation of inhabitants in several parts of the city. Agatha also caused damages to the drinking water system (damage to pipes, pumping stations and a water treatment plant) affecting water supply in several parts of the metropolitan area. The economic cost of Agatha was estimated to be $112 million in El Salvador. A significant portion of that cost was related to the metropolitan area of San Salvador.

Responses to climate change

The development of the UNFCCC spotlighted climate change in the context of the 1992 Summit of Rio de Janeiro. However, adaptation arrived late as a priority on the climate change agenda. The role of media in broadcasting the importance of mitigation (reducing GHGs), the comparative ease of mitigation (i.e. the ability to measure and identify it), as well as the economic incentive stemming from the market component of emissions reductions (i.e. emissions trading) contributed to the emphasis on mitigation over adaptation. In addition, the shared responsibility for reducing GHG emissions as a common good has brought particular attention to this side of the climate change issue.

The perception that the negative impacts of climate change will occur in the future contributes to the reluctance to invest scarce resources in this problem. Given the multi-decadal life cycle (over 70 years) of infrastructure development, this perception must change. While current infrastructure designs use present and historical climate trends, these will not be sufficient under varied climatic conditions in coming decades.

Important considerations

Adaptation to climate change does not occur independent of other social processes. Problems of poverty, social inequality and economic and financial crisis affect how society can respond to global challenges of the 21st Century, not only in the case of climate change, but also in terms of globalization and the international economic crisis. In addition, uncertainty about the negative impacts of climate change makes it difficult to define national and local adaptation strategies and policies. Who should adapt to what, where, how and when? This justifies not inaction, but rather the need to link climate change responses to development at the national and subnational level.

Adaptation to climate change is a learning process, rather than a sole end. The knowledge and lessons learned coming out of development programmes is informing adaptation policies and strategies. Relationships are uncovered, such as the dynamics of socio-economic and environmental conditions and their influence on opportunities and obstacles for development, that help to improve our understanding of the issues and our ability to create effective strategies. A similar process occurs for climate change and adaptation. The dynamic interactions between climate and society will expand their consequences during the next decade. Adapting to climate change will require a periodical assessment of climate impacts, changes in socio-economic conditions, needs, resources, and values in societies. Defining adaptation to climate change, a multidimensional process, will help societies determine policies and strategies that reflect current knowledge and information on climate change impacts and development needs. By defining adaptation, decision makers can better pinpoint the broad range and cumulative effects of climate change impacts.

Coordination between the national, departmental and local levels is fundamental. Climate change adaptation happens mostly at the local level, yet access to economic, human, technical, and financial resources in local communities is limited, particularly in low-income and middle-income countries. Cooperation between the national and subnational levels is therefore essential to provide society with the strength and capacity to respond to climate change.

The need for multilevel coordination necessitates a system for the monitoring and evaluation (M&E) of the climate change response process. Despite being a fundamental aspect of development plans, M&E is still a very weak component of the process. Evaluations tend to be uncritical regarding successful and unsuccessful approaches. Given the underdeveloped institutional capacity to monitor and evaluate development plans, it is important to highlight and assess this step in future plans.

Reflections for an adaptation plan

The following factors are crucial for the successful design and implementation of an adaptation plan in El Salvador:

1. **Coordination of the design and implementation of policies and actions at a high political level.** El Salvador has the capacity for institutional coordination — based on an existing process of interministerial coordination — for creating national and subnational policies that take climate change into account. The country's Five-Year Development Plan for 2010-2014, which is coordinated by a Technical Secretariat of the Presidency, and the Interministerial Commission for Landfills provide examples of strong national coordination.

   By using national and subnational development plans as the starting point for integrating climate change adaptive responses to national and local development policies, climate change adaptation become tangible to decision makers and relevant to the problems they address on a daily basis. Regional collaboration with other countries in Central American can strengthen and facilitate policies addressing transboundary problems (management of transboundary water resources, health emergencies).

2. **Leadership.** In the case of adapting infrastructure to climate change, national leadership for coordination among ministries is imperative. Leadership must also exist at subnational and municipal levels, where many adaptation actions occur.

3. **Creation of useful integrated knowledge from public, academic, private and social sectors.** The creation of useful knowledge is an important issue at the international level. The results of research on climate change have had little impact on decision-making at national and local levels up to now. This is in part due to the disconnection between scientific knowledge on climate change and decision-making and implementation. Practical knowledge derived from practitioners implementing specific development actions can complement scientific knowledge. This integrated view, taking advantage of diverse and broad perspectives, should lead to new ways of seeing and thus addressing climate change problems.

4. **A comprehensive and multidimensional perspective, based on knowledge and actions originating from the public, academic, private and social sectors, contributes to this integrated approach.** In El Salvador, the National Development Plan creates opportunities for amalgamating different forms of knowledge. In particular, the National Council for Science and Technology, the creation of new research and technological innovation, and the National System of Innovations help to develop knowledge based on national interests, and determine where to start making changes in response capacity.

5. **Adaptation to climate change beyond attention to disasters caused by extreme weather events; climate change as a challenge to development.** Adaptation to climate change needs to extend beyond natural disasters. This requires consideration of climate change, not only as a global environmental problem, but also as a development issue requiring coordination among ministries and different levels of government.

6. **Integration with national policies, departmental and municipal development; strategy of relief, rehabilitation and reconstruction.** El Salvador's Five-Year Development Plan incorporates emergency rehabilitation and reconstruction through the Technical Committees of Civil Protection Sector and the Departmental Commission for Civil Protection. Responding to natural disasters and improving response capabilities, through early warning systems, for example, are fundamental. However, reactive actions are not sufficient. Anticipatory action and networks are also necessary for building local and national capacity and addressing long-term development issues associated with climate change.

7. **Environmental policy, risk reduction and vulnerability assessment.** Policies need to include reactive solutions to solve short-term problems, as well as proactive strategies to reduce vulnerability to future events. It is important to distinguish between assessments of risk to extreme events and vulnerability assessments.

   Vulnerability is defined by the IPCC in its Fourth Assessment Report (2007) as "the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity." Vulnerability, more so than risk assessment, provides a broader analytical framework that helps to better identify the linkages with adaptation and other development goals and policies.

8. **Link between vulnerability and adaptation with efforts to reduce poverty.** The focus on vulnerability suggests that responsiveness is related to society's access to tangible and intangible assets that increase accessibility of resources to resist extreme climatic events. Examples of tangible assets are income, housing/infrastructure availability and quality, and material goods. Intangible assets include social relations, which allow formation of partnerships and improved responsiveness.

   In the case of El Salvador, its Five-Year National Development Plan sets forth important guidelines that can be linked to building adaptation capacities to climate change. It emphasizes three complementary objectives: reduction of poverty and economic inequality, the reduction of environmental risks with long-term prospects, and the promotion of social development organizations in the process of formulating public policies. These objectives, together with those strengthening rural and urban communities (i.e. human capital, expanding access to infrastructure, income generation, productive development and land management), represent potential linkages with efforts seeking to reduce the vulnerability of individuals and communities climate change and strengthen their capacity to adapt progressively to new climatic conditions.

   As projects focusing on social development and poverty reduction have shown, poverty is a dynamic multidimensional phenomenon that depends on not only income and employment, but also access to basic infrastructure. Analysis of poverty reduction should provide attention to the factors that lead individuals and households into poverty, as well as those that help move people out of poverty. Causes of poverty indicated by project experience include health problems and exceptional events (e.g. climate related disasters) that drain income. This level of analysis is a valuable input to the design of strategies seeking to reduce vulnerability to climate variability and climate change, as well as the social consequences of extreme climatic events.

9. **Strategies and projects combining proposals from the top down (public sector) and the bottom up (social sector).** Creating strengths at local and national levels requires strategies and projects that combine proposals from the top down (i.e. those designed by the public sector at the central level that trickle down to the local level) and from the bottom up (i.e. those originated from the social sector). While the public sector helps to decide where investments will have the most long-term impact, the public sector alone does not provide enough resources to overcome poverty and reduce vulnerability in the time necessary to avoid severe impacts from disaster. Because the development of response capacity cannot wait, the interests and abilities of communities also need to be part of the solution for building resilience. This requires establishing programmes that create a balance between structural aspects (top-down actions) and individual and collective agencies (bottom-up initiatives).

In addition, strengthening the public and social sectors through institutional change is also essential. Current public institutions were designed to address 20th Century problems. The complexity of problems in the 21st Century is illustrated by climate change and globalization, and necessitates upgrading current institutions to help them better respond to these more complex processes. The design and planning of infrastructure in the context of climate change illustrates this point. Planning for infrastructure is a multidimensional task beyond the traditional engineering approach. Institutions responsible for infrastructure need to coordinate with other sectors, and not only focus on social and economic needs of societies and their environmental values, to create efficient responses to climate change. They also need to consider the best possible alternatives to provide a range of response measures under different future climatic conditions. The structure and operation approach of our current institutions needs to be upgraded to meet the needs of societies in the 21st Century.

Case Study: Mexico City

The construction and implementation of adaptation policies and strategies has not been easy for societies around the world, particularly for low-income and middle-income countries like El Salvador and Mexico. This case study on Mexico City brings together a number of the issues mentioned above, and it illustrates the need to cope with current and future developmental challenges in the context of climate change. It is also relevant due to the similarities between Mexico City and San Salvador (geographical location, fast urban and population growth, the demand to expand and upgrade its urban infrastructure). The case study presents parts of the results of a broader study on the future of Mexico City in the context of climate change. This study concentrates solely on the infrastructure needs of the city to address the impacts of climate change on water.

Mexico City confronts two major challenges related to water. On the one hand, it has historically suffered floods that create serious problems for the operation of the city and have severe social and economic consequences. On the other hand, this mega-city is rapidly running out of resources to secure its water supply in the near future. Water shortages are already a major problem in parts of the city. These two problems can be aggravated by climate change. Recent simulations of climate change scenarios show an increase in temperature and a decrease in the water availability during the dry season in the three basins supplying water to the city. The decline in water availability is between 10 to 17 percent in each of the basins. The results also show an increase in precipitation during the rainy season.

The city is facing important infrastructure-related decisions to address these two problems. Historically, the local authorities have addressed these two problems in isolation. The results of our study show that the problems are interrelated and shed light on more integrated approaches to addressing water problems in Mexico City in the context of climate change that may be useful to local authorities as they confront these issues.

The Problem

The geographical location of Mexico City helps sheds light on its current water problems and its vulnerability to the impacts of climate change. The city was developed on the low part of a closed water basin in the Valley of Mexico on top of five lakes, and it is prone to floods. Since colonial times, lakes were dried up as a solution to frequent floods. One of the five lakes remains but continues up until the 20th Century was to subject to regular floods. In the 1950s, the federal government undertook a major infrastructure project to solve the floods problems in Mexico City. The infrastructure system put in place combines hundreds of kilometres of deep drains, pump stations, and water treatment plants.

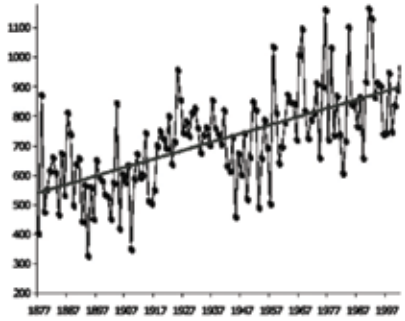
The infrastructure system came on line in the 1970s, and it was expected to be a permanent solution to flood problems. Part of the system is used to drain out sewage from Mexico City, reducing the capacity of the system to cope with the extreme precipitation. Deficient maintenance in the system during almost two decades further reduced the capacity of the system. An additional problem has been the subsidence of the urban area that has reverted the slope in some of the major drains. The federal and local governments have invested millions of dollars solving some of the most critical and immediate problems in the storm water system, but it is clear the city needs to find a long-term solution to this critical problem. It is worth noting that San Salvador also has flood problems and needs to find a long-term solution to avoid major economic and social consequences. Flood problems in the two cities are impacted by climate variability, and they could become aggravated by climate change.

Figure 6.4: Pre-Columbian Mexico City

Note: Aztecs adapted to the area as the city grew by building structures called *chinapa* that floated over the lake; (Right) Modern-day topography of Mexico City

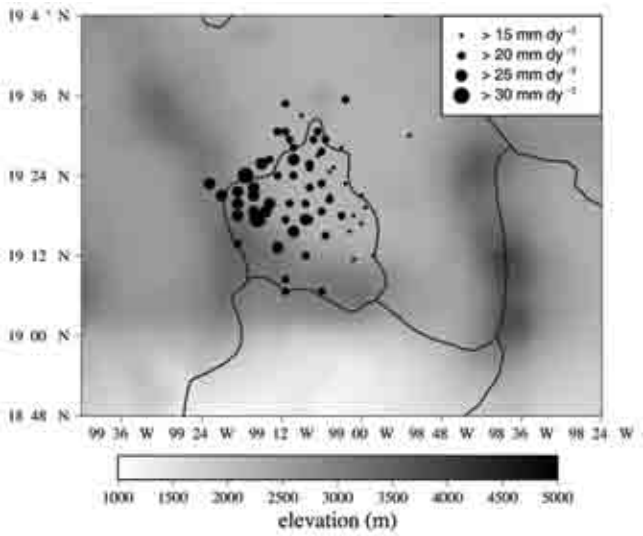
Recent studies document that urbanization has led to an increase in precipitation in Mexico City over the last 100 years (see Figure 6.5). Particularly important is the significant increase in extreme daily precipitation during the last decades. Other studies have shown the 'heat island effect' in Mexico City has led to microclimates within the urban area creating significant differences in the concentration of precipitation (see Figure 6.6). These research results are relevant to the design of infrastructure (storm water). While rainfall is concentrated in the east and south, the current drainage system design assumed an equal distribution of rain throughout the city.

Figure 6.5: Evolution of precipitation in Mexico City



Source: Jauregui (2004).

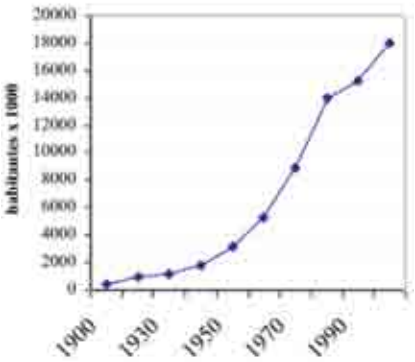
Figure 6.6: Distribution of precipitation in Mexico City



Source: Magana and Perez (2003).

Mexico City also faces serious problems to secure its future water supply. The major source of water for this mega-city is the aquifer below the urban area (60 percent of the total water consumed in the city). Decades of overexploitation of the aquifer to cope with the increase in demand of water caused by fast population and urban growth during the 20th Century (Figure 6.7) caused a serious subsidence problem in parts of the city (up to 9 meters in the downtown area during the last 100 years). Water recharge in the aquifer is only 50 percent of the water extracted every year. The limited capacity of the aquifer to meet the water demand in Mexico City led, decades ago, to the importation of water from two neighbouring basins, the Lerma and the Cuztmala. These basins supply up to 40 percent of the total water consumed in Mexico City but they have reached their capacity. Parts of the city have periodic water shortages, and there is concern about the future sources of water to meet the growing demand.

Figure 6.7: Population growth in Mexico City in the last century (population in thousands [x 1000])

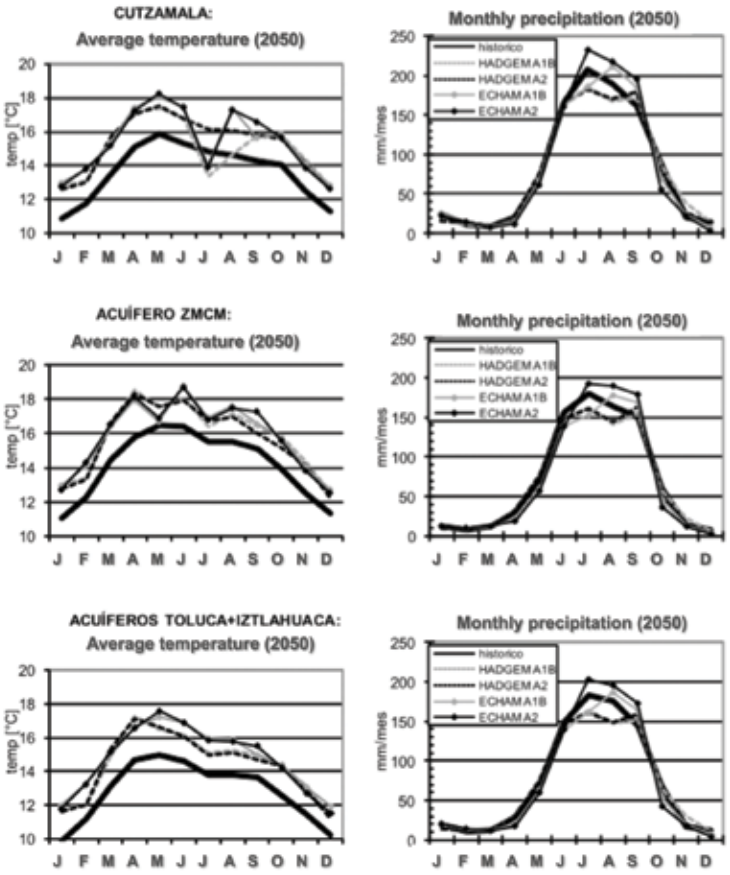


Source: Aguilar (2004).

Other problems also affect Mexico City's water supply: limited options for importing water from other basins, water leaks (25–30 percent leakage), high per capita consumption, imbalances in water consumption between social groups, water quality, future increases in demand, poor collection service, and an inadequate legal framework. In addition, Mexico City has problems protecting the main area of recharge of the aquifer. This is a forested area in the South and West part of the Federal District declared protected area. However, local authorities have had problems controlling illegal and informal settlements in that area jeopardizing the recharge of the vital aquifer for Mexico City (Schteingart y Salazar, 2002, Ruiz-Gomez, 2006). Recent studies have documented other threats to the protected area. Fires threaten the stability of the forest ecosystem (Vazquez (2010) documents 2,772 fires between 2008 and 2010 in this area). Acid rain caused by air pollution in Mexico City also weakens the forest ecosystem, making it vulnerable to the attack of pests (Bauer and Hernandez-Tejeda, 2007). The loss of forest in this area will dramatically affect the recharge of the aquifer.

The impacts of climate change are predicted to further exacerbate Mexico City's water problems. The application of models to analyse climate change and water supply for Mexico City show that water availability could decrease by at least 10-16 percent (see Figure 6.8). The actual impact of climate change will likely be even higher due to the monthly distribution of changes, including more intense periods of rain, minor infiltration and increased erosion. The scenarios also show a potential increase in temperature during the dry season. This would likely aggravate ozone pollution in Mexico City and the number and intensity of fires in the forest area south of Mexico City, accelerating the death of trees and further compromising the recharge of the aquifer mentioned above. Climate change will increase the demand of water in the urban area at the same time.

Figure 6.8: Climate models applied to different areas of Mexico City (right) and summary of model results indicating likely impacts of climate change in these areas (left)



Source: Escolero et al. (2009).

Integrated approach

Local authorities in Mexico City have addressed flooding and water supply as separate problems. However, an integrated perspective of water problems in Mexico City shows linkages among these problems that can lead to very different alternatives for a long-term solution in the context of climate change. The interconnections among water drainage, water supply, and urbanization are illustrated in Figure 6.9. This figure highlights the need for a multidimensional approach to resolve water issues in Mexico City. This holistic view can stimulate the intersectoral approach necessary for adequate infrastructure design and investments, not only under present conditions, but also for future responses (six to seven decades).

A critical step is transforming stormwater floods to being part of a long-term solution for water shortages in Mexico City. Aquifer protection is likely the best alternative to secure present and future water supply in Mexico City. Harvesting rainwater within the urban area can increase the recharge of the aquifer. Several cities have alternatives to capture rainwater within the urban area to reduce pressure on the stormwater system and facilitate the reuse of water (Pauleit and Duhme, 2000). Capturing stormwater and using it to recharge the aquifer can help the Mexico City solve two of its major problems. It would also strengthen its resilience to climate change and become an important part of its adaptation strategy. The implications of

this approach for the design and funding of infrastructure are significant. Current funding is only oriented to maintain the operation of the current drainage system. Mexico City would need to consider creating separate systems for sewage and for stormwater to facilitate the recharge of the aquifer. Treated sewage could also be used to recharge the aquifer. This strategy is already part of sustainable urban planning in other major urban areas in the world.

A number of other actions are necessary to strengthen the long-term sustainability of Mexico City. For example, the use of ecosystem services can also help alleviate conditions within the urban area and build resilience to the negative impacts of climate change. The use of vegetation within the urban area can alleviate the impact of the heat island effect, reduce the demand of energy and water, and increase the index of comfort to higher temperatures. It is important that discussions and debate take place to plan the future of the city within the context of climate change.

Unfortunately, Mexico City has not initiated a serious debate about its future sustainability. Although the city has an adaptation plan to climate change (published in 2009), the plan has a significant imbalance between mitigation and adaptation measures. There are 29 mitigation actions (costing 56,152,000 million pesos) in the Climate Action Plan compared to 12 adaptation actions (costing 2,998,000 million pesos). About 95 percent of the climate change budget is allocated to mitigation efforts rather than to adaptation. Given the needs for adaptation in Mexico City, this emphasis should be inverted so that more of the budget is spent on adaptation. The Climate Action Plan does not consider the potential impacts of climate change on floods or water supply as part of the adaptation needs in Mexico City.

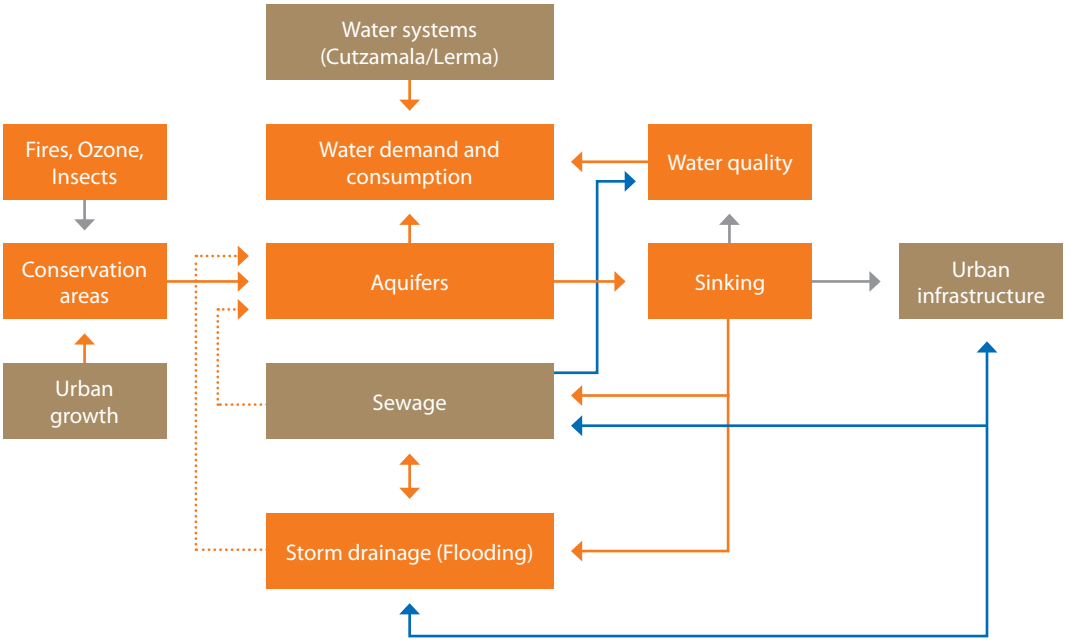
These lessons are helpful for El Salvador, particularly for its capital city San Salvador, that faces similar problems to those described above in Mexico City.

Data from the last population census indicated that the metropolitan area of San Salvador had 1,566,629 inhabitants. 10.4 percent of them live in extreme poverty, and they are located in hazardous areas along the ravines and rivers that run through the metropolitan area. However, exposure to flooding, erosion, and landslides extends to larger areas of San Salvador and a larger part of the population due to the lack of control of urbanization and constant modification of the landscape.

Urban growth, driven by low- and high-income groups, has given little consideration to the flow and control of stormwater within urban areas. Public authorities have not been able to orient the rapid process of urbanization protecting key physiographic conditions of the landscape allowing the flow of runoff during extreme climatic events. There is no complete hydrological model for the metropolitan area of San Salvador, and the stormwater system is incomplete. Deficiencies in planning urban growth and its incomplete enforcement have resulted in the reduction, modification, or blocked water flow in the rivers and ravines used as primary drains for stormwater. The path of urbanization in San Salvador has created urban and social vulnerability to climatic events, which can be exacerbated by climate variability and climate change.

The impact of recent tropical storms illustrates this point. Climate related hazards have become more frequent as rapid urban growth has modified the landscape in San Salvador. Studies report flooding, erosion and landslides problems in several parts of the metropolitan area with precipitation higher than 50 mm per hour. Using data from the meteorological station in San Salvador and its surrounding area, other studies estimate that there is 50 percent chance that events with precipitation of 90 mm in 24 hours occur every year (Fernandez-Lavado, 2010).

Figure 6.9: Water and climate change in Mexico City; interconnectedness of factors



Source: Sanchez-Rodriguez (2010).

San Salvador like Mexico City is confronted by the urgent need to define short-term and long-term solutions to the flooding problems and the sustainability of the metropolitan area. The critical change pending for the two cities is the development of new infrastructure solves current problems and enhances the climate resiliency of the city to the potential impacts of climate change. The experience in Mexico City shows that traditional approaches to water problems create fragmented solutions to complex problems. San Salvador and Mexico City should consider a multisectoral and integrated approach for the redesign of its stormwater system. Other cities have successfully implemented such redesigns, integrating ecosystem services in their approaches to reduce and retard the flow of stormwater to the main drains and reduce the risk of flooding. In the coming decades, water harvesting is a valuable resource that could be adopted by Mexico City and San Salvador to alleviate the pressure of water supply.

San Salvador has limited resources to manage the rapid expansion of informal urbanization. Adaptation strategies to climate change should be an integral component of the national development policies seeking to reduce poverty, improve social well-being, and promote economic growth. Those policies should incorporate top-down actions addressing formal urban growth through planning regulations, construction standards, and an updated legal framework for urban growth. It is equally important to include bottom-up initiatives strengthening agency (individuals and communities) to reduce their vulnerability to the negative impacts of climatic events. A multisectoral and integrated approach to the design of water infrastructure suggested above for Mexico City and San Salvador opens opportunities to combine top-down and bottom-up initiatives.

Final thoughts

The following is a summary of the key points addressed in this chapter:

- Climate change should be seen as a development problem, so that adaptation is integrated into the daily development process.
- Adaptation to climate change is a learning process that should be based on complementary knowledge (i.e. the integration of scientific knowledge with public sector knowledge and private and civic sector knowledge).
- Infrastructure and urban areas built today will operate under different climate conditions in the coming decades. New infrastructure design and investment need to prepare for these new climate conditions.
- An integrated and multidimensional vision of climate change is fundamental to addressing the cumulative effects of climate change impacts and associated problems. A holistic, multidimensional view provides alternative ways of defining problems and possible solutions.
- Approaches to managing risk, vulnerability and adapting to climate change should be complementary; vulnerability, adaptation, livelihoods and development should all be considered simultaneously.
- Given the importance of informal urban growth, a balance between structure (top-down actions) and agency (bottom-up actions) is necessary to address climate change problems.
- Institutions play a crucial role in the design, implementation, monitoring and evaluation of climate change adaptation.
- Multidimensional and integrated perspectives of climatic hazards and the role of infrastructure in their solution can provide more efficient and cost-effective approaches with short and long-term benefits. The Mexico City case study and the suggestions for San Salvador illustrate the importance of opening up debate on the future of these cities in the context of climate change. They emphasize the need to make critical decisions in the short-term in order to secure sustainability and development in the long-term.

7 Technical Presentation 3: A Framework for Risk Assessment and Risk-Informed Decision-Making for Infrastructure Development

Michael H. Faber

Key Messages

- Natural hazards and effects of climatic change pose pressures on society, with inequitable distribution of consequences leaving less-developed, resource-poor countries to suffer the most.
- Risks are real and represent society's best knowledge about future costs and losses. Reducing knowledge uncertainty by quantifying information and knowledge contributes to better optimization of risk reduction.
- Resilience is only possible by planning in advance, i.e. by basing decisions on risks (future losses) rather than observations (current losses). Decisions must be robust with regard to assumptions and adaptable to future realities.
- Strategic resource allocation, including prioritization between prevention and aid, is required. Resources may consistently be allocated between different activities that affect health and the economy. The hierarchical organization of resource distribution and fund allocation to make distribution more equitable.
- Improving best practices in design, procedure for operations, and maintenance is another way to optimize prioritization of resource allocation on a global scale and for individual projects.
- Sustainable development necessitates that, to ensure intergenerational equity, risks must be managed through normative risk-informed centralized governance from global to local levels.
- Modern risk assessment frameworks and tools greatly enhance risk management. Risk management frameworks based on Bayesian probabilistic decision theory emphasize the significance of both direct and indirect consequences on a hierarchy of systems and risk-based systems modeling.
- Generic modeling facilitates updating of risks through indicators (of exposure, robustness, and vulnerability) for both small- and large-scale management.
- Modeling can be applied for individually and jointly acting hazards, and can be utilized to optimize robustness and resilience of structures, infrastructure systems, procedures and organizations.
- Life safety acceptability of decisions can be based on the societal willingness to pay (SWTP) criterion, which stems from the Life Quality Index (LQI) criterion. In El Salvador and the surrounding region, the amount that should be invested, is between $600,000 to $800,000 per life saved.
- Climate change is only part of a greater issue that threatens societies. Money and efforts invested into climate change should be in balance with economic and social capacity of communities at local, national and global levels.

Dr. Michael H. Faber, Professor of Risk and Safety Chair of the Department of Civil Engineering, DTU - Technical University of Denmark

Full Presentation

Research on risk and safety at the Swiss Federal Institute of Technology Zurich (ETH) has focused on risk management of infrastructure, such as earthquake risk management for existing and new bridges in Argentina and Europe. This technical session provides explanation of a framework for risk assessment and risk-based decision-making for infrastructure development. The framework is presented in the context of the need for risk assessment, risk-based decision-making, sustainability, and multi-level governance.

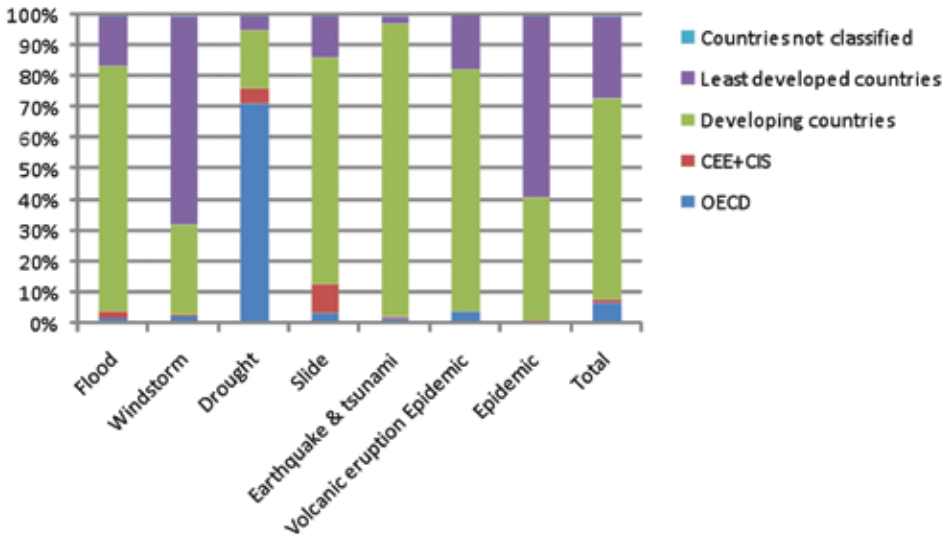
Relevance and motivation

The need for sustainability and equity

The need for sustainability, and ultimately risk assessment and risk-informed decision-making, stems from the fundamental problem that the Earth's 6.8 billion people are exhausting the planet's available resources. Inequitable distribution of resources among societies adds to the vulnerability of resource-poor populations. In order for all societies to develop to the fullest of their potential, resources not only need to be used sustainably but they also need to be shared equitably throughout the world.

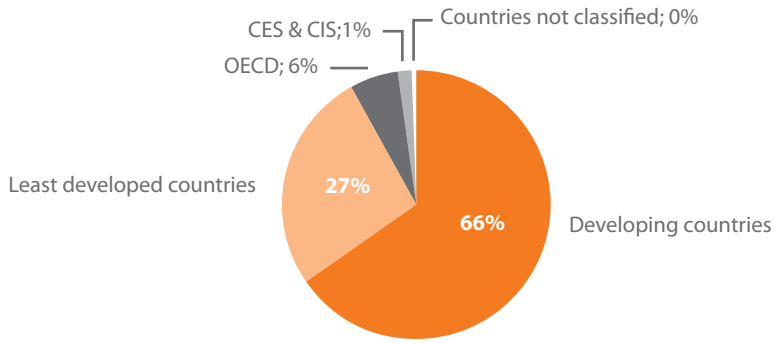
Over a recent 15-year period, natural events, such as windstorms, mudslides and earthquakes, resulted in one million lives lost (see Figure 7.1). Although this number may seem small within the global context of 10–20 million yearly poverty-related deaths, the geographic concentration of climate-related casualties raises concern (see Figure 7.2). Due to the capacity of certain countries (e.g. the United States) to insure against economic damage, the impacts of economic losses (see Figure 7.3) are also inequitably distributed across different societies. Economic losses in poorer countries are much greater as direct consequences of hazards hinder the possibility for development in those affected areas.

Figure 7.1: Percentage of natural disaster events by country



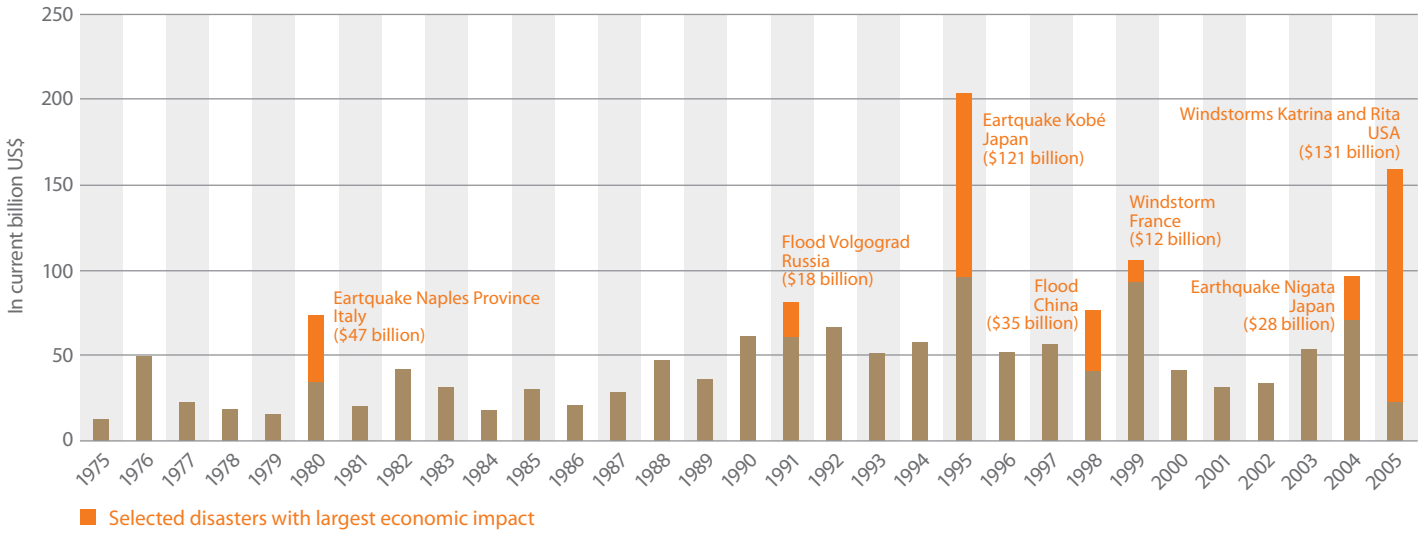
Source: EM-DAT - The OFDA/CRED International Disaster Database.

Figure 7.2: Distribution of consequences (losses of lives) due to natural disasters from 1991 to 2005 by national economic category



Source: EM-DAT - The OFDA/CRED International Disaster Database.

Figure 7.3: Annual reported economic consequences from natural disasters from 1975 to 2005



Source: EM-DAT - The OFDA/CRED International Disaster Database.

While life expectancy has increased significantly in the last half century, this trend is less identifiable on a local scale; instead, correlation between local life expectancy and economic capacity is more apparent (see Figure 7.3). Inequities in economic capacity, correlatively, vulnerability translate to increased consequences or losses for lower-income, less-developed countries.

Threats and influence of climate change

Climate change exacerbates the gravity of overusing and mismanaging natural resources, and thus imposes further pressures on societies and sustainability efforts. According to the Intergovernmental Panel on Climate Change, predicted climate change phenomena include increased frequency of heavy precipitation events, drought, tropical cyclone activity and high sea level. Increases in rainfall, landslides and floods are particular threats in El Salvador.

Threats of climate change in the context of limited resources can motivate societies to improve development for its ensured sustainability. The consequences of increased climate-related events necessitate immediate support based on best available knowledge. Using scenarios and knowledge developed by natural scientists, engineers must focus efforts on assessing and identifying efficient means for circumventing or mitigating risks.

The need for risk assessment and risk-informed decision-making for infrastructure

Infrastructure plays a key role in society by providing the basis for production and economic growth. Reciprocally, economic capacity and access to natural resources affect the capacity to develop and maintain infrastructure. Investing in infrastructure must be balanced with benefitting economically from infrastructure on local, national, regional and global scales. This requires a holistic perspective for prioritizing societal investments.

The primary challenges in sustainable risk-based infrastructure development are in assessing risks, communicating risks to all stakeholders, identifying relevant and efficient risk-reduction measures, and deciding how to prioritize resources in society for risk management. These challenges warrant a framework for risk assessment and risk-informed decision-making.

Risk, sustainability and governance

The need for sustainable development implies the current generation's responsibility to ensure that resource use is in balance with long-term capacity building and the priority of equity for safeguarding both current lives and the lives of future generations. Given that risks indicate not what might happen, but what certainly will happen in the future, the need to develop sustainably suggests the critical importance of good practices in risk assessment and optimal risk-based decision-making.

Climate change risk constitutes a local, national and global issue caused by human decisions, and so must be addressed through centralized governance from local to global levels. Because risk is effectively equivalent to future losses, failure to make decisions about how to manage risks efficiently and consistently can result in the most significant loss for society: systemic failure. While knowledge for predicting scenarios (of what hazards will look like) and for analysing future situations is available, societies have still failed to make good decisions based on this information. Risk-informed governance supported by normative decision analysis provides the basic framework for ensuring sustainable development.

The risk management framework

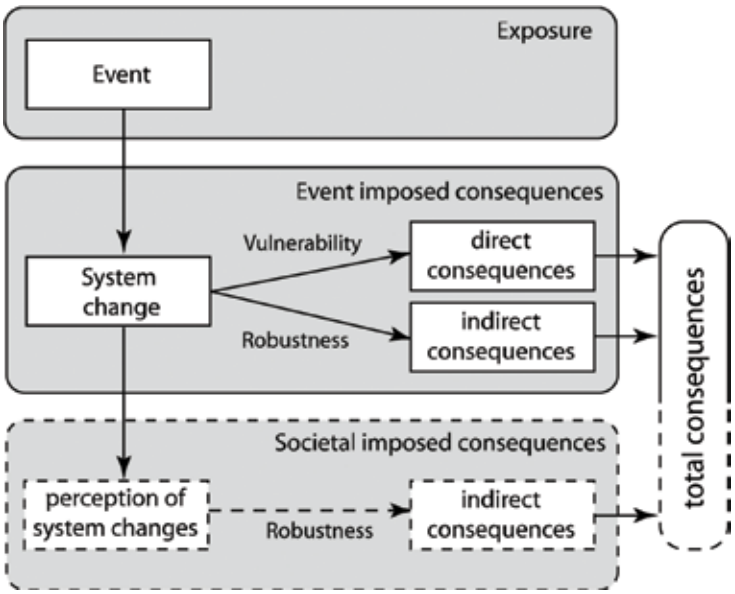
In the last ten years, the Joint Committee on Structural Safety (JCSS) has developed a technical framework for assessing and managing risks. This systematic approach includes several principles established by JCSS for risk-based decision-making in engineering: (1) Bayesian probabilistic decision theory (as economic decision theory; i.e. theory of probability decision rules based on a priori information), (2) methods of probabilistic mechanics, (3) direct/indirect consequences, (4) risk-based systems modeling, (5) generic risk models using indicators (i.e. generic models that can be adapted to different situations), (6) decision ranking/selection (consistent with available knowledge), (7) socio-economical assessment of life safety, and (8) socio-economic sustainable discounting.

Representing the system

Risk management utilizes models that apply experiences of the private sector and expertise of science to make predictions about the real world. These models are based on observable indicators of exposure (i.e. events), vulnerability (associated with constituent failure events and direct consequences) and robustness (associated with indirect consequence), and are influenced by risk reduction measures (i.e. actions). Consistent with Bayesian probability theory, these real-world indicators provide valuable information concerning risks (i.e. probable losses) of a given system for improved decision-making.

The three primary indicators of risk — exposure, vulnerability and robustness — contribute to the generation of consequences within the risk management framework. An exposure event (e.g. tropical cyclone, earthquake, or volcanic eruption) stimulates a system change. Based on the vulnerability and robustness of the system, change in the physical system can lead to two types of event-imposed consequences: direct and indirect consequences (see Figure 7.4).

Figure 7.4: The generation of consequences from exposure, vulnerability and robustness



Direct consequences depend on vulnerability of the system and do not alone impede performance of the system. These physical impacts, such as loss of a house or impairment to a bridge, though damaging, can typically be repaired and do not necessarily result in system failure. The less vulnerable a system is, the fewer the direct consequences.

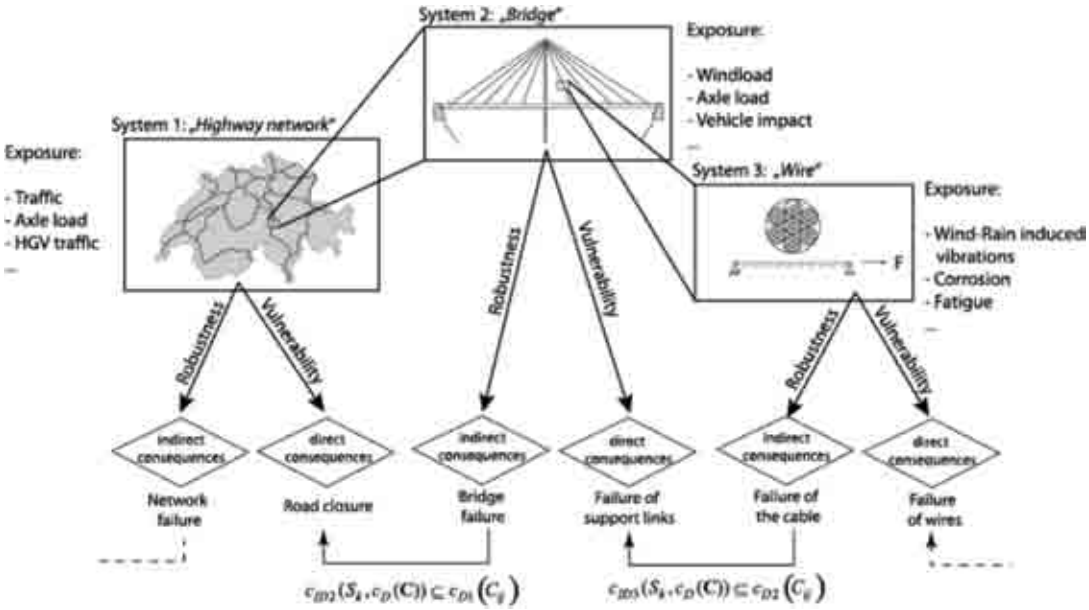
Indirect consequences due to system change depend on the robustness of the system and are related to decreases in the system capacity. These event-imposed consequences, such as decreased functionality of the network, result in reduction of economical output of the societies where direct losses occur.

Perception of system change can also result in societal-imposed indirect consequences. For example, as illustrated by the effect of society's reaction to Hurricane Katrina in New Orleans, the influence of public pressure on politicians' decisions can result in ill-judged actions in response to an extreme event. Effective communication and education about a hazard can help to mentally prepare society and thus reduce this latter type of indirect consequence. With regard to all indirect consequences, the more robust a system is, the fewer the losses. Changes in risk management approach can further reduce these indirect consequences.

Quantifying risks

Bayesian probabilistic models, a probability-based tool for modeling risks, can be used to capture interdependencies among exposure events, effects on direct consequences and effects on loss of system functionality (due to indirect consequences). This type of approach is always sustainable and can be used to assess risks at different levels. For example, the highway network as the primary system **(System 1)**, one bridge as one component of the network **(System 2)**, and a wire as one individual structural component of the bridge **(System 3)** together represent the hierarchy of systems for which risks can be quantified (see Figure 7.5). Each of these systems may be threatened by different exposures and system-specific direct and indirect consequences. The indirect consequences of one system in the hierarchy tend to influence the direct consequences of another.

Figure 7.5: Hierarchy systems modeling approach



Within this hierarchy systems approach, the level of the system determines what decisions are made to maximize its functionality. Decisions to ensure sufficient performance of the components of the system (e.g. a bridge for System 1 or the wires of that bridge for System 2) contribute to the overall reliability of the system.

Updating risks

After the creation of risk models, it is possible to update risks by inputting improved exposures, vulnerability or robustness information into the models, reassessing risks and re-evaluating benefits of changing the system. This type of Bayesian updating includes both spatial and temporal changes. For spatial-related risk updates in large-scale hazard risk management, real-world data and observations based on a geographic information system (GIS) interface platform (e.g. satellite observations, airplane observations, insurance data, on-site observations) can contribute to indicators for models and optimization of risk management strategies. Risk updates based on temporal changes take into account different stages of risk management depending on the timing of risk-based decision-making relative to the occurrence of the exposure event.

Risk management with regard to any kind of exposure is a problem that constitutes three different situations: before, during, and after hazards take place. There is a significant difference in risk management depending on whether there is time to deal with a hazard before or during its impact, or whether impacts are being addressed during or after they affect society. Before a hazard hits, risk management is based on prioritization, capacity strengthening and being prepared. For example, risk reduction resources are optimally allocated for retrofitting and rebuilding in light of possible earthquakes. During the presence of a hazard, risk management focuses on doing the right thing (i.e. carrying out the appropriate actions) according to plan, based on the evolution of the exposure event. Monitoring and control of damage, emergency help and rescue, aftershock hazard assessment, and identification of the seismic event comprise possible components of this stage. After a hazard hits, risk management means reinvesting in recovery of consequences. Activities in this situation include rehabilitation of infrastructure functionality, condition assessment and updating, and (again) optimal allocation of resources for retrofitting and rebuilding.

Uncertainty

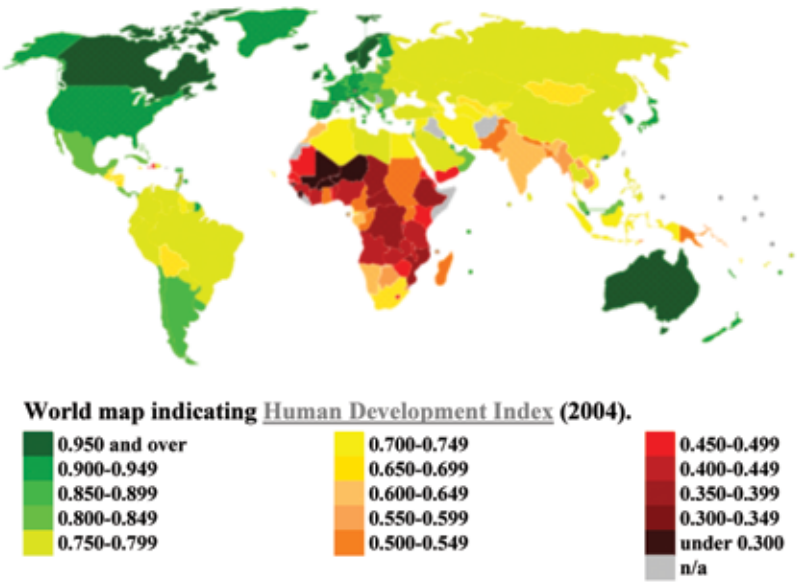
In the context of climate change and its many uncertainties, adaptable, robust decision-making is necessary. There are two types of uncertainties associated with climate change: (1) uncertainty due to natural variation ('regulatory uncertainty') and (2) uncertainty due to the fact that knowledge about climate change and its potential impacts is lacking ('knowledge uncertainty'). Knowledge uncertainty can be reduced; regulatory uncertainty cannot. Reducing knowledge uncertainty — through quantifying information and knowledge — contributes to better optimization of risk reduction. Decisions must therefore be robust with regard to assumptions and adaptability to future reality.

Climatic changes will evolve over the next 50 years. Newly built infrastructure could have a lifetime of 50 to 100 years. Therefore, given uncertainty about climate change—regarding whether outcomes will mimic best-case or worst-case scenarios—risk-based decisions need to be robust and ensure protection of systems independent of predictive assumptions.

Life Safety acceptability of decisions

The Human Development Index (HDI) measures the performance of nations and is an indication of the world's conditions. The HDI illustrates development of different societies in the world in terms of life expectancy, education, and gross domestic product (GDP). As shown in Figure 7.6, even very geographically different societies can provide similar human developments.

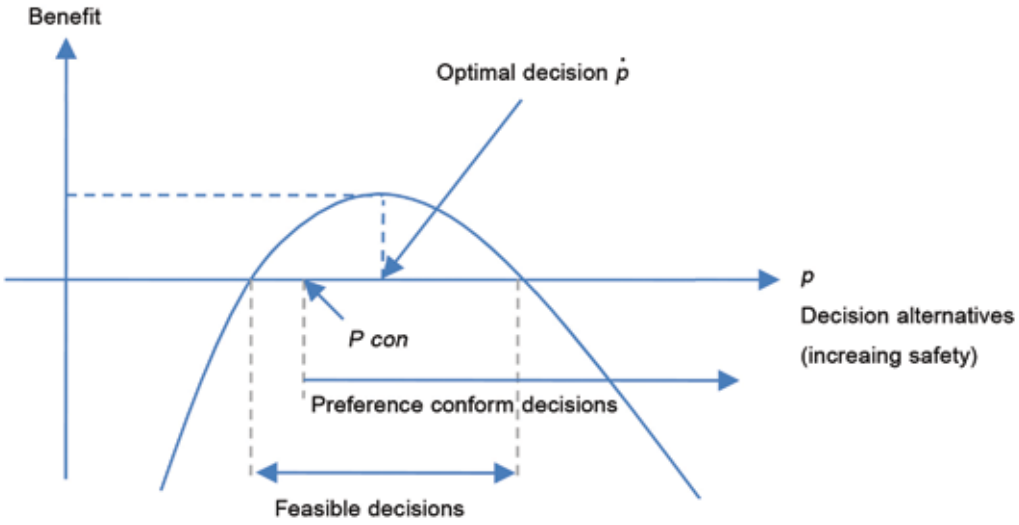
Figure 7.6: Human Development Index (HDI) for 2004



Source: UNDP Human Development Report (2004).

The Life Quality Index (LQI) is an indicator, alternative but similar to HDI, showing performance of a society in terms of GDP per capita, life expectancy at birth and the amount of time in life spent working relative to leisure time. This scientifically verifiable model expresses societal revealed preferences for investments in life savings (health). The LQI is expressed in the following equation: $L(g,l) = gql$, where g is the part of the GDP available for investment into safety; l is life expectancy at birth; w is the part of life spent working; $q = (1/\beta)(w/(1-w))$; and β is a factor that takes into account that only part of GDP is based on human labour.

Figure 7.7: General principle of societal resource allocation and life safety



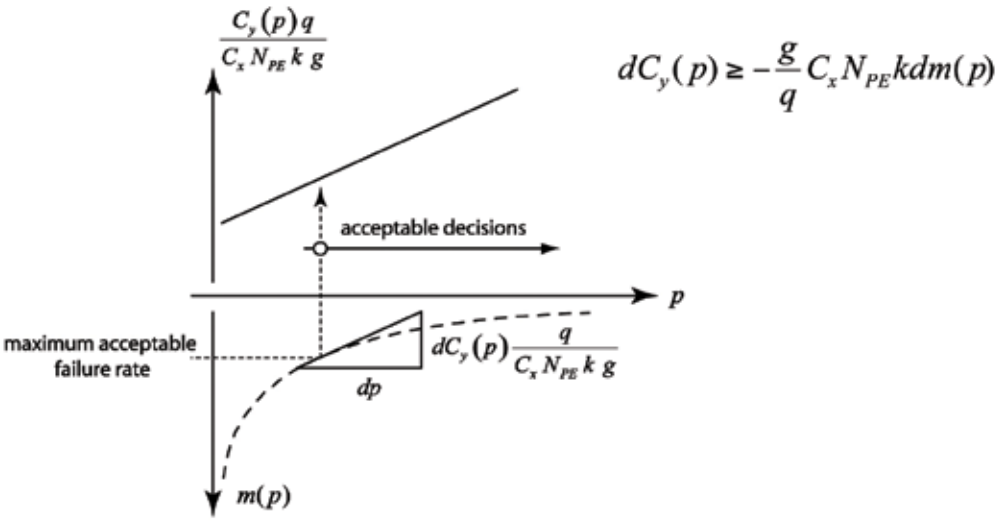
The type of decision curve in Figure 7.7 shows the balance between investments in activities for improving health and losses in society in terms of the economy. LQI can be used for making decisions with regard to improvements of health, measured by life expectancy. Optimization of LQI based on these criteria indicates the amount of life expectancy gain for the cost of one dollar. This translates to the relationship between costs of risk reduction and effects of risk reduction. Figure 7.7 illustrates this relationship as benefit (y-axis) versus decision of alternatives, ranked against each other in terms of improvement in life health or life safety (x-axis).

This criterion indicates that investment in life safety should be made until the gradient of alternative reduction equals the gradient of the cost curve. This suggests a certain cost for saving lives, and effectively the amount of money that different nations should invest in saving one additional life. Further investment, beyond this value, for a given activity in life safety, deprives resources for other possible life safety activity. Inefficient investment in life safety thus means stealing life from somebody else. This is the principle of equity for the distribution of life safety investments in a society.

Based on the LQI, the consideration that every investment in life safety should lead to an increase in life-expectancy results in the **risk acceptance criterion,** $(dg/g) + (1/q)(dl/l) \geq 0$. This risk acceptance criterion leads to the following **societal willingness to pay (SWTP) criterion:** $SWTP = dg = -(g/q)(dl/l)$, where GDP = 59,451 SFr; l = 80.4 years; w = 0.112; β = 0.722; g = 35931 SFr; and $q = 0.175$.

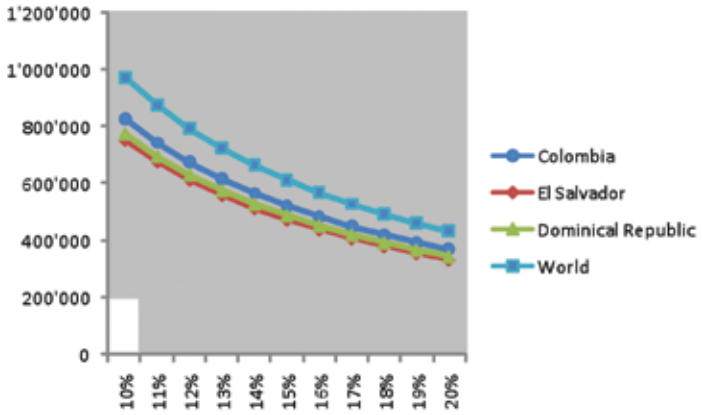
The SWTP criterion is readily applied for the purposes of determining acceptable structural failures probabilities: $(dl/l) \sim Cxdu = Cxkdm$, where Cx is a demographical constant, k is the probability of dying in case of structural failure, and m is the failure rate of a considered structural system.

Figure 7.8: The SWTP criterion



Because investments depend on social-economical capacity, these investments vary for different societies suggesting nation-specific values of SWTP (the amount of money to save the last life) for national decision-making. SWTP can also be derived for supranational decision-making regarding global investments available through resources (e.g. from the UN). In El Salvador and the surrounding region, SWTP, and thus the amount that should be invested, is between $600,000 and $800,000 per life saved (see Figure 7.9).

Figure 7.9: SWTP in $ in El Salvador, surrounding areas, and the world



From the LQI, the **societal value of a statistical life (SVSL)**, ***SVSL = (g/q)E***, the costs of compensation for a lost life, can also be assessed. In Switzerland, SVSL is about 6 million SFr.

Sustainable decision-making

Sustainable decision-making takes into consideration three primary units—societal, economical and environmental factors—for both present and future generations. Optimization of these three factors depends on cost-benefit evaluations for all generations in the future. Based on this principle of intergenerational equity, the transfer of income, costs and resources over generations of decision makers results in one joint intergenerational decision maker. By assessing utility as the sum of utility of all generations—through summation of costs and benefits for all generations in the future—and maximizing benefits for the sum of all generations, it is possible to derive general guidelines for sustainable decision-making. For example, because current overuse of non-renewable resources deprives future generations of these resources, present generations need to compensate future generations for this loss by developing resource substitutes (e.g. through investment in research of renewable resources and energy efficiency).

Equity also implies that utility for future generations should be reduced based on assumed economical growth. Based on utility functions, the derivation of predicted economic growth indicates what discount rate is affordable (from a sustainability perspective) to use in cost-benefit analysis. Discounting considered for present and future generations should include economic growth, as 2 percent per annum, and preference to spend early rather than late, referring to 3 percent per annum.

The consideration of intergenerational equity concerns decision-making about infrastructure and the importance of economical development exercises. Optimally, decisions regarding affordable performance of infrastructure, including safety issues, must be seen in close relation with the interaction between performance and economy. Improvement of efficiency of infrastructure has a tendency to increase GDP up to 40 percent. While societies often make the mistake of investing predominantly in maintenance of infrastructure, they would generally benefit more from expansions of infrastructure.

It is possible to derive these types of decisions through the coupling of economic models. By coupling models and analysis of economies that describe economical performance of society as a function of performance of infrastructure, it is possible to evaluate different strategies with regard to the quality and quantity of the infrastructure. These evaluations can reveal the optimum balance between greater investment in cheaper, less reliable infrastructure and less investment in more expensive but less reliable infrastructure. In other words, sustainable decisions informed by these coupled models optimize the use for society's resources for infrastructure with respect to society's capacity and need for the infrastructure.

Instruments for implementation

Instruments for risk management are based on society's hierarchy of organizational management. Allocation of resources among ministries, sectors, divisions, departments, branches and individual projects should reinforce optimum distribution. Risk assessment following LQI principles provides the tool for evaluating where investment yields the greatest value.

The hierarchical organization of distributing resources and allocating funds is one way to improve a situation; enhancing best practices is another way. Improving best practices in design, procedure for operations, and maintenance optimizes prioritization not only on a global scale, but also for individual projects. Risk assessments can be applied to identify best practices for improvement, again based on greatest benefit or return on investment.

Examples: Typhoons and earthquakes

ETH currently works on typhoon (tropical cyclone) risk modeling and has developed complete risk models, including events and potential damages, for the islands of Japan (see Figure 7.10). For a given a development event, researchers are able to update risks based on additional data, including extreme wind field maps and risk maps as a function of where a typhoon is moving, its location, and its pressure (see Figure 7.11).

Figure 7.10: Complete risk modeling for typhoons (tropical cyclones), including several models based on updated data and information about events and potential damages

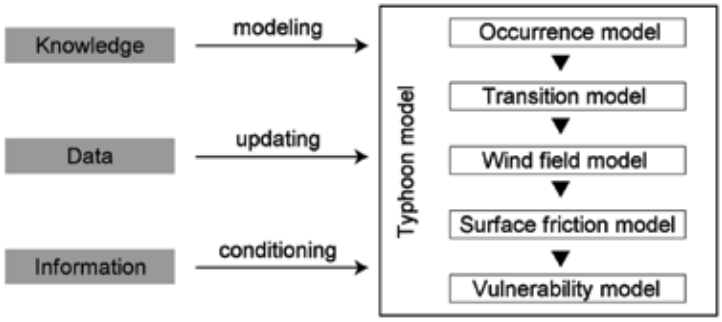
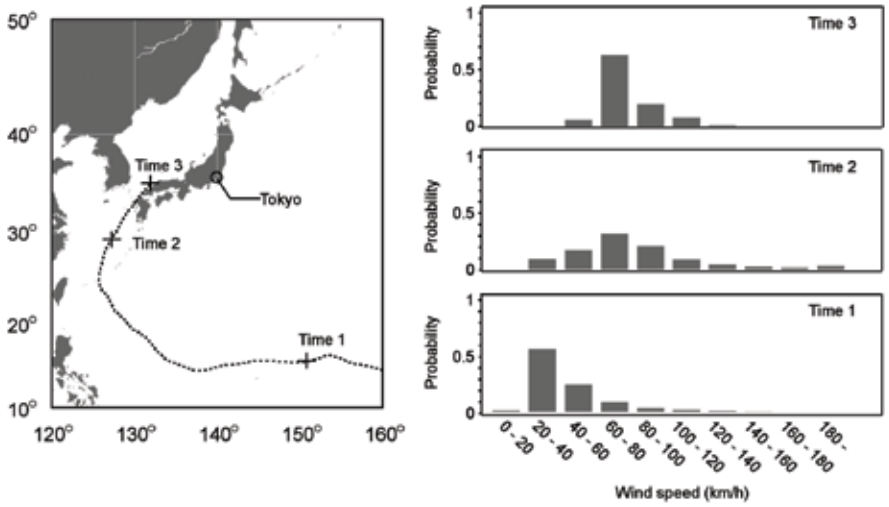
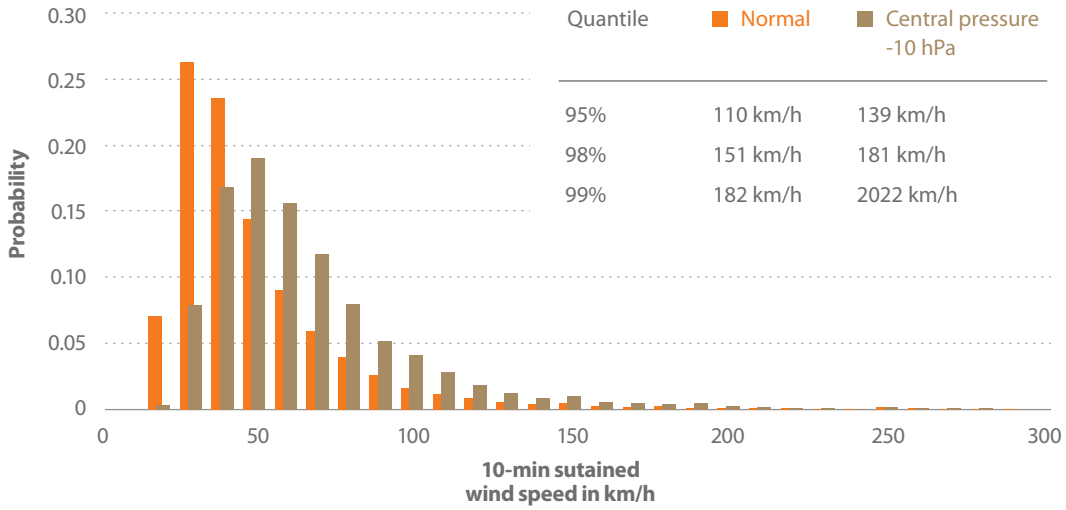


Figure 7.11: Updating wind field maps and risk maps over time for islands of Japan



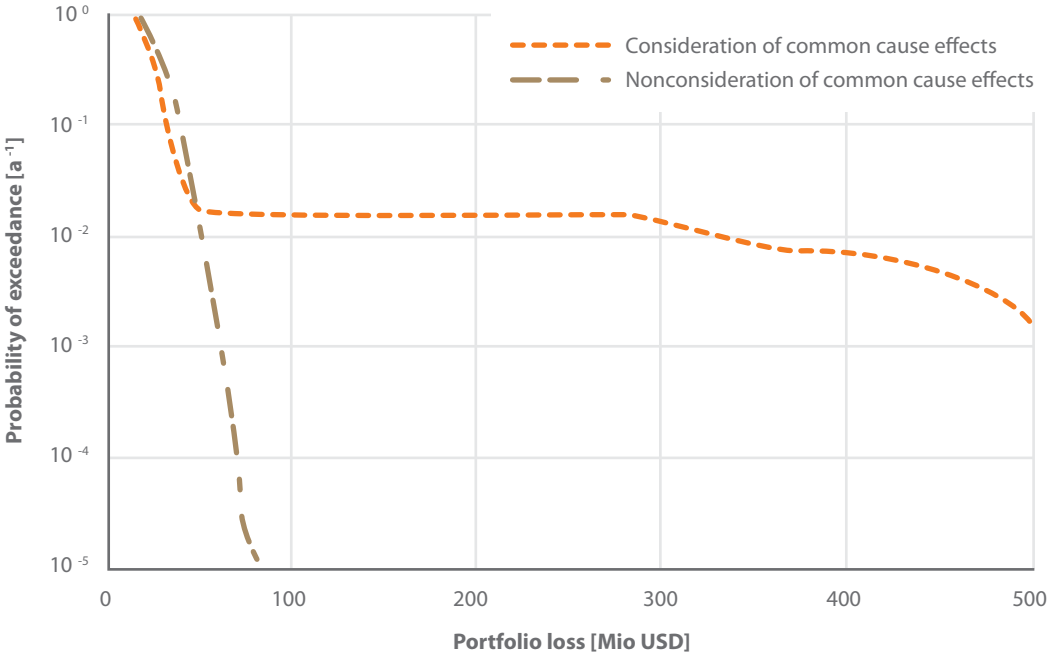
Consequence assessments can also be integrated into decision-making for determining what action to take given climate change, what this means for extreme wind distribution, and whether to design a new structure. For example, increase in intensity of typhoons corresponding to a homogeneous reduction of central pressures by 10hPA (with effect of climate change) has implications for extreme wind distribution (see Figure 7.12). This distribution of extreme winds is key information for designing structures. Similar consequence assessments can also be created for rainfall or other climate-relevant effects.

Figure 7.12: Annual maximum wind distribution in Tokyo, 'normal' vs. with climate change



ETH also considers risks and impacts of earthquakes and other large-scale natural hazard phenomena on the hundreds of thousands of components of societal infrastructure. Analysis includes not only the modeling of risks of each individual object, but also modeling of the loss for the portfolio. This is represented as the exceedance probability curve for losses of certain sizes (see Figure 7.13).

Figure 7.13: Probability of exceedance by portfolio loss, consideration of common cause effects (dependence of losses) vs. no consideration of common cause effects



The 'no consideration of common cause effects' curve in Figure 7.13 would traditionally be produced if dependencies were not taken into account in the risk assessment. As indicated by the dashed line in the above graph, consideration of the dependency of losses within a portfolio has a significant effect on the loss exceedance curve. This is important for understanding what type of extreme losses a society has to address — not only the extent of these losses, but also the probability of extreme losses.

Concluding remarks

1. Natural hazards and effects of climate change pose pressures to society.
2. Risks are real; they are not just numbers. Societies will suffer these losses in the future.
3. Sustainable development necessitates the management of these risks. Knowledge about future outcomes is reliable; the range of outcomes is certain, even if a specific outcome is not. In the long run, it is necessary to deal with the losses now through centralized governance of risks.
4. Strategic resource allocation (prioritization between prevention and aid) is required. Many resources are being lost due to actions that are based on observations rather than risk-informed decision-making. Rather than acting surprised in response to an earthquake, tropical cyclone or tsunami, society must recognize that, on average, these losses are very stable.
5. Resilience is only possible by planning in advance. Technical knowledge and knowledge of phenomenon are available. While the precise effects of global climate change are unknown, the range of possible scenarios are known. The best course of action is to take all possible scenarios into account in decision-making. Knowledge about how to deal with this uncertainty and how to adapt strategies in the future is also available. Thus, from a technical and scientific point of view, all required information is available to start acting now; societies must act immediately.
6. Modern risk assessment frameworks and tools greatly enhance risk management.
7. Resources may consistently be allocated between different activities having effect on health and the economy.
8. Generic modeling facilitates updating of risks through indicators for both small-scale and large-scale management.
9. Modeling can be applied for individually and jointly acting hazards.
10. Modeling can be utilized to optimize robustness and resilience of structures, infrastructure systems, procedures and organizations.

Climate change is an important issue; however, it is an issue that stands not alone, but within the complexity of sustainable development. Therefore, not all resources should be invested into climate change. Instead, the effort invested into climate change should be in balance with economic and social capacity of communities — local, national and global.

8 Technical Presentation 4: Probabilistic Risk Modeling: Basic Principles and Applications

Travis Franck

Key Messages

- Risk of climate change in coastal communities is a function of economic activity, population trends, amount of sea-level rise (SLR), frequency and intensity of tropical storms, and the social response to disaster.
- The uncertainty of all these factors necessitates the consideration of uncertainty and risk management in conjunction with the creation of development plans, including infrastructure investments.
- Probabilistic risk assessment (PRA) is a systematic and comprehensive methodology to evaluate risks associated with a complex problem.
- By incorporating uncertainty into development planning, PRA provides a tool for developing infrastructure in a way that is more resilient and more robust, that offers value under a wide range of climatic conditions, and that increases social benefits while decreasing social and financial losses.
- PRA also provides a framework for discussing future risks that allows for a structured approach to decision-making for cost-effective choices.
- Infrastructure investments impose both hard (structural) and soft (economic, social) impacts, and therefore necessitate a holistic, integrative approach to probabilistic risk assessment.
- PRA can be carried out through three primary methods: scenarios, probability trees and Monte Carlo simulations.
- Scenarios embody a set of parameters (e.g. economic growth, population, sea-level rise) and allow for a comparison of possible different futures, which can provide structure for development planning.
- Stakeholder involvement is key to determining which variables and parameters are important for El Salvador and Central America.
- Continual probability (PDF) information can be communicated to decision makers through relevant metrics, odds tables and probability wheels.
- Limitations of PRA: PRA only accounts for risks that can be quantified and included in the model. Probabilities need to be defined; yet data is sometimes lacking.

Travis Franck, Climate and Energy Consultant/Research Affiliate, Massachusetts Institute of Technology

Full Presentation

This presentation explains how to incorporate probability and uncertainty into risk management and modeling. The session provides an overview of probabilistic risk assessment (PRA) method, gives a concrete example of modeling for coastal impacts of climate change, considers the strengths and limitations of PRA methods, and discusses alternative ways to communicate PRAs.

Rationale: Why probabilistic risk assessment (PRA)

The need for probabilistic risk assessment stems from the uncertainty of climate change. There is uncertainty in climate science, economic conditions and how societies will respond to additional greenhouse gases, problems or specific disasters resulting from climate change. To better adapt to climate impacts, it is necessary to consider uncertainty and manage risk in conjunction with the creation of development plans.

The ultimate goal of applying PRA is to develop infrastructure in a way that is more resilient and more robust, that provides value under a wide range of climatic conditions, and that increases social benefits while decreasing social and financial losses. This refers to both hard and soft actions of infrastructure investments (e.g. bridges and roads, as well as societal aspects and policy measures, including zoning). Different language to describe PRA is evident in different disciplines. From an engineering perspective, PRA enhances robustness by reducing 'failure modes.' From a finance perspective, the benefits of PRA are two-fold: (1) PRA increases return on investment by lengthening the pay-back period (e.g. longer economic life expectancy of a bridge means longer-term benefit of that bridge); (2) climate proofing certain projects is an investment in having the option to retrofit in the future).

Coastal community risk analysis and adaptation approaches

Threats to coastal communities (population and infrastructure along a coast) are particularly relevant and familiar to El Salvador and Central America. Coastal communities face two primary impacts exacerbated by climate change:

(1) **Increase in sea-level rise (SLR):** The long-term, gradual global trend in SLR can be used as a starting point in a PRA, but needs to be adapted for different regions. Adjusting global SLR trends to local conditions on specific coastlines gives rise to 'relative sea-level rise.'

(2) **Increase in storm frequency and intensity:** Though this trend is a bit more controversial as an impact of climate change, the increased severity and frequency of storms results in infrastructure losses, enormous amounts of coastal areas flooded, loss of homes, disruption to economy and to society, and tragic loss of lives.

Coastal studies indicate that coastal exposure can be dramatic. Sea-level rise can severely damage infrastructure. An early 1990s study in the United States (Titus, 1991) states that millions of dollars are at risk due to threats of SLR alone, excluding tropical storms. Furthermore, globally, millions of people live in flood planes (i.e. 67 million people are in hazard zones [Nickolls, 2004]). However, with adaptation long-term exposure has decreased.

Adaptation to address potential impacts of both SLR and storms in coastal areas have included several approaches:

(1) **Zoning requirements:** Zoning requirements in coastal areas can prohibit building very close to the beach or shoreline. This prevents the affect of long-term SLR on buildings and provides a buffer to storm surges during tropical storms. Zoning can also prevent rebuilding in vulnerable areas in order to avert further exposure.

(2) **Protective publicly financed structures:** Protective structures, such as sea walls built in Louisiana, can reduce impacts of storm surges.

(3) **Elevated houses:** Elevated houses can also prevent impacts of flooding, such as Mississippi River flooding, on homes.

(4) **Insurance options:** Soft policy options, including disinvesting along the coastline, can help protect and build robustness of coastal communities.

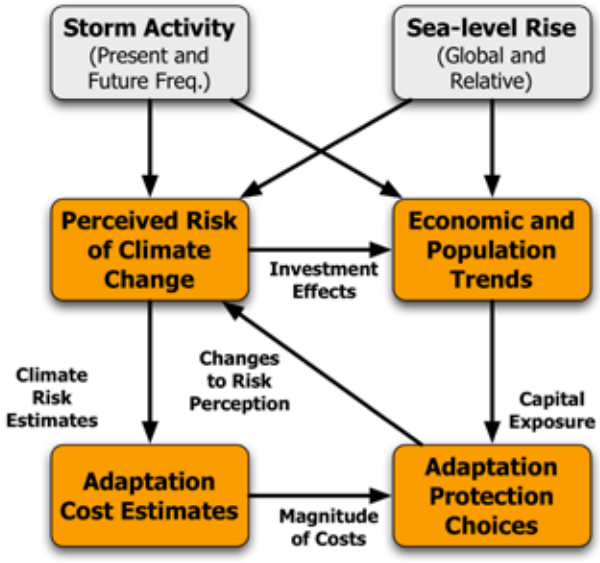
Risk of climate change in coastal communities is a function of the economic activity, population growth and trends, amount of sea-level rise, frequency and intensity of hurricanes, and the social response (i.e. how people respond to disaster, perceive risk themselves, and how this affects their daily lives). All of these factors remain uncertain and thus necessitate probabilistic risk assessment.

Probabilistic Risk Assessment: Definition and methods

PRA is a systematic and comprehensive methodology to evaluate risks associated with a complex problem and can be carried out through three primary methods: scenarios, probability trees and Monte Carlo simulations. All of these methods require a model to evaluate the probability.

The Feedback-Rich Adaptation to Climate Change (FRACC) Model (developed at The Massachusetts Institute of Technology [MIT] for coastal communities) pulls together interactions in the PRA related to climate change, specifically for coastal communities. The arrows in the diagram of this model (see Figure 8.1) show the interconnectedness and feedback of factors. Climatic drivers (sea-level rise and tropical storms) can be parameterized, as it is necessary to understand risks associated with these drivers. These drivers affect economic and population trends. Large economic growth and high population can lead to exposure and vulnerability by increasing the amount of capital that might be at risk. Adaptation decisions also affect risks, as adaptation protection choices resulting from risk assessment influence people's perception of risk; if people are well prepared, they tend to perceive less risk. All of these factors contribute to further adaptation options and cost of adaptation.

Figure 8.1: The Feedback-Rich Adaptation to Climate Change (FRACC) Model



This framework suggests the need for a systematic and holistic approach to probabilistic risk assessment to climate change and infrastructure adaptation.

Scenarios and decision trees

Scenarios embody a set of parameters (e.g. economic growth, population, sea-level rise) and allow for a comparison of possible different futures, which can provide structure for development planning. Assigning probabilities to the scenarios provides guidance for decision-making.

Table 8.1: Scenario examples

Parameter	Low	Reference (median)	High
Economic growth	0.2% / year	2.0% / year	4.0% / year
Population growth	0.1% / year	1.5% / year	4.2% / year
Sea-level rise in 2100	0.40 m	0.75 m	1.25 m

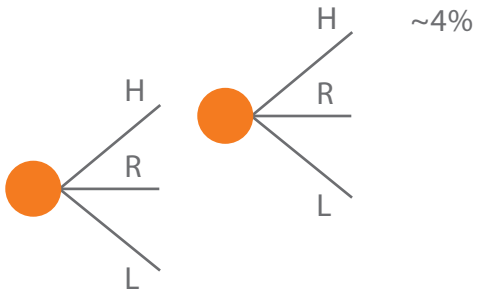
For each scenario, important variables (i.e. drivers) of risk are highlighted. For each driver, three different scenarios can be developed: low, reference (median) and high scenarios. With these three scenarios, we can examine three possible futures in a model. The minimum amount of exposure is low economic/population growth and low sea-level rise. These scenarios can be used for adaptation planning and decision-making.

Table 8.2: Assigning probabilities

Parameter	High	Probabilities
Economic growth	4.0% / year	15%
Population growth	4.2% / year	(15%, correlated)
Sea-level rise in 2100	1.25 m	25%

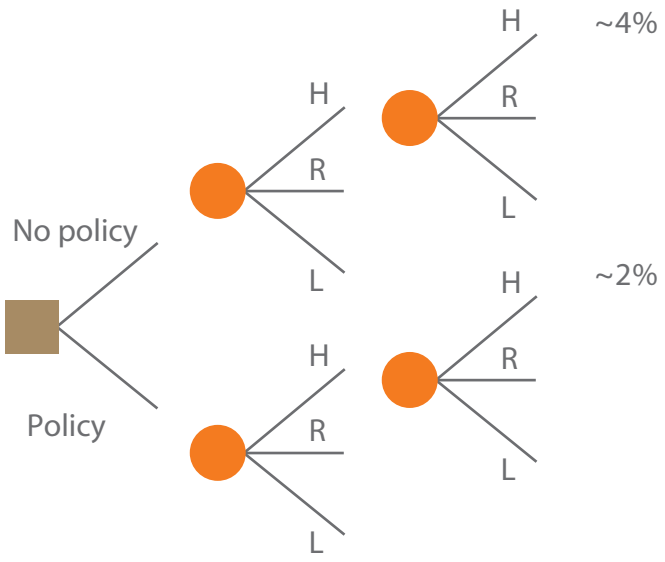
Because economic growth and population growth are perfectly correlated, the same probability (15 percent) is assigned to these two parameters (15 percent). With the additional probability of high sea- level rise (25 percent), there is about 4 percent likelihood of a scenario of high-risk impacts. If an infrastructure project performs well under the 'high' scenario, then it will perform well for 96 percent of the sea-level rise conditions, given high economic growth.

Figure 8.2: Decision tree for infrastructure project (based on scenario, without policy assumptions)



Decision trees can be used to guide implementation of a policy to reduce potential damages implicit in the scenario (e.g. policy requiring elevated houses in flood low-lying areas to reduce damages from flooding). Based on the assumption that this policy (elevating homes) reduces the likelihood of economic damages by 50 percent, the policy reduces the likelihood of damages of high amounts of sea-level rise from 4 percent (without policy) to 2 percent (with policy).

Figure 8.3: Decision tree for infrastructure project (based on scenario, with policy assumptions)



With this new probability, the economic value of the policy option can be evaluated using the integrative FRACC model that presents a holistic view of infrastructure.

Monte Carlo simulation

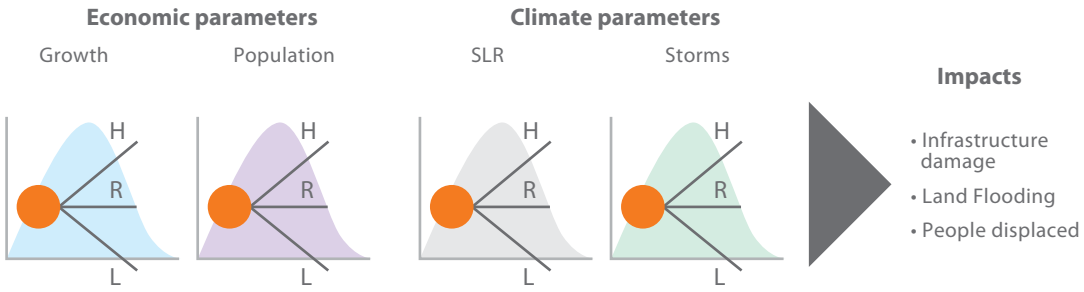
While decision trees can be very useful, the Monte Carlo simulation is a more complex way to look at a variety of problems. Rather than using distinct probabilities for high, reference, and low scenarios, the Monte Carlo simulation uses a continual spread of probabilities.

Development plans are complex, as many possible development paths for coastal communities can be considered on a continual basis. Robust development should heed all factors of economic growth and population, including sea-level rise, storm frequency, storm intensity, and policy option. The dynamics of a coastal community should also be evaluated over time. While probability trees do not show well the dynamics of economic growth over time, Monte Carlo analysis can simulate a community and how it will respond over 20 to 100 years. Using the FRACC diagram (Figure 8.1) as a simulation model, Monte Carlo analysis can therefore evaluate uncertainty even with the complexity of coastal development planning. Though a hurricane can affect economic capital (upper right yellow box in the diagram), and consequently factors represented in all other yellow boxes, investment and disaster relief can allow the entire system to recover.

Probability density function (PDF)

With economic parameters (growth and population) and climatic parameters (sea-level rise and storms) in an integrated approach to coastal climate projects, climate impacts can include infrastructure damage, land flooding and displacement of people. Probability density functions (PDFs) allow these factors to be considered as a more continual representation of risk. PDFs, represented below as skewed bell curves, are defined by empirical research, expert literature, or expert elicitation.

Figure 8.4: Probability density functions (PDFs)



Within the Monte Carlo simulation, using PDFs (e.g. of sea-level rise) as an input produces PDFs as an output. This approach can be used to calculate the outcomes of many parameter sets. With defined PDFs for important parameters, these parameters are correlated (e.g. high population growth with high economic growth). A model with samples of the input PDFs help to create hundreds of thousands of simulation runs (e.g. by brute force or Latin hypercube sampling).

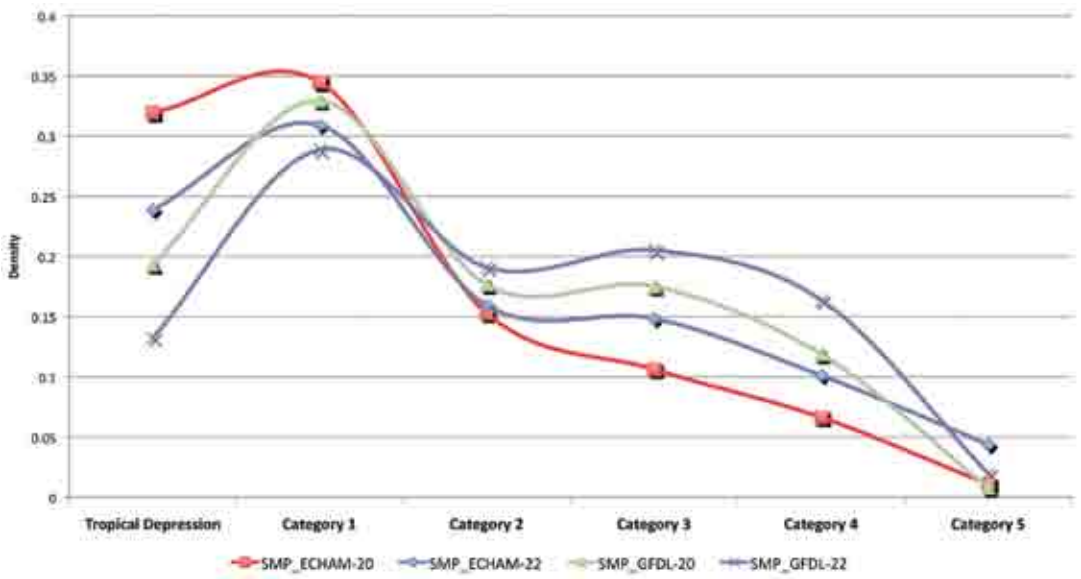
Characterizing a PDF

Academic literature, statistical or empirical evidence, or expert elicitation can provide the basis for characterizing PDFs. Scientific literature supports parameters of sea-level rise, for example, as long as published SLR trends are adjusted for local conditions. Empirical data supports parameters of economic growth and population trends. PDFs for low-frequency, high-consequence events (e.g. tropical storms), however, are more difficult to characterize. Science does indicate that storms will become more intense and more frequent, particularly in the Atlantic basin (Kossin, 2007), but this trend is still uncertain and difficult to quantify in a particular area. While historical tracks (e.g. from National Hurricane Center, 2005) show that El Salvador and Central America are particularly prone to these problems, it is still necessary to quantify risks of these storms in El Salvador.

Models can help to estimate storm trends for a specific location. The physics-based Couple Hurricane Intensity Prediction System (CHIPS) model (MIT), for example, can help determine which and how many of thousands of storms seeded will persist and hit El Salvador. By simulating thousands of storms, the frequency of storms passing near Central America and the distribution of storm intensities can be defined. With this model, given physics of ocean, winds and the atmosphere, it is possible to gain a better idea of what types of storms and frequency will hit a particular area.

The CHIPS model has been used to create PDFs of storms for St. Mary's Parish (Louisiana) and illustrates frequency of tropical depressions and category 1 – 5 storms. In Figure 8.5, the four lines in this graph representing four different climates (two present-day and two future climates) indicate variance among the four models but also a shift in storm distribution toward stronger storms.

Figure 8.5: PDF of storms for St. Mary's Parish



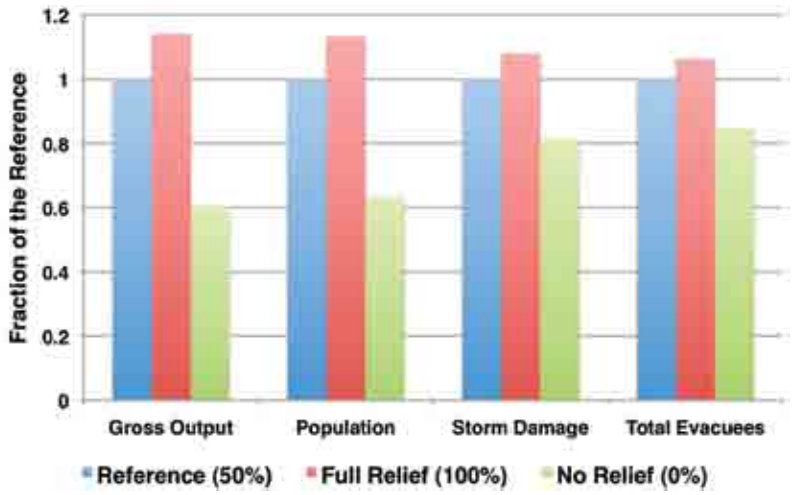
Presenting results of PRA

Given that the goal of PRA is to guide decisions, probability information needs to be presented in a way that is relevant and useful to decision makers and policy makers. Relevant metrics (identified through stakeholder involvement), 'odds tables' and 'probability wheels' serve as useful ways of presenting this probability information to a variety of audiences.

Relevant metrics

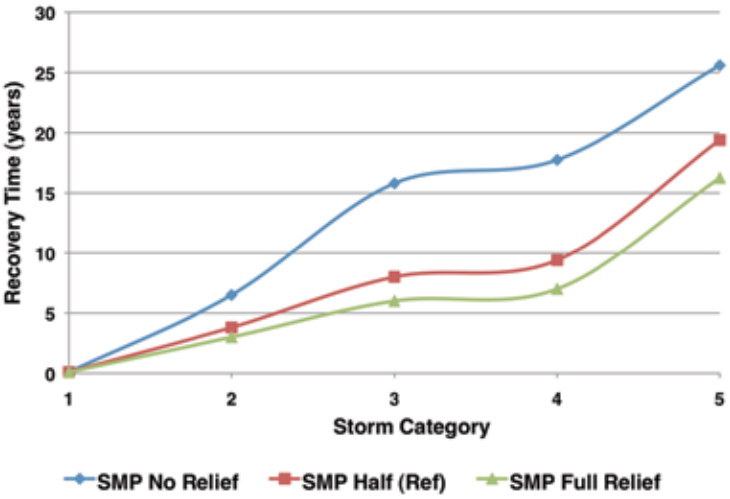
The following study, evaluating a soft policy option for providing disaster relief to the coastal community, exemplifies the use of relevant metrics. For this policy choice, the relevant metrics (policy measures) include not only economic output (dollar value), but also population, storm damage and total evacuees (i.e. displaced people). Policy choices are identified as full relief (100 percent return on relief investment), 50 percent relief (50 cent return on every dollar invested; reference) and no relief (no investment). According to the study (see Figure 8.6), full relief does produce greater economic output and population growth, but (perhaps counter-intuitively) also leads to more damages and displaced people; greater prosperity of coastal communities leads to higher exposure.

Figure 8.6: Relevant metrics for disaster relief policy choices in coastal community



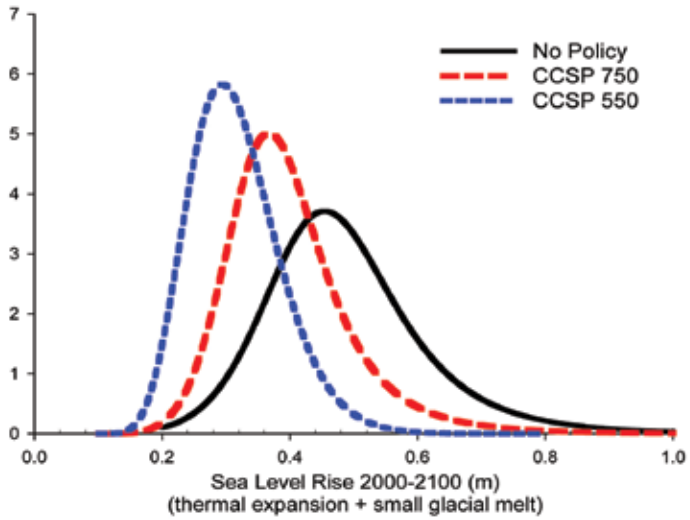
Recovery time can also serve as a relevant metric, as shown by the study in Figure 8.7. The graph of recovery time versus storm category indicates robustness of a policy choice (relief) by showing the amount of time it takes to recover from a storm depending on the category of the storm. All of these metrics used in the study help to quantify probabilistic risk assessment in an integrative model.

Figure 8.7: Recovery time vs. storm category, showing robustness of relief over time



The PDFs of sea-level rise in Figure 8.8 show the distribution of sea-level rise given mitigation policy (action to reduce greenhouse gases; not adaptation). Moving from the black curve (PDF without policy) to either the red or blue curves (PDFs with mitigation actions), the mean shifts to the left. This shows that the tail high-end sea-level rise drops. In other words, taking mitigation actions leads less toward extreme events (1-2 meter SLR possible by 2100) and, instead, more toward the median of possible SLR.

Figure 8.8: Probability density function showing joint program SLR estimates



Source: MIT Joint Program on the Science and Policy of Global Change SLR estimates.

Odds tables

As PDFs can be difficult to explain, an odds table (see Table 8.3) can characterize PDFs in a way that is easier for decision makers and others to grasp more intuitively. This presentation approach communicates probabilities in terms of odds (e.g. 19 in 20 odds that two-fifths of a meter will be exceeded given different policy options).

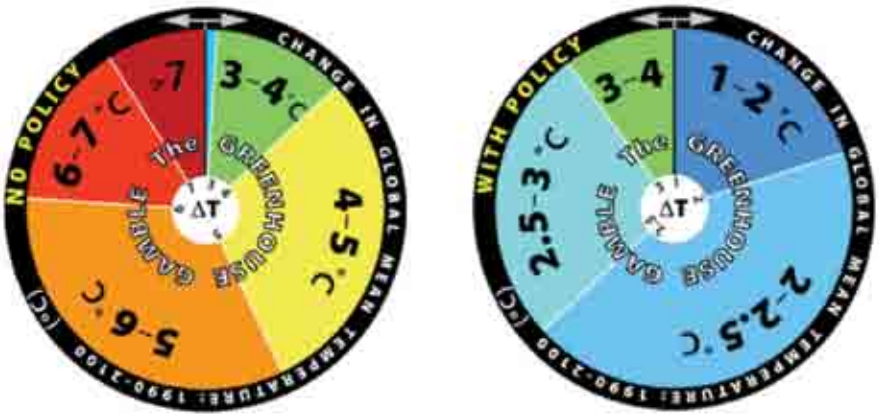
Table 8.3: Joint program SLR odds

Atmospheric concentrations (ppm)	Sea-level rise > 0.3m	Sea-level rise > 0.6m
No policy	19 in 20	3 in 20
Stabilize at 750	17 in 20	1 in 25
Stabilize at 650	15 in 20	1 in 50
Stabilize at 550	11 in 20	<1 in 400
Stabilize at 450	1 in 4	< 1 in 400

Probability wheels

The final way of communicating a continuous probability is to include PDF information in probability wheels (see Figure 8.9). The wheels in the example below illustrate temperature change in 2100 without policy (left wheel) and with policy (right wheel). Probability wheels provide visual representation of percentages for the likelihood that temperatures will reach a certain level in 2100 given different policy options.

Figure 8.9: Probability wheels of temperatures in 2100 given no policy and given policy



Source: MIT Joint Program on the Science and Policy of Global Change.

These wheels provide another tool for presenting risk information in a way that is more accessible for decision makers and diverse audiences unfamiliar with PDFs and PRAs.

Conclusions

Investment in infrastructure projects affect society in both hard (structural) and soft (economic, social) ways. It is therefore necessary to take a holistic, integrative approach to probabilistic risk assessment with regard to infrastructure.

Limitations of PRA

Limitations of probabilistic risk assessment are as follows:

- **PRA only accounts for the risks that can be quantified.** It is difficult to quantify the many uncertainties associated with infrastructure. One way to characterize uncertainty may be to arbitrarily expand PDFs so that the tails are larger (farther apart). This would allow the possibility of designing systems knowing that some information is lacking.
- **PRA only accounts for risks that have been included in the models.** There may be other risks besides the ones that have been characterized in a PRA model (e.g. if a model only includes SLR, the possibility of tropical storms is not accounted for in the PRA). The exclusion of certain risks can introduce structural uncertainty into the model and consequently misguide investment decisions that might come out of the analysis.
- **Probabilities need to be defined, but sometimes data is lacking.** This is particularly a problem for low frequency events, such as hurricanes.

Benefits of PRA in adaptation

Despite its limitations, PRA has several benefits for adaptation:

- **Development of infrastructure plans can incorporate uncertainty** so that communities will be more resilient under a range of possible climatic conditions. This increases return on investment, provides social benefits, and improves the community.
- **PRA provides a framework for including and discussing future risks** that allows for structured thinking and approach to decision-making. Decision makers can discuss policy options in a meaningful ways based on probability by debating whether a risk should be included or whether a probability is important.
- **PRA helps to identify high-leverage policies to decrease exposure over time.** With a properly integrative model, decision makers can study policy options and choose most cost-effective choice.

Action steps

Moving forward, the government of El Salvador can take the following steps:

1. Identify the variables and parameters related to development (e.g. trends in population, economic growth, storms, seal-level rise, rainfall) that should be used to run optimization models to get most benefit from system. The best way to determine which variables are most important to El Salvador and Central America is through stakeholder involvement and feedback.
2. Estimate range of values for parameters by creating scenarios and defining parameters.
3. Simulate using an integrative model.
4. Combine with economic valuation to understand value of risk reduction in economic dollars and how best to distribute development projects.

Goal of PRA

The goal of PRA is to incorporate climate, economic, and social uncertainty into planning so that infrastructure will be more robust. Ideally the approach improves investment decisions and reduces long-term exposure (risk) to society.

9 Technical Presentation 5: An Economic Framework for Evaluating Climate Proofing Investments on Infrastructure

Matthew J. Kotchen

Key Messages

- El Salvador suffers significant risk of damages due to climate change impacts, but contributes little to the cause of climate change (i.e. greenhouse gas emissions). It is appropriate for El Salvador to focus on climate change adaptation over mitigation.
- An economic approach to setting climate-proofing priorities implies a focus on efficiency, whereby the goal is to choose projects that have the greatest net social benefits.
- Determining the net social benefits of infrastructure projects, and the climate proofing of them, requires consideration of both costs and benefits.
- Estimating costs and benefits often requires the use of both market and nonmarket valuation techniques.
- The framework developed here is useful for setting priorities for the climate proofing of infrastructure investments and determining how much to invest in each.
- The framework can also be modified to incorporate climate-proofing externalities, such as co-benefits of projects and regional network effects.
- Other important considerations include changes in infrastructure priorities more generally due to climate change impacts and the importance of discounting.
- Building capacity for efficient climate change adaptation requires identifying the set of potential infrastructural adaptations, expanding knowledge of nonmarket values, and strengthening institutions for greater international and regional coordination of efforts.
- Building human capital for institutional support is also important and could include the use of geographic information systems to identify vulnerability, census and economic data, storm impact and response data, training in microeconomic theory and statistical methods, and ongoing program evaluation.

Dr. Matthew J. Kotchen, Associate Professor of Environmental Economics and Policy, Yale University

Full Presentation

This technical presentation offers an economic framework for evaluating the climate proofing of investments on infrastructure. Emphasis on economic valuation focuses on consideration of costs and benefits, evaluated through market valuation (impacts measureable through prices) and nonmarket valuation (impacts not easily monetized, such as risks to human health). The framework proposed here for setting priorities given finite resources complements frameworks previously discussed during the conference. Further considerations include co-benefits, geographic scope, proofing vs. prioritizing infrastructure projects, and discounting. Recommendations for building capacity to implement the framework for efficient climate-change adaptation precede final thoughts.

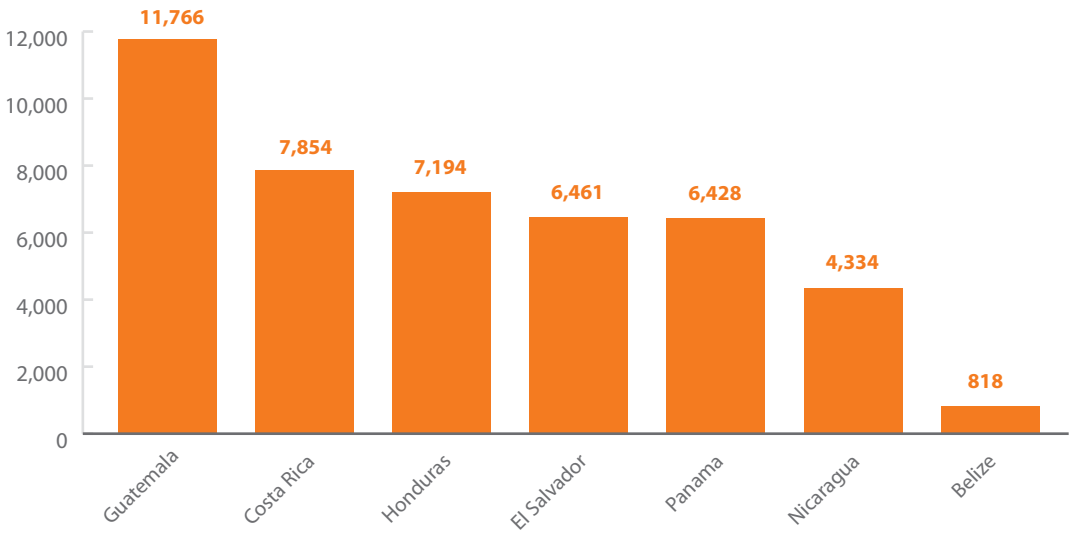
Rationale

Focus on adaptation over mitigation

Where climate change discussions and policy tend to focus on mitigation (i.e. the reduction of greenhouse gas emissions), dialogue is often embedded in scepticism and debate about whether or not climate change is a problem. Where climate change effects are already being seen and thought to be getting worse, dialogue tends to focus on adaptation, that is, not on whether climate change is a problem, but rather on what needs to be done about it.

El Salvador's focus on adaptation, rather than mitigation, is appropriate given that the country accounts for less than 0.1 percent of worldwide CO_2 emissions (the primary greenhouse gas) and ranks 107th among nations for emissions (based on 2006 data). All of Central America emits only 1.6 percent of global emissions, of which El Salvador contributes the median amount (see Figure 9.1).

Figure 9.1: Carbon dioxide emissions (in 1000s metric tons) from fossil fuels by country in Central America (2006)



Forecasts of climate change impacts in El Salvador

In El Salvador, according to predictions reported by the Central American Integration System (SICA), the average temperature will increase between 0.8°C and 1.1°C by 2020, and between 2.5°C and 3.7°C by 2100. It is likely that in the next 10 years annual precipitation will change, with estimates showing a high degree of variability, from a decrease of 11.3 percent to an increase of 3.5 percent. By 2100 these changes are predicted to range from a decrease in precipitation of 36.6 percent to an increase of 11.1 percent. These forecasts also include significant seasonal differences. There are also predictions that sea level will increase by 20 cm by 2030, 40 cm by 2040 and by 70 cm by 2100. While there is much variability in these numbers, the probabilities are alarming enough to necessitate serious consideration about how best to adapt to a changing climate.

Costs and benefits

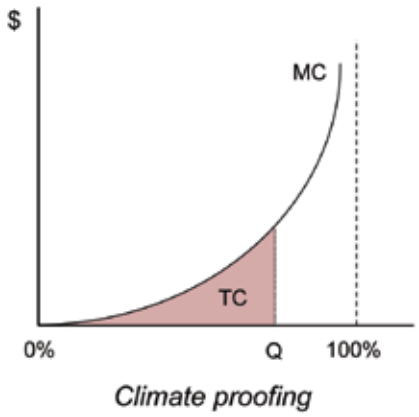
The climate proofing of infrastructure can be conceptualized from an economics standpoint as insurance against the adverse impacts of climate change. Determining the right amount of climate proofing requires consideration of both the costs and benefits.

The costs of climate proofing infrastructure

The climate proofing of infrastructure projects (e.g. roads, bridges, etc.) seeks to reduce vulnerability of the investments to increased variability in climatic conditions (e.g. increased rainfall, high-speed winds, flooding, etc.). In principle, we can measure the effectiveness of an infrastructure project as ranging between 0 and 100 percent, where 100 percent means that with certainty floods or winds will not damage or destroy the infrastructure. Climate forecasts, as well as input from engineers, can be used to determine such effectiveness and the specifications need.

With this information, market valuation can be used to evaluate the direct costs of climate proofing based on the additional costs necessary to increase effectiveness. Figure 9.2 is useful to illustrate the basic relationship.

Figure 9.2: The costs of climate proofing effectiveness



The horizontal (x) axis represents effectiveness of climate proofing, ranging from 0 to 100 percent; zero percent effectiveness indicates immediate destruction of a project (e.g. a bridge) due to high vulnerability, while 100 percent effectiveness indicates that construction of the bridge will withstand climate-change impacts.

The curve represents the marginal cost (MC), that is, the additional cost of constructing the bridge to increase effectiveness. The increasing curve shows how improving the strength of the bridge becomes increasingly more costly. Also, because some uncertainty always exists, it becomes increasingly more costly to increase effectiveness, until it may be infinitely expensive to approach 100 percent effectiveness.

The total cost (TC), represented by the shaded area under the curve, is the total cost of constructing the bridge at Q value of climate proofing (i.e. the sum of marginal costs for each unit of climate proofing up to Q). Communicating with engineers to determine the costs of climate proofing for any level of Q is relatively straightforward compared to estimating the benefits, but information on both costs and benefits is necessary to determine the economically efficient level of Q.

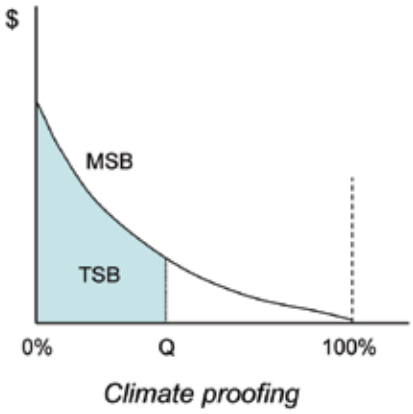
The benefits of climate proofing infrastructure

The benefits of climate proofing are avoided damages to property (e.g. destruction of buildings), forgone economic activity as a result of damages (e.g. electrical outages, failed bridges), effects on health and human life, and impacts on environmental services (e.g. erosion, loss of natural capacity to protect from future climate change). Typically, these benefits are not straightforward to monetize because they are not observable through market transactions and do not have prices. Quantification of them, therefore, usually requires some form of nonmarket valuation.

Recognizing the difference between the private perspective and the social perspective is important when it comes to thinking about the right benefits to include. From the private investment perspective, the benefits of climate proofing are financial returns. From the social perspective, the benefits often include the non-market values associated with things like avoiding loss of life, health benefits, diffuse economic activity, and environmental services. Here we consider the social perspective for purposes of public sector investments and policy.

In parallel to the cost curve above, modeling the benefits (see Figure 9.3) uses the same metric on the x-axis, 0 to 100 percent climate-proofing effectiveness. In Figure 9.3, the curve represents the marginal social benefits (MSB), that is, the additional benefit to society of having one more unit of climate proofing effectiveness. These benefits are positive but decreasing with increased fortification of infrastructure against climate risks.

Figure 9.3: The benefits of climate proofing effectiveness



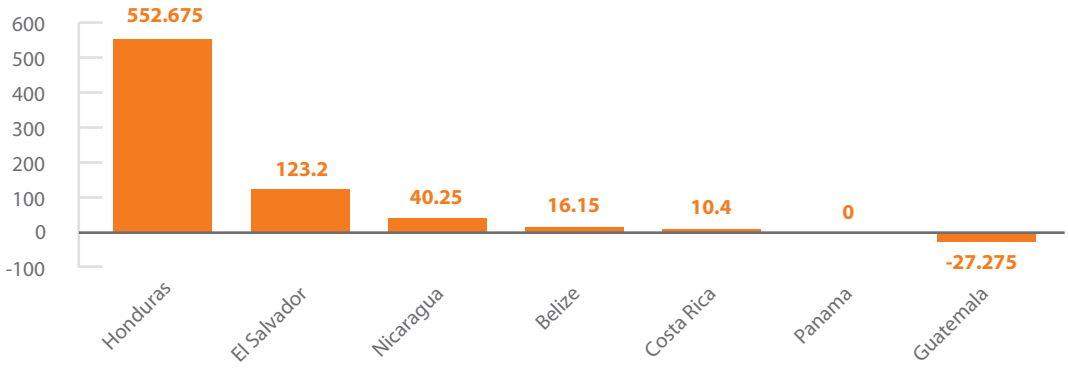
The total social benefit (TSB) of climate proofing to level Q, represented as the shaded region in Figure 9.3, is the sum of all marginal benefits to society for each unit of effectiveness up to Q.

The example of tropical storms

Statistics for Hurricane Mitch and Hurricane Stan provide examples of how storm impacts can be translated into estimated costs and benefits. Hurricane Mitch (1998) destroyed 49 percent of the agricultural and livestock sectors in El Salvador, and resulted in 240 direct fatalities and $400 million in estimated damages. Hurricane Stan (2005) destroyed 70 percent of basic crops and resulted in 69 direct fatalities and $355 million in estimated damages. These statistics represent the damages that could have been reduced or avoided with climate-proofing policies.

Climate models predict an increase in the frequency and intensity of these types of storms. Using four different models to predict storms, a recent study by a Yale colleague simulates data on damages that storms are likely to cause over the next 90 years as a result of climate change (see Figure 9.4). The study uses past damages and predications about how climate change will increase storm intensity to derive the estimates.

Figure 9.4: Damages relative to no climate change baseline 2100 (million $/year)



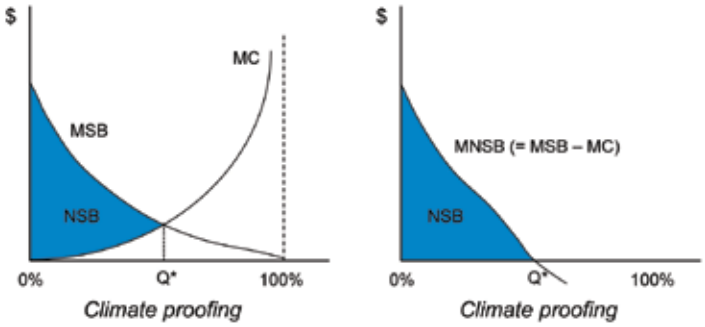
Source: Forecasted impacts in Central America (Mendelsohn et al. 2010).

Figure 9.4 shows economic damages (in millions of dollars per year) from storm impacts predicted to be significantly greater than the expected baseline of what damages would be in the absence of climate change (Honduras is an outlier with especially high damages). In El Salvador, estimation of the annual average cost of climate change from storm damage (without adaptation measures) is over $100 million. Total economic damages for El Salvador would be equal to this value plus damages predicted in the absence of climate change. This is an example of how nonmarket valuation can be used to estimate the benefits of what can be gained by pursuing adaptation strategies.

Economically efficient climate proofing

Cost-benefit analysis for economically efficient climate proofing can help to determine the efficient amount of climate proofing for a nation such as El Salvador. Considering the cost and benefit curves (Figures 9.2 and 9.3) simultaneously is the way to determine the optimal, or economically efficient, level of climate proofing. The graph on the left-hand-side of Figure 9.5 defines Q* as the optimal level of climate proofing. This is where the MC and MSB curves intersect. The graph also indicates the net social benefit (NSB) as the area representing the difference between TC and TSB. Note that Q* is the level of climate proofing that maximizes this area.

Figure 9.5: Efficient level of climate proofing



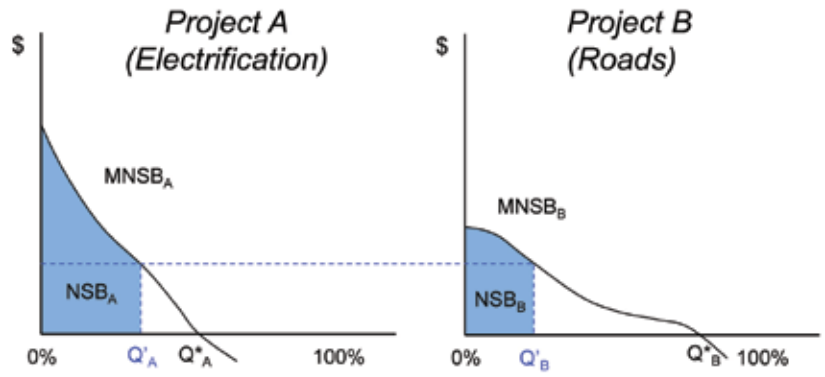
Note: Net social benefit (NSB); marginal net social benefit (MNSB) = MSB - MC.

Another way to see this is with the right-hand-side graph in Figure 9.5. This shows the marginal net social benefit (MNSB) curve, which traces out the area beneath it representing the NSB (the same area on both graphs in Figure 9.5). From this graph, it is clear that efficient climate proofing occurs up to the point where the MNSB curve remains positive, for beyond that point the additional marginal social benefits would not exceed the additional marginal costs.

Prioritizing among projects with a fixed budget

When prioritizing climate-proofing actions among projects given a budget that prohibits doing them all at the economically efficient level, the objective is to optimally allocate investments by maximizing total net social benefits subject to the budget constraint. For example, when comparing Project A for electrification (e.g. bolstering the strength of power lines while expanding the distribution of electrical services) with Project B for roads (e.g. constructing and fortifying bridges and roads for flood-resistance), the net social benefit for a given budget can be identified for each project (see NSBA and NSBB in Figure 9.6).

Figure 9.6: Prioritizing among projects with a fixed budget



Note: Objective is to maximize total net social benefits subject to a budget constraint; solution is MNSBA = MNSBB while also exhausting the budget.

Figure 9.6 illustrates the nature of an efficient solution. The efficient amount of climate proofing for each project occurs at the levels of QA and QB where the marginal net social benefits are equated between them both, and simultaneously achieving the values of QA and QB that exhaust the budget. If both of these conditions are met, then total net social benefits (=NSBA + NSBB) are maximized.

Implications of the framework

In general, the framework described here requires information about marginal social net benefits of projects, which are based on estimates of the marginal costs and marginal social benefits. At the crudest level, when information is incomplete, the objective can be understood to imply that priority should be given to projects expected to yield relatively large social net benefits, which requires consideration of both costs and benefits. The framework also provides a mechanism for choosing which projects to undertake (the extensive margin) and how extensively to pursue them (the intensive margin).

Importance of climate proofing externalities

The framework can be modified to incorporate climate-proofing externalities, such as valuable co-benefits of projects. For example, infrastructure for flood control might also provide water storage. Vegetation planted along coastlines to prevent landslides might also promote biodiversity and provide opportunities for carbon-offset payments.

In addition, infrastructure is often closely tied with networks, which can contribute to the spread of benefits. Infrastructure projects for climate proofing a country's transportation system, for example, can benefit international trade, but only to the extent that transportation across national boundaries is also less vulnerable to climate change impacts. This requires multinational coordination. Likewise, infrastructure projects can result in positive and even negative externalities across regions (e.g. department borders within El Salvador) and ministries (e.g. transportation, communication, and electricity distribution). Hence maximizing all positive benefits may entail spillovers across jurisdictional boundaries.

Figure 9.7: Map of Central America (left) and departments of El Salvador (right)

Note: Potential for infrastructure (e.g. transportation) to lead to positive externalities across borders.

Prioritizing among projects accounting for externalities

Positive externalities can be mapped into the framework if included in the graphs for prioritizing investment projects. For example, considering the transportation benefits of roads (Project B) to either neighbouring departments or countries, the social benefits for Project B become the benefits (indicated in Figure 9.6) plus the positive externality, as shown on the right-hand-side graph of Figure 9.8. Then equating the adjusted marginal net social benefits between projects, we see that pursuing less electrification (Project A) and more of road network (Project B) optimizes total benefits given the same budget constraint. This results in greater overall social net benefits, as illustrated with the graphs in Figure 9.9. There is less benefit associated with electrification but more benefit associated with roads, and the latter effect is larger than the former.

Figure 9.8: Prioritization among projects accounting for externality

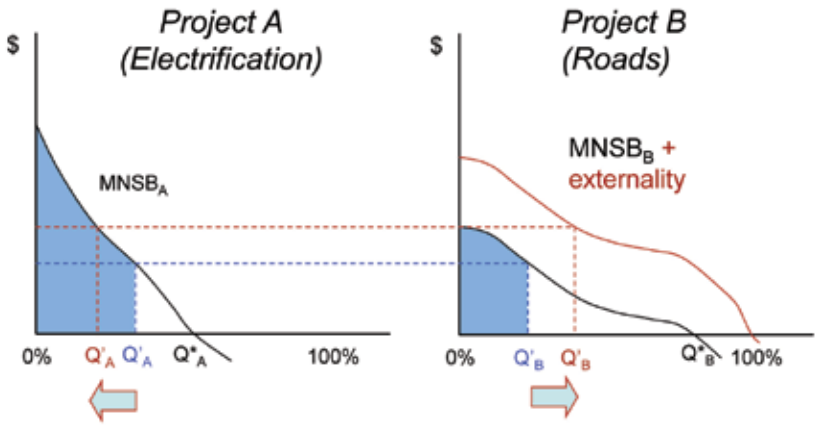
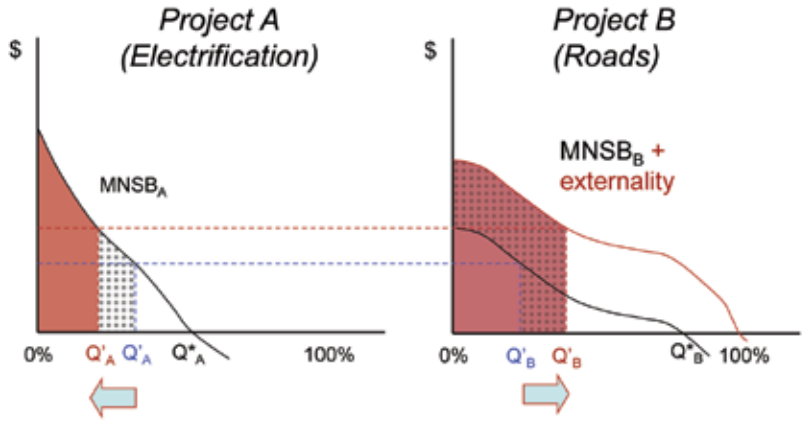


Figure 9.9: Prioritizing among projects accounting for externality



Note: Additional net social benefit represented by difference between pink dotted area and white dotted area.

Accounting for these external effects is crucial, as it not only can change climate-proofing strategies across different investment projects, but it also can affect decisions about when to optimally invest and at what levels.

Further considerations

Proofing vs. prioritizing infrastructure projects

The framework presented here has been discussed in terms of climate proofing infrastructure projects. However, it is worth emphasizing that when the impacts of climate change are considered, the priorities for which infrastructure projects to undertake at all (regardless of whether they are climate proofed or not) could very well change. In El Salvador, for example, the Intergovernmental Panel on Climate Change (2007) predicts a 10 to 27.6 percent decrease in land area by 2100 due to sea-level rise. Such information might not only change which infrastructure projects would be efficient to climate proof; it is likely to change which infrastructure projects to undertake at all.

Discounting

Though controversial in the field of economics and policy analysis, discounting is the standard way to account for differences in the timing of costs and benefits. Discounting takes into consideration that a dollar today is worth more than a dollar in the future because (1) that dollar can be invested for future returns and (2) there is an inherent impatience for the present over the future. Higher discount rates imply less value placed on the future.

Discounting is an important consideration for infrastructure investments that deal with future risks of climate change. In general, the costs occur now, or relatively soon, while the benefits of potential avoided damages happen far into the future and are often quite uncertain. It is often argued that considering climate change for the welfare of future generations thus calls for a lower discount rate.

Building capacity for efficient climate change adaptation

Three recommendations can be made about how to develop concrete strategies for adaptation:

1. **Identify the set of all potential infrastructural adaptations:** Initially, this list should be complied without regard to costs and benefits, considering both nationwide and region-specific impacts, as well as historical successes and failures. Then based on this list, economic analysis of the type outlined here should be applied to those of greatest interest, after eliminating those that seem infeasible or not likely to be efficient candidates.
2. **Expand knowledge of nonmarket valuation:** This may include conducting additional studies on nonmarket valuation in developing nations, as well as improving availability of existing data through 'benefits transfer' (i.e. the transfer of benefit estimates from one study area to another). Canada's Environmental Valuation Reference Inventory (EVRI) — which lists nonmarket valuation studies for North America (1,178 studies), Asia (229 studies) and Latin America (38 studies) — may be a useful resource for benefits transfer information. In the long-term, Central America and El Salvador, specifically, might benefit from efforts to bolster the capacity for conducting nonmarket valuation studies throughout the region.
3. **Strengthen institutions for greater international and regional coordination of efforts:** Nations can share information and experience about the climate proofing of infrastructure: what works, what doesn't, and what are the most cost-effective ways of getting it done. And when it comes to regional coordination, this meeting has been great example of what needs to be done.

Human capital for institutional support

Recommended capacity building includes the development of human capital for institutional support. For example, the value of geographic information systems with mapping software is key for identifying vulnerabilities. El Salvador can benefit from capacity building for developing methods to synthesize such geophysical and socioeconomic information. Consideration of the interconnectedness of different regional economies can also influence how best to build infrastructure and take advantage of positive externalities. In addition, census and economic data are important for developing tangible recommendations. By collecting data during storm events, capacity can be built for evaluating damages, impacts and responses; past records of disaster responses can help to improve future responses to similar events. Finally, training in microeconomic theory (particularly in the fields of welfare economics and nonmarket valuation) and quantitative statistical methods, as well as ongoing program evaluation, can build the human capital necessary to improve decision-making about infrastructure investments and climate-proofing priorities.

Concluding thoughts

From an economic perspective, the role of public policy is to intervene in markets to promote efficiency. This often means taking account of public goods and externalities. There are real opportunities in this regard for the management of the climate proofing of infrastructure. Because infrastructure is effectively a permanent or irreversible investment, careful analysis and assessment is crucial for reducing 'regrettable' public policy decisions. These policies can include direct regulation or the setting of price signals to get incentives right.

Finally, it is important to keep in mind that economic development is among the most important adaptation strategies. Nevertheless, it is important not to focus exclusively on the most vulnerable (poorest) populations. While they often need the most immediate help, sometimes the best way to promote further development is to increase efficiency were development is already occurring.

10 Technical Presentation 6: Supporting El Salvador to Reduce Infrastructure Risks within a Green, Low-Emission and Climate-Resilient Framework for Development — Strategy for Adapting Public and Private Infrastructure to Climate Change

Stephen Gold

Key Messages

- UNDP supports governments to reduce infrastructure risk through the development of prospective integrated green, low-emission and climate-resilient development strategies (Green LECRDS) designed to attract and direct public and private investment towards catalysing and supporting sustainable economic growth.
- UNDP provides a wide range of services — knowledge, data and analysis, training, project identification and access to financing — to facilitate countries' implementation of Green LECRDS.
- UNDP's approach to helping countries prepare a green, low-emission and climate-resilient development strategy involves the following five steps:
  1. Develop a multi-stakeholder planning process;
  2. Prepare climate change profiles and vulnerability scenarios;
  3. Identify strategic options leading to green, low-emission and climate-resilient development trajectories;
  4. Identify policies and financing options to implement priority climate change actions (i.e. assess existing financing options; undertake cost-benefit analysis of priority options; identify financial flow requirements and identify policy and financing options based on available resources); and
  5. Prepare green, low-emission and climate-resilient development roadmap.
- UNDP provides support to develop long-term sustainable strategic frameworks in conjunction with immediate on-the-ground adaptation and mitigation actions (i.e. through Fast Start/demonstration/pilot projects).

Full Presentation

This concluding presentation synthesizes technical discussions from the conference into a coherent, practical and strategic framework for adapting public and private infrastructure to climate change. The UNDP framework is outlined as a five-step process for preparing a Green LECRDS.

Stephen Gold, Principal Policy and Technical Adviser, Green, Low-Emission and Climate-Resilient Development Strategies, UNDP

Highlights from previous conversations

Technical discussions and statements throughout the day have highlighted the following key points:

- Countries (specifically, El Salvador) need to internalize the 'new reality' of the implications of increasing frequency of extreme events and long-term climate change on public and private infrastructure.
- It is necessary to develop sustainable capacities, credible information — from a national to territorial level — and information systems (e.g. GIS and climate systems) to guide robust decision-making and ultimately an integrated strategic framework for reducing additional risks to infrastructure.
- Adapting to this new reality requires a cross-cutting intersectoral approach among key line ministries and other partners.
- Risk management actions need to take place at national, subnational and community levels. Statistics show that 60 percent of actions occur at the territorial level.
- Adapting to climate change is costly and requires access to the full array of available sources of finance and investment. UNDP is working to help countries access these financing options.
- Both physical infrastructure and natural ecosystems infrastructure need to be considered in climate-proofing strategies.

These considerations must be embedded in an integrated, strategic and practical framework for reducing additional risks to infrastructure.

Outcome

UNDP is working to support governments to reduce infrastructure risk through development of prospective integrated Green LECRDS designed to attract and direct public and private investment towards catalysing and supporting sustainable economic growth. UNDP is working at the local, territorial level in several countries including Colombia, Nigeria, Peru, Senegal, Uganda, and Uruguay.

Five key steps to prepare Green LECRDS

UNDP has developed, with its partners, the following five-step process for assisting countries to prepare Green LECRDS:

STEP 1
Develop a Multi-Stakeholder Planning Process

STEP 2
Prepare Climate Change Profiles and Vulnerability Scenarios

STEP 3
Identify Strategic Options Leading to Green, Low-Emission Climate-Resilient Development Trajectories

STEP 4
Identify Policies and Financing Options to Implement Priority Climate Change Actions

STEP 5
Prepare a Green, Low-Emission Climate-Resilient Development Roadmap

This presentation focuses on this five-step process as a whole, the interconnection among these steps and the support that UNDP is providing to implement them.

What does UNDP provide to countries?

UNDP provides a wide range of services — knowledge, data and analysis, training, project identification and access to financing — to facilitate countries' implementation of Green LECRDS. First, UNDP supports knowledge exchange of lessons learned and best practices within and between regions. UNDP also provides data and analysis, supporting bio-physical and socio-economic assessments and the development of scenarios specifically designed to inform national and subnational climate change strategies, action plans and related products through the provision of methodological tools and techniques. In addition, UNDP offers training on the use of these tools and on design of integrated Green LECRDS. UNDP also facilitates the selection of projects in support of Green LECRDS and the identification of appropriate regulatory and financial instruments (i.e. public policy and public and private investment projects for infrastructure). Finally, UNDP provides technical assistance to facilitate access to new financial mechanisms. Given the difficulty of attaining credibility at the decision-making level, these services help to meet the need for cross-ministerial support by strengthening relationships among elected officials via steering committees and sustaining project approach via technical working groups.

"UNDP provides a wide range of services — knowledge, data and analysis, training, project identification and access to financing — to facilitate countries' implementation of Green LECRDS."

Step 1: Developing a Multi-Stakeholder Planning Process

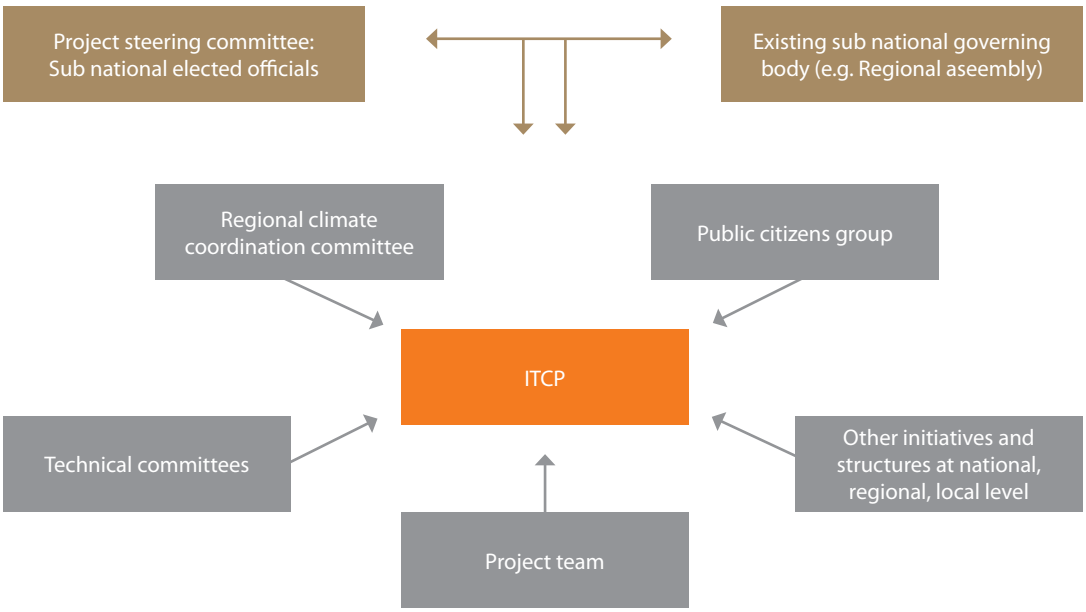
The first step in preparing Green LECRDS — developing a multi-stakeholder planning process — emphasizes the cross-sectoral nature of the Green LECRDS approach. This process includes undergoing internal preparation and stocktaking exercises; raising awareness among national and subnational authorities; identifying and establishing a decision-making structure (e.g. steering committee, project coordinating unit, sectoral working groups); and identifying/establishing a multi-stakeholder consultative process to identify priority options and develop a Green LECRDS roadmap.

The first step in the Green LECRDS process should consider the following activities.

- Establish Green LECRDS project team and project coordinator;
- Review and compile information on existing climate assessments and plans, existing projects, policies, funding sources, key authorities and financial and technical experts, i.e. map key climate issues, opportunities and stakeholders;
- Establish Green LECRDS steering committee (using existing committees and structures when possible) composed of high-level elected officials and civil servants in sectoral ministries to ensure appropriate level of policy and political involvement;
- Identify and create policy and technical working groups (e.g. finance, energy, agriculture, forestry, urban development and transport, etc.) composed of representatives from national/regional/local authorities, sectoral ministries, private sector, non-governmental and community organizations, and other civil society entities;
- Identify technical capacity needs and implement training; and
- Put in place communications and awareness-raising strategy directed towards a wide range of authorities, partners, and stakeholders.

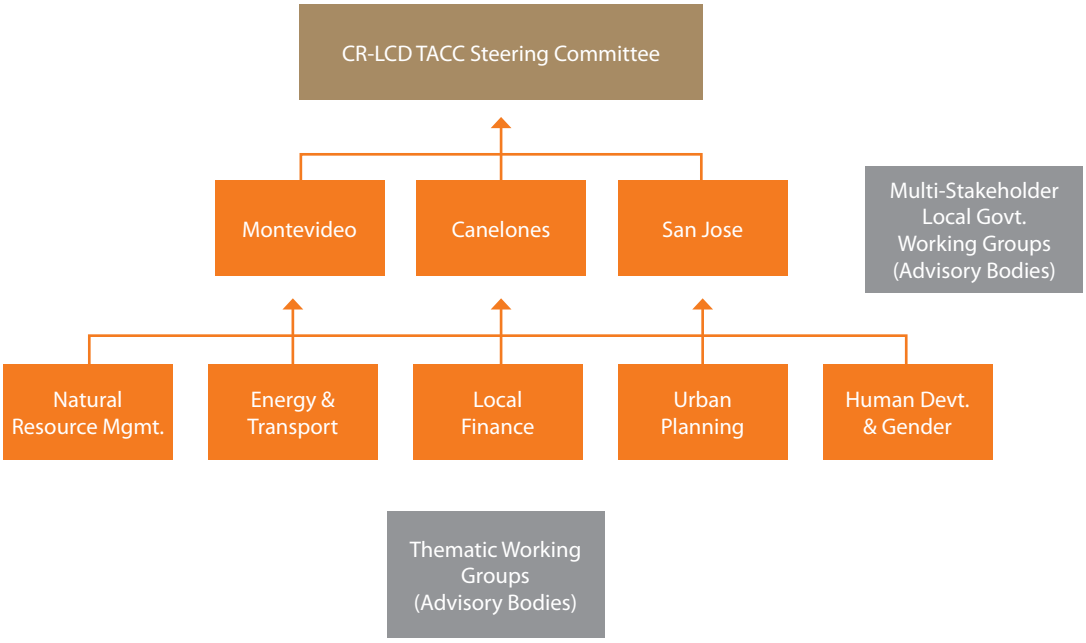
Figure 10.1 is an example of a partnership framework of the multi-stakeholder participatory decision-making process at the subnational level. In this model, existing subnational governing bodies (e.g. regional assemblies) identify elected officials to sit on the project steering committee to make decisions in a series of project teams, public citizens groups, and technical and climate change committees at national, regional and territorial levels. This process links to the national communications and ongoing development strategies in which the country is engaged.

Figure 10.1: A partnership framework through a multi-stakeholder participatory decision-making process



Uruguay, for example, has established an upper-level decision-making body, the CR-LCD TACC Steering Committee, and three municipalities in Montevideo, Canelones and San Jose (see Figure 10.2). Five technical working groups — natural resource management (fisheries, forestry, etc.), energy and transport, local finance, urban planning, and human development and gender issues — support and report to these three decision-making bodies.

Figure 10.2: Example of decision-making hierarchy in Uruguay



Step 2:
Preparing Climate Change Profiles and Vulnerability Scenarios

UNDP works with a number of scientific and research institutions focusing on downscaling global climate models (GCMs) to assist in decision-making. This includes generating locally relevant climatic data from low spatial resolution GCMs and integrating a range of global scale forecasts with local dynamics to develop a locally specific range of prospective scenarios. Based on temperature and precipitation (as well as wind, humidity and solar radiation, when relevant) as climatic variables, climate change scenarios provide a necessary tool for understanding the range of possible future impacts related to agriculture, coastal zone management, water resources, human health, biodiversity and infrastructure. Table 10.1 presents the potential impact of climate change for each of these sectors.

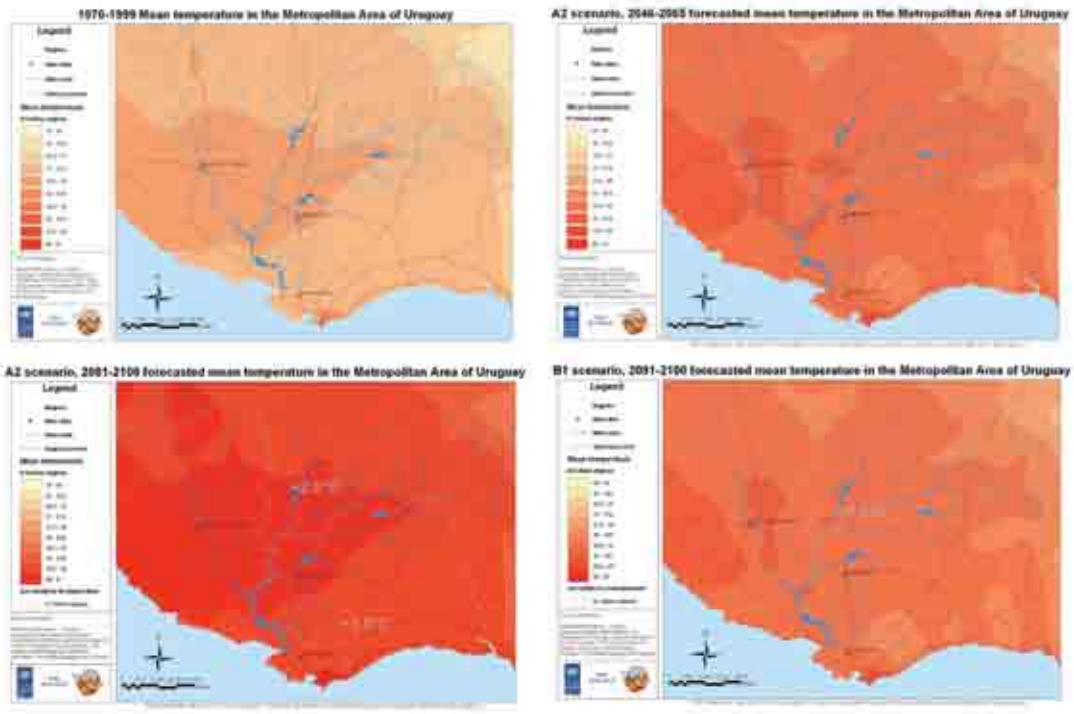
Table 10.1: Common climatic variables used for climate impact and risk assessment

Sector/system	Area of potential impact	Relevant climatic variables
Agriculture	◖ Insect outbreaks ◖ Soil properties ◖ Crop yields ◖ Livestock herds	Temperature and precipitation (optional variables: wind, humidity and solar radiation whenever relevant)
Biodiversity	◖ Primary production ◖ Abundance and distribution of species ◖ Coral bleaching and mortality	
Coasts	◖ Coastal erosion ◖ Coastal flooding ◖ Store surge return periods and area inundated	
Human health	◖ Heat stress and related mortality ◖ Infections disease	
Infrastructure	◖ Road and rail maintenance costs ◖ Building ◖ Energy production	
Water resources	◖ Water availability and supply ◖ Water resources reliant on snow melt	

Source: Modified from CSIRO (2007).

The four maps of Uruguay in Figure 10.3 show examples of climate change scenarios (based on 1970 – 1999 climatology data) for 2046 – 2065 and 2081 – 2100 assuming business as usual (see A2 Scenario maps), compared to 2081 – 2100 assuming significant global cooperation towards sustainable development (see B1 Scenario map).

Figure 10.3: Downscaling of Global Climate Models (GCMs) for two emission scenarios and two time periods in the metropolitan area of Uruguay



Source: ClimSAT (2010). Note: Climatology scenario maps of mean temperature (based on 1970 – 1999 data) comparing 2046 – 2065 and 2081 - 2100 business-as-usual predictions (A2 Scenarios) with 2081 – 2100 assuming global cooperation toward sustainable development.

In the business-as-usual scenario, temperature trends in the metropolitan area of Uruguay at the end of the 21st Century increase by 2.6°C on average. In the global-cooperation scenario, temperature trends for the same time period increase by 1.3°C on average. Rather than provide predictions, these scenarios present a range of possibilities, from best case (1.3°C temperature increase) to worst case (2.6°C temperature increase).

According to these scenarios, current hazards to infrastructure include coastal flooding (i.e. sea-level rise), inland flooding, heat waves, storms and drought. Identification of new reality hazards related to changes in agriculture yield and livelihood losses due to changes in biodiversity suggest impacts on natural ecosystem infrastructure in addition to physical infrastructure.

Step 3:
Identifying strategic options leading to green, low-emission and climate-resilient development trajectories

Step 3 focuses on the adaptation and mitigation options through the multi-stakeholder participatory process outlined in Step 1. This includes identifying priority development options from a variety of relevant thematic areas and sectors, such as energy, transport, natural resource management and urban planning. Once the hotspots are identified and risk exposure is assessed, it is necessary to make cost-benefit analyses and address technical feasibility.

From UNDP's perspective, adaptation and mitigation are inextricably linked. Mitigation is about more than large power generation and heavy industry. The use of renewable energy (e.g. hydro power) to supply electricity to the grid, biomass residues for cogeneration, and energy efficiency appliances, lighting, and buildings plays a fundamental role in the reduction of greenhouse gases (GHGs) and Green LECRDS.

A methodological framework for assessing vulnerability can be used for identifying adaptation options. Within this framework, explained in Figure 10.4, vulnerability is a product of exposure, sensitivity (i.e. resistance of the exposed system) and adaptive capacity (existing defences or coping mechanisms) (see Technical Presentation 3 by Dr. Faber for more discussion on this topic).

Figure 10.4: The methodological framework for assessing vulnerability

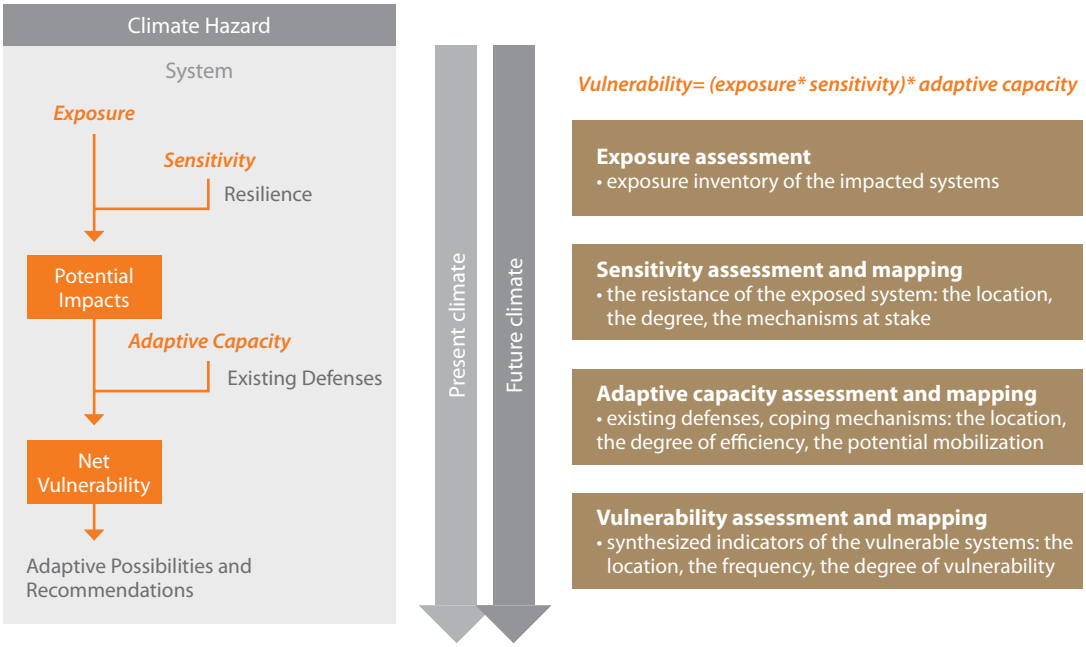
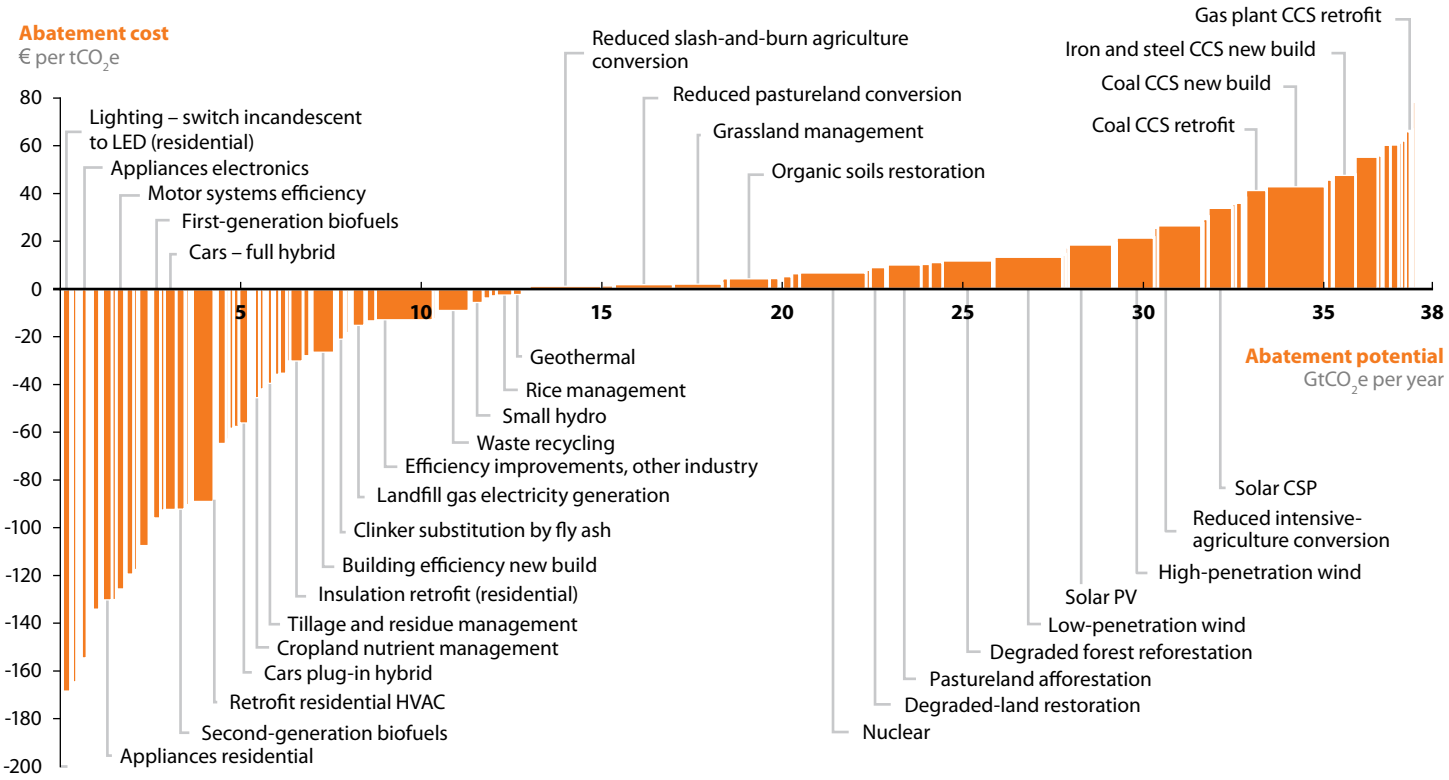


Figure 10.5: Global GHG abatement cost curve beyond business-as-usual 2030 (v2.1)



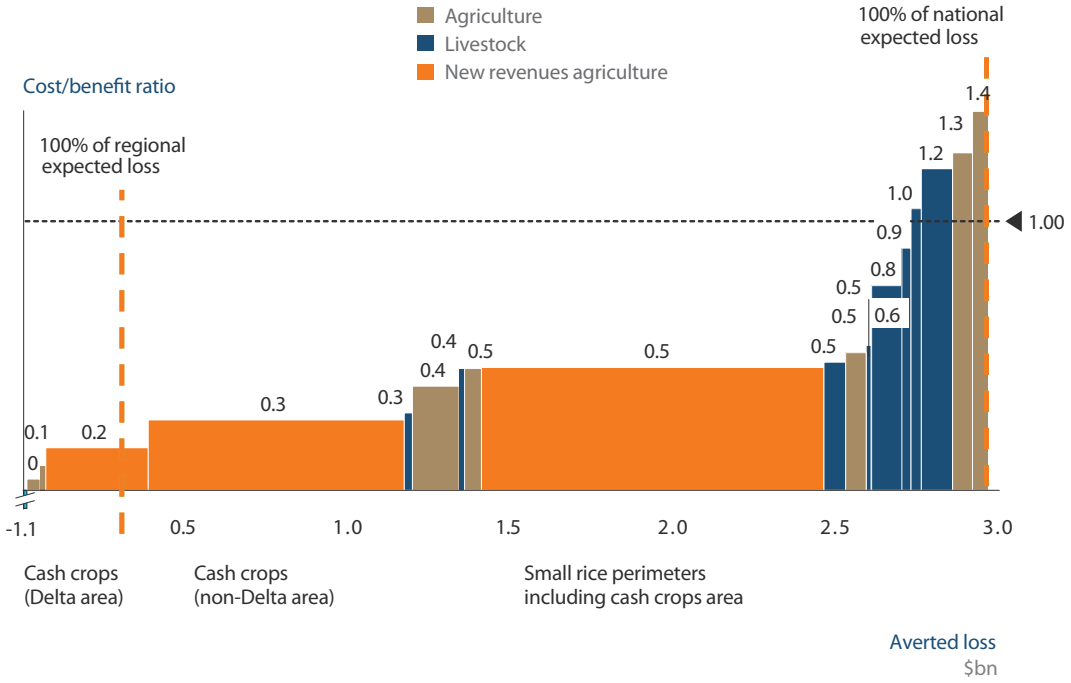
Source: McKinsey & Company (2009). Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below €80 per tCO_2e if each lever was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play.

Step 4:
Identifying policies and financing options to implement priority climate change actions

The fourth step, identifying policies and financing options to implement priority climate change actions, focuses on determining how to allocate resources based on the costs of implementing the adaptation and mitigation options discussed in Step 3. This includes assessing existing government financing strategies; undertaking cost-benefit analysis of priority options; and identifying financial flow requirements, as well as policy and innovative financing instruments.

UNDP has developed expertise to guide countries through the many available policy and financial instruments. A series of practical guidebooks that outline these different options and associated considerations for planners and decision makers are being prepared. The reports are available for download from www.undp.org/climatestrategies. These resources are intended to empower countries to make strong policy decisions by increasing their knowledge of available policies and associated mechanisms and their practical application.

Figure 10.6: Impact of cash crops on ability to avert expected loss — Mali test case



Source: From Economics of Climate Adaptation Working Group, "Shaping Climate-Resilient Development: A Framework for Decision-Making" (2009).

UNDP has developed expertise to help guide countries through the many available policy and financial instruments and is developing a series of practical guidebooks that outline these different options and associated considerations for planners and decision makers. These resources are intended to empower countries to make strong policy decisions by increasing their knowledge of available policies and associated mechanisms and their practical application.

Step 5: Preparing Comprehensive Green, Low-Emission and Climate-Resilient Roadmap

With mitigation and adaptation options prioritized through a multi-stakeholder participatory process and assessed for cost, countries can then prepare a comprehensive LECRDS roadmap outlining components for carrying out the strategy. An example of an input to a roadmap with a focus on wind power in a particular country is pictured in Figure 10.2 and summarizes detailed options, including a timeline, donors, players and actions.

The roadmap facilitates the development of a long-term sustainable strategic framework for addressing climate risk and its effects on public and private infrastructure. The creation of this framework occurs simultaneously with the implementation of concrete mitigation and adaptation actions, via demonstration and fast-track projects. Learning from these immediate on-the-ground actions helps to guide the strategy throughout its development.

Table 10.2: Example of green, low-emission and climate-resilient roadmap for wind power

		2010-2015	2015-2025	2025-2050
Public authorities (national, regional or local depending on the institutional setup) and regulators	Control and regulatory instruments	◖ Review permitting and licensing procedures to offer simple, clear, predictable rules for wind projects ◖ Review grid connection and usage rules (with grid operators	◖ Adopt targets for share of wind energy in electricity ◖ Set mandatory Feed-in tariffs or quotas (e.g. RPS, etc.) ◖ Adopt environmental integration regulations to increase acceptance without hindering the development of wind energy ◖ Control new grid connection operators to develop the grid in anticipation of future wind development	◖ Increase national/regional targets ◖ Decrease tariffs as wind energy becomes more competitive ◖ Update regulations as technology and impacts evolve ◖ Monitor grid development
	Financial incentives and market instruments	◖ Support demonstration programmes ◖ Create a favorable environment for CDM projects	◖ Offer tax credits, subsidies, and soft loans where necessary ◖ Promote CDM projects	◖ Stimulate the availability of financing matching the characteristics of wind energy projects ◖ Stimulate regulated and voluntary carbon markets
	Information and training	◖ Conduct wind resource assessments ◖ Organize information campaigns on wind energy	◖ Make wind resources assessments available to developers ◖ Create standards and labels for turbines and set up testing facilities ◖ Develop technical training programmes	◖ Expand and update information ◖ Enforce standards and promote labels ◖ Make disclosure of the carbon content of electricity mandatory
Developers		–	◖ Avoid environmentally and socially sensitive areas and adopt 'good neighbour' practices	◖ Adopt best technologies to minimise impacts
Investors/Financial institutions		◖ Train staff on wind energy	◖ Develop financial products adapted to the specificities of wind energy (long-term pay-back, small projects)	–
Utilities and grid operators		◖ Train staff on wind energy ◖ Review grid connection and usage rules (with regulators)	◖ Launch commercial offers promoting wind energy ◖ Adopt internal wind energy generation/ purchase objectives ◖ Develop standard power purchase contracts ◖ Ensure fair and transparent access to and use of the grid ◖ Include future wind development for grid planning ◖ Develop new technologies on smart flexible grids, electricity storage and management of intermittent sources	◖ Maintain 'green' offers and adjust them to customer requirements ◖ Tighten objectives ◖ Incentivize staff on wind results ◖ Offer fair and simple power purchase contracts ◖ Ensure fair and transparent access to and use of the grid ◖ Continue to develop the grid to connect new wind farms ◖ Integrate new technologies allowing easier management of intermittent generation sources
Contractors		◖ Train on installation and maintenance of wind farms	–	◖ Update training on new technologies
Suppliers and manufacturors		◖ Train installers	◖ Pursue research to decrease costs and environmental impacts and improve the management of intermittency ◖ Provide technical support to installers	◖ Promote new technologies and make them available in as many countries as possible ◖ Provide technical support to installers

Source: Schwarz (2009), included in Chapter 3 of Glemarec and others (2009).

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